

Analysis of Road Potential and Bottlenecks Based on Operating Speed

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Vehicle detectors have been installed at approximately every 300 meters on each lane on Tokyo metropolitan expressway. Various traffic data such as traffic volume, average speed and time occupancy are collected by vehicle detectors. We can understand traffic characteristics of every point by comparing traffic data collected at consecutive points. In this study, we focused on average speed, analyzed road potential by operating speed during free-flow conditions, and identified latent bottlenecks. Furthermore, we analyzed effects for road potential by the rainfall level and day of the week. It's expected that this method of analysis will be utilized for installation of ITS such as drive assist, estimation of parameters for traffic simulation and feedback to road design as congestion measures.

Keywords: *Road potential, Operating speed, Percentile speed, Latent bottleneck*

1. Introduction

Vehicle detectors have been installed at approximately every 300 meters on each lane for the total length of 283.3km on Tokyo metropolitan expressway. Various traffic data such as traffic volume, average speed and time occupancy are collected by vehicle detectors and processed in order to provide traffic information about traffic congestion, road works, accidents, traffic regulations and so on.

Traffic characteristics of every point where detectors are installed can be understood by comparing traffic data collected at other points because traffic data are collected at very short space interval. Road potential based on percentile speed was analyzed using average speed among these traffic data by focusing on this point [1]. In the complex Tokyo metropolitan expressway network, on-ramps, off-ramps and junctions (hereon referred as JCTs) are constructed at short spacing, and the traffic volume changed in each section. Using this method of analysis, there was a problem that percentile speeds at each point were not under the same traffic condition and therefore cannot be compared.

In this study, we analyzed road potential by comparing operating speeds under the same traffic condition in each consecutive point, and verified the validity of this method using pulse data.

It's expected that we can use the results of this study as basic data for installation of ITS such as drive assist, estimation of parameters of traffic simulation and feedback to road design. This paper reports the result of analysis and recommends future development.

2. Definition of road potential

The drivers are regarded to operate their vehicles by maintaining their own desired speed if there are no factors of speed reduction such as changes of the road structure (roadway width, horizontal alignment, and longitudinal gradient), following a front vehicle and so on, when the relative headways between front and rear vehicles are safe enough. Here we assumed that road potential is high at the section where the drivers can stably drive at their desired speed without speed reduction, and road potential is low at the section where the drivers cannot drive at their desired speed with speed reduction by some factors.

While the speed limit is usually governed by the road type with exception of curves, the free-flow speed along a route is not the same. This could be due to some factors such as the longitudinal gradient, the horizontal alignment and so on. By measuring the free-flow speed at points along the route, a continuous speed profile can be observed. A continuous speed profile should be essentially made of section mean speed, but spot mean speed can be used as a substitute because traffic data are collected at very short space interval. The benefit of such a plot is that the true road potential of the route can be determined. Improving the capacity of the bottleneck through ITS measures or others, would probably shift the bottleneck to another point. Hence, knowing the road potential, a more holistic approach to solving bottlenecks can be realised.

AASHTO defined operating speeds as the speed at

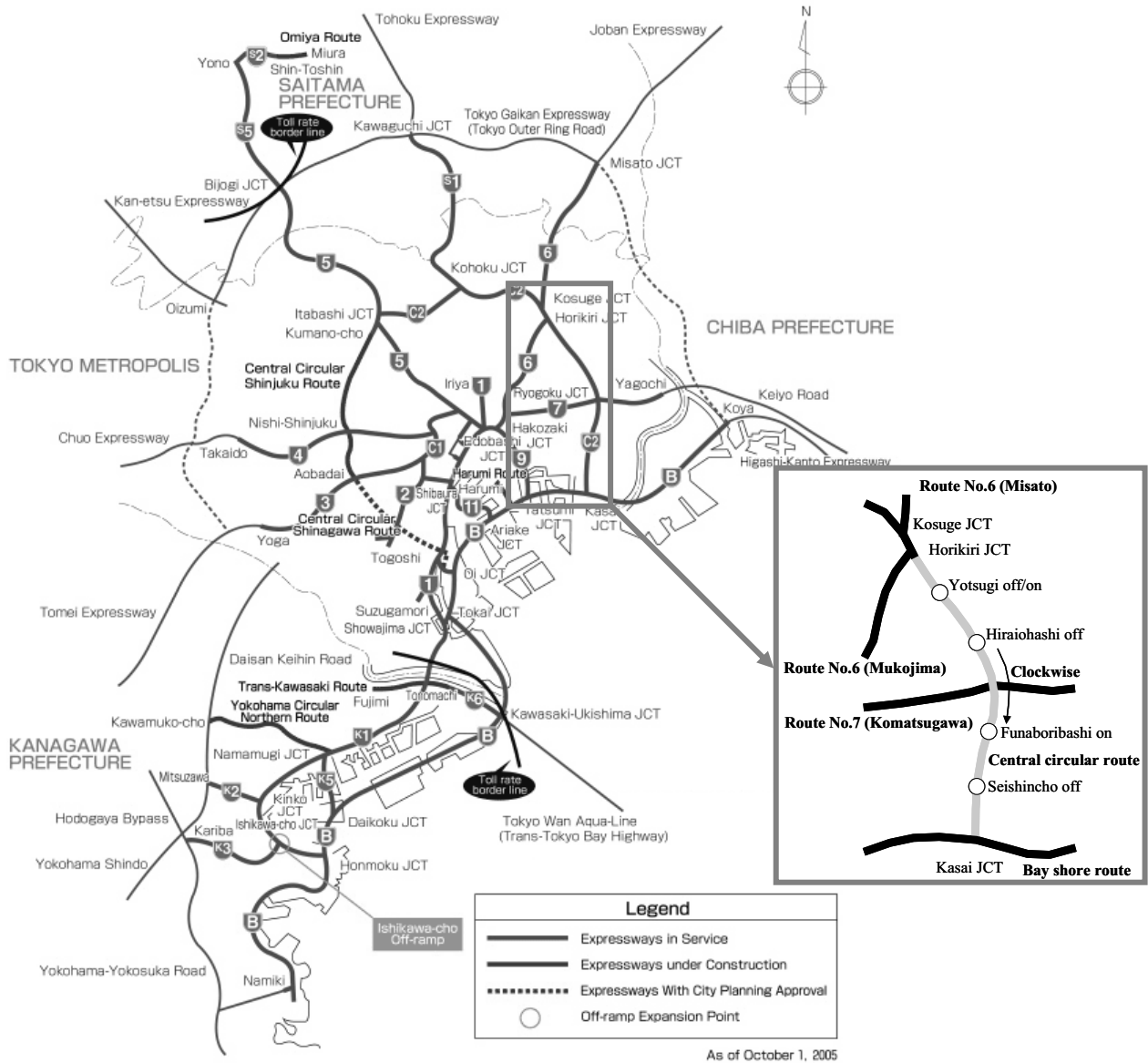
which driver are observed operating their vehicles during free-flow conditions [2]. In this study, according to the definition of AASHTO, we analyzed road potential by operating speed observed during free-flow conditions.

3. Analysis of speed-flow relationship by external factors

3.1. Data for analysis

In this study, we analyzed the data shown in Table 1, and the network of Tokyo metropolitan expressway with an enlarge illustration of the target route of analysis is shown in Figure 1.

A lot of traffic congestions are frequently caused in



Source: "2005 Corporate Profile" , Metropolitan Expressway Co., Ltd.

Figure 1. Network of Tokyo metropolitan expressway

the vicinity of the Funaboribashi on-ramp and in the vicinity of the Hiraiohashi off-ramp in the section for analysis.

Table 1. Data for analysis

Route	Central circular route , Clockwise
Section	From Horikiri JCT to Kasai JCT (consisted of 2 lanes)
Data	Vehicle detector data aggregated by 5 min -Traffic volume -Average speed -Time occupancy
Period	From 2004/4/1 to 2004/9/30

3.2. Identification of speed-flow relationship according to external factor

Traffic capacity is affected by external factors such as the rainfall level, daylight (daytime and nighttime), and day of the week (weekday, Saturday and Sunday/holiday), other than the road structure [3]. The components of speed-flow relationship in the section for analysis were resolved according to these external factors, and their features were analyzed.

Aggregated data for 6 months from 2004/4/1 to 2004/9/30 at points near the upstream of Funaboribashi on-ramp are shown in from Figure 2 to Figure 6. All data from the 6 months period are shown in Figure 2, and they describe a parabolic curve. Weekday data with no rainfall and daytime that is the most standard condition are shown in Figure 3. Figure 3 shows that there is little data in free-flow condition, especially in upper left of the graph. The data where the three external factors i.e. days of the week, rainfall and daylight are changed one by one are shown in Figure 4 to Figure 6. Figure 6 shows during night time a lot of the data are for traffic condition in which traffic volume is low, and each driver operates his vehicle at his desired speed. Following, we compared operating speeds under the same traffic condition based on the standard data during nighttime, on weekdays and without rainfall.

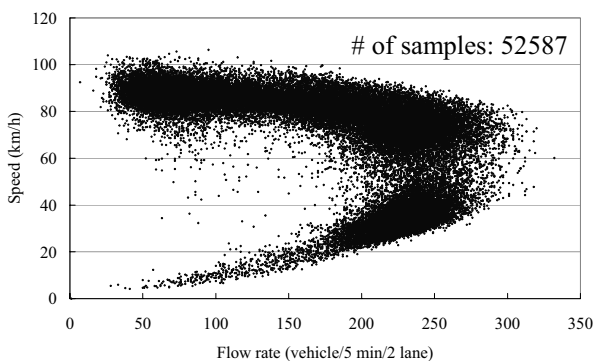


Figure 2. Speed-flow relationship (all data)

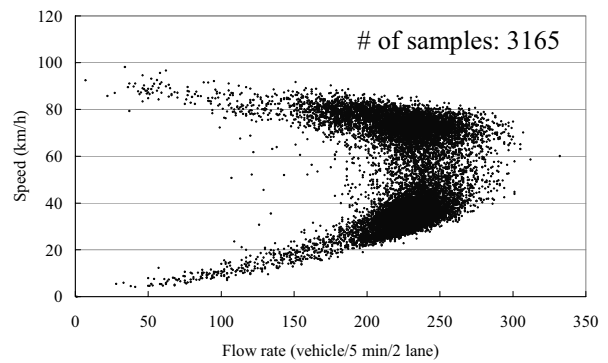


Figure 3. Speed-flow relationship (weekdays, no rainfall and daytime)

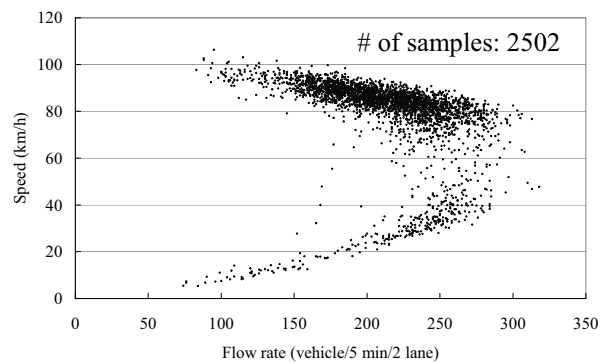


Figure 4. Speed-flow relationship (Sunday/holiday, no rainfall and daytime)

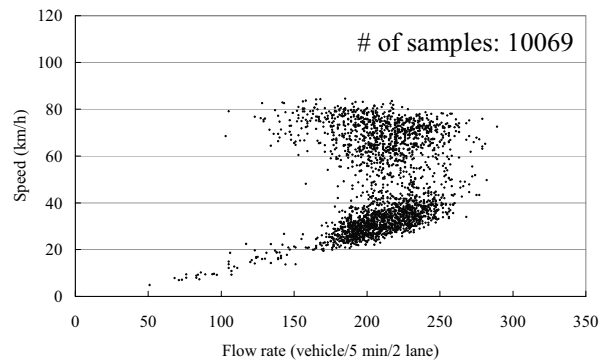


Figure 5. Speed-flow relationship (weekdays, rainfall and daytime)

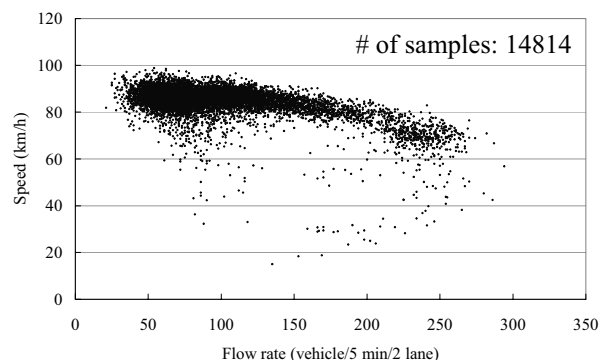


Figure 6. Speed-flow relationship (weekdays, no rainfall and nighttime)

4. Analysis of operating speed

In order to analyze the data under the same traffic condition, it is assumed that the traffic condition where aggregated speed data for 5 min reflects operating speed is the traffic condition where it meets the following two requirements.

Requirement 1

Average speed is more than 50 km/h.

Requirement 2

Average headway is more than 10 sec/vehicle.

(=Traffic volume is less than 60 vehicles/5 min/2 lanes.)

In addition, the data which meets requirement 2 are substantially distributed from 30 to 60 veh/5 min/2 lanes, and it is confirmed that operating speed is almost the same at this level of traffic volume.

The median of average speed for each point has been

identified as operating speed from data that meets the above-mentioned requirements. The identified operating speed and percentile speed at each point are shown in Figure 7.

The identified operating speed shows roughly the same tendency as 80th percentile speed though there are points with some speed differences.

The operating speed of Figure 7 shows that the operating speed has reduced, compared with that of the upstream point in the existing bottleneck such as the vicinity of Funaboribashi on-ramp and the vicinity of Hiraiohashi off-ramp.

It is thought that the factor of the bottleneck is the shockwaves generated by slight speed reduction because of the change in the longitudinal gradient of approximately 2 %. Slight speed reduction of approximately 5 km/h in the vicinity of Funaboribashi on-ramp and approximately 3 km/h in the vicinity of

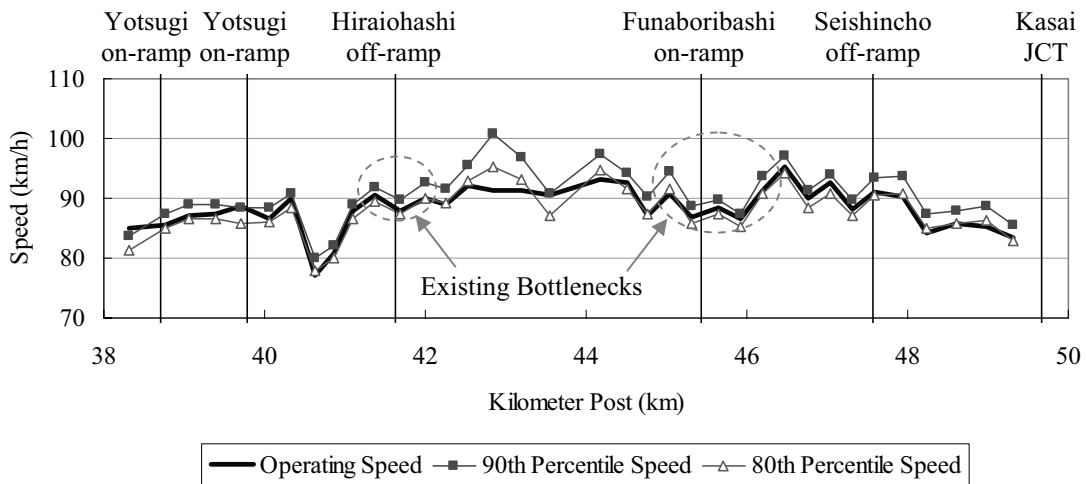
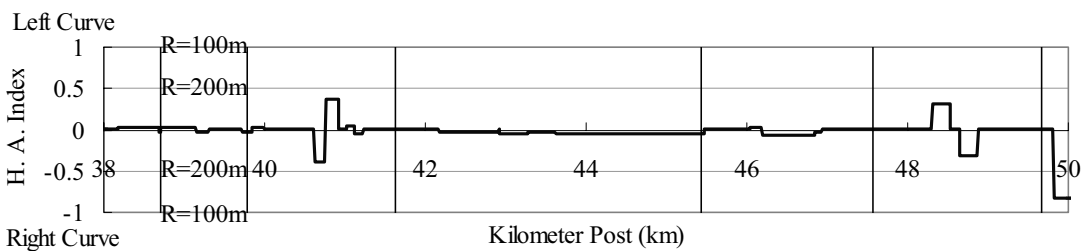


Figure 7. Change of the operating speed at different points along the route



*Horizontal Alignment Index = 100/curvature radius

Figure 8. Change of the horizontal alignment at different points along the route

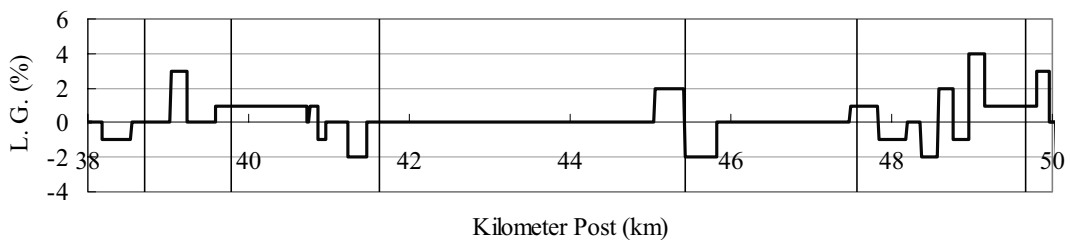


Figure 9. Change of the longitudinal gradient at different points along the route

Hiraiohashi off-ramp are observed.

The other existing bottlenecks of Central circular route, Clockwise such as weaving section between Horikiri JCT and Kosuge JCT, Ogiohasi on-ramp and Senju-Shinbashi on-ramp were explained by changes of speed contours [1].

Moreover, there is a possibility that the point where the operating speed is low compared with that of the upstream point is thought as a latent bottleneck and may become a future bottleneck, when the capacity of the bottleneck has been improved by the congestion measures.

For example, the vicinity of 41 kilometer post (KP) and the vicinity of 48 - 49 KP are listed up as the latent bottlenecks. The factor of speed reduction in the vicinity of 41 KP is a combination of a right-hand curve with R = 255 (m) and a left-hand curve with R = 270 (m) of Katsushika harp bridge (See Figure 8). Road potential in the vicinity of 41 KP is lowest in the route, but this section hasn't become an existing bottleneck because drivers smoothly accelerate the speed on the curve unlike sags and tunnels. And the factors of speed reduction in the vicinity of 48 - 49 KP are a left-hand curve with R = 320 (m), the longitudinal gradient of 4 % in the maximum and conflict by lane changes for the diversion at Kasai JCT (See Figure 8 and Figure 9).

The method of identifying the latent bottlenecks is considered reasonable and proper because the listed points above have the reasons for becoming to the bottlenecks such as the horizontal alignment, the longitudinal gradient and so on.

5. Verification of identified operating speed

The validity of the operating speed identified in Section 4 was verified with the pulse data of individual vehicle.

The brief of the pulse data utilized for the verification is shown in Table 2. Time of the sunrise of the day was 6:31AM, and the period from 5:00 to 5:30AM was during dawn. In addition, there was no rainfall and the traffic condition was free-flow.

Table 2. Data for analysis

Route	Central circular route , Clockwise
Section	From the vicinity of Hiraiohashi off-ramp to the vicinity of Funaboribashi on-ramp (consisted of 2 lanes)
Data	Pulse data of individual vehicle -Transit time -Headway -Speed -Type of vehicle
Period	2006/2/13(Mon) 5:00 - 5:30

The seven vehicle detectors in the vicinity of the Hiraiohashi off-ramp and in the vicinity of the Funaboribashi on-ramp that are the existing bottlenecks were selected, and the mean speeds of the vehicles which the drivers operate at their own desired speed were calculated at different locations and lanes along the route. Here, "a vehicle with the headway of 5 seconds or more" was defined as "a vehicle which a driver operates at his own desired speed".

The result of the calculation is shown in Table 3 and Figure 10. The maximum speed difference between lane 1 and lane 2 is over 20 km/h. The operating speed identified in Section 4 exists between lane 1 and lane 2, and the ruggedness tendency is almost same.

Operating speed obtained from aggregated data includes data of car following vehicles, and as a result they don't completely reflect the true operating speeds. But, this result shows that the operating speed identified in Section 4 is appropriate in the viewpoint of examining the level of the road potential because the ruggedness tendency of aggregated data and pulse data is almost same.

Table 3. Comparison between aggregated data and pulse data

Kilometer Post	Item	Aggregated data	Pulse data*	
		Section	Lane 1	Lane 2
40.62	Speed (km/h)	77.2	61.7	83.5
	# of vehicles (veh/30min)	----	101	74
40.87	Speed (km/h)	80.7	70.1	88.0
	# of vehicles (veh/30min)	----	110	71
41.37	Speed (km/h)	90.6	80.8	100.5
	# of vehicles (veh/30min)	----	112	74
41.69	Speed (km/h)	87.9	78.1	92.1
	# of vehicles (veh/30min)	----	108	74
45.32	Speed (km/h)	86.8	71.4	94.4
	# of vehicles (veh/30min)	----	108	77
45.64	Speed (km/h)	88.4	75.8	97.7
	# of vehicles (veh/30min)	----	117	71
45.92	Speed (km/h)	86.5	74.0	88.2
	# of vehicles (veh/30min)	----	110	70

* Data of vehicles with the headway of 5 seconds or more were aggregated.

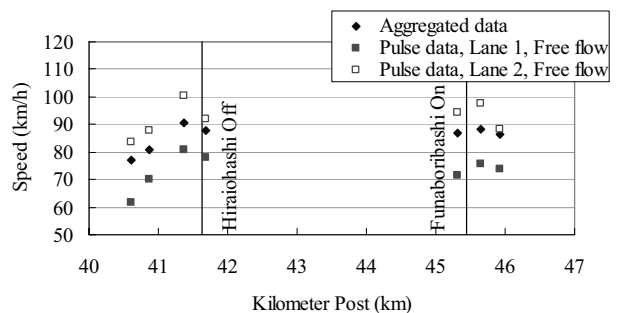


Figure 10. Comparison between aggregated data and pulse data

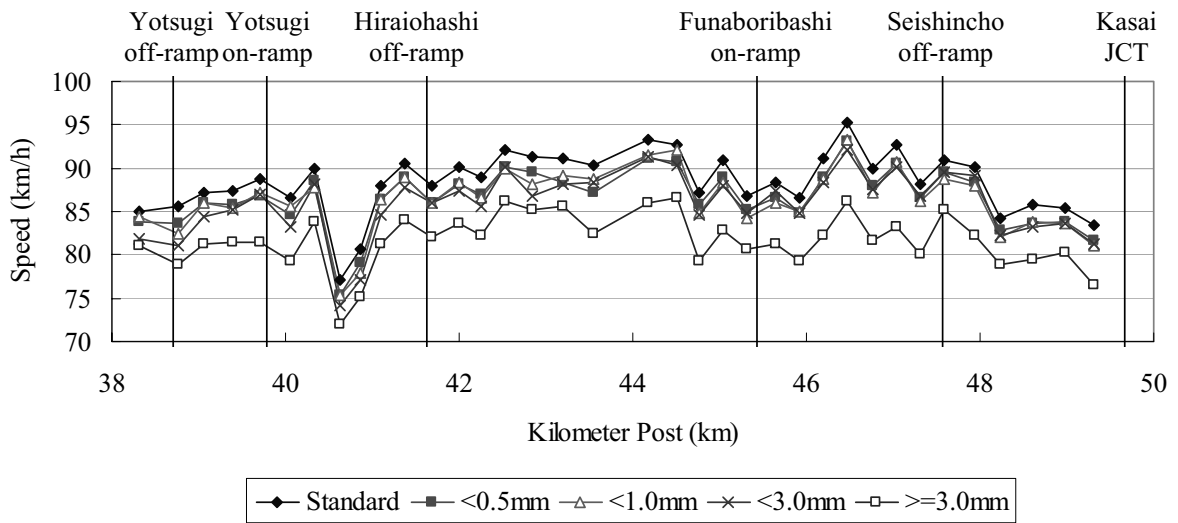


Figure 11. Difference of operating speed by rainfall level

6. Change of road potential by rainfall

A lot of researches concerning the traffic capacity and the operating speed by the rainfall have been studied up to now. Concerning the traffic capacity during rain, the traffic capacity is reduced by approximately 11% at the bottleneck in the vicinity of Hakozaki rotary on outbound Route No.6 (Mukojima) and in the vicinity of Funaboribashi on-ramp on clockwise Central circular route [4]. And concerning the operating speed during rain, the higher the rainfall level is, the lower the operating speed [5] [6]. Though it is shown that the road potential reduces at rainfall time, the pattern of the reduction of road potential at each point is not clear. Therefore, the influence of the rainfall is quantitatively analyzed at consecutive locations in this study.

Compared the operating speed during nighttime, weekdays and no rainfall shown in Figure 7 with that of nighttime, weekdays and rainfall according to the rainfall level, the result is shown in Figure 11. Then the rainfall level is divided into four categories shown in Table 4 as well as reference [2].

Table 4. Categories of rainfall level

Category	Rainfall level
Standard	no rainfall
Rainfall 1	0.0 mm or more, and less than 0.5 mm
Rainfall 2	0.5 mm or more, and less than 1.0 mm
Rainfall 3	1.0 mm or more, and less than 3.0 mm
Rainfall 4	3.0 mm or more

As for the traffic capacity, a significant difference is observed by four categories of the rainfall level [4]. As for the operating speed, a significant difference is not observed in the operating speeds of rainfall <0.5mm, <1mm and <3mm, whose rainfall levels are low. A slight

reduction of the operating speed is observed, compared with at no rainfall. But a clear reduction of the operating speed is observed in the operating speeds of rainfall $\geq 3\text{mm}$ whose rainfall level is high, compared with no rainfall.

The operating speed during rain and no rain conditions have almost the same ruggedness tendency and the difference of the operating speed is approximately 10 km/h. This shows that the relation of the road potential level does not change by rainfall, but road potential becomes lower by rainfall.

7. Change of road potential by day of the week

The traffic capacity on Sunday and holiday reduced by approximately 8 % at the bottleneck in the vicinity of Hakozaki rotary on outbound Route No.6 (Mukojima) and by approximately 6 % at the bottleneck in the vicinity of Funaboribashi on-ramp on clockwise Central circular route [4]. This shows that the way Sunday drivers drive, reduces the traffic capacity. In this study, the influence of day of the week is analyzed.

Compared the operating speed during nighttime, weekdays and no rainfall shown in Figure 7 with that of nighttime, Sunday/holiday and no rainfall by locations, the result is shown in Figure 12.

The operating speeds at weekdays and Sunday/holiday have almost the same ruggedness tendency and the operating speed of Sunday/holiday is higher than that of weekdays by approximately 5 km/h at the maximum. This is because the ratio of the large vehicle whose desired speed is generally lower than that of small vehicle on Sunday/holiday is much lower than that on weekdays that is shown in Figure 13. As for the influence of the Sunday drivers, it is necessary to

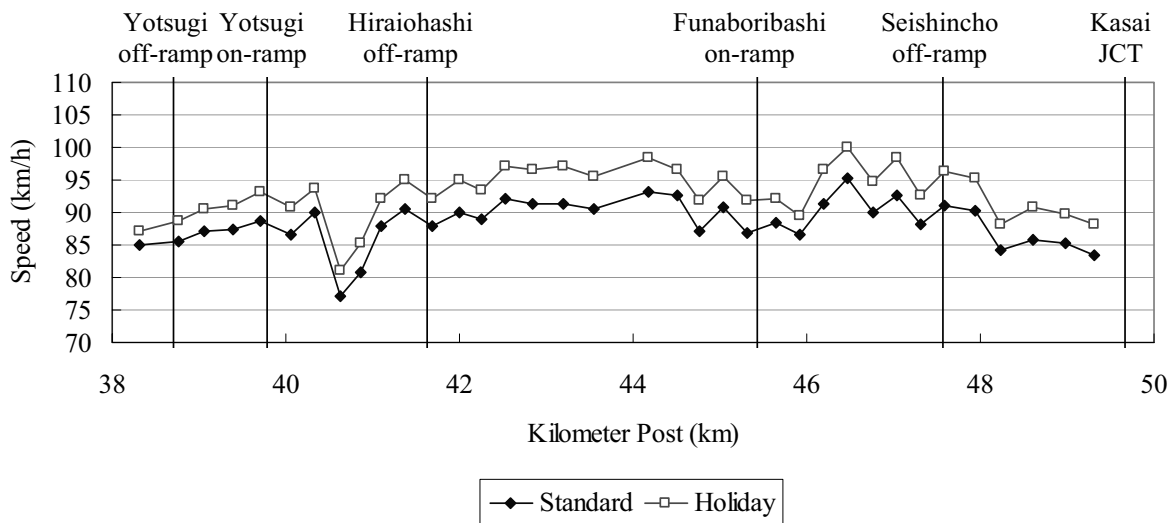


Figure 12. Difference in the operating speed by day of the week

analyze the operating speed according to days of the week and types of vehicles. Therefore, this analysis is an important step for future research.

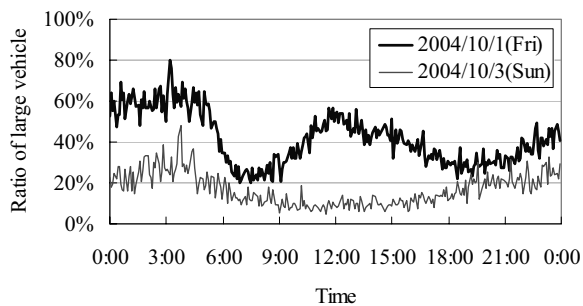


Figure 13. Difference of the ratio of large vehicle by a day of the week

8. Conclusion and future tasks

In this study, the operating speed was calculated by using 5 min aggregated speed data for with low traffic volume. The road potential along a route was analyzed, and the method of identifying latent bottlenecks was proposed.

The conclusion that this method is appropriate was obtained by calculating and comparing the operating speed with aggregated data and with pulse (individual vehicle) data. However, aggregated data using data of all vehicles included car following vehicles, and as a result the operating speed obtained does not completely reflect the operating speeds. If the operation speed identified from pulse data is calculated according to lanes and types of vehicles, it is obvious that more precise road potential can be calculated.

Judging from changes of the operating speed, we qualitatively determined latent bottlenecks in this study.

We must make the threshold for determination of latent bottlenecks clear, and quantitatively determine both existing bottlenecks and latent bottlenecks.

Besides, it is necessary to validate the application to other latent bottlenecks with similar conditions such as horizontal alignment, longitudinal gradient and road structure. If possible, we may be able to calculate traffic capacity of latent bottlenecks and points on new routes.

At a later stage, installation of ITS below will be expected as congestion measures with the use of road potential analysis.

- (i) Contribution for reducing congestion because of road potential improvement of low road potential points by drive assists with the use of ITS technology such as ACC, AHS and so on
- (ii) Estimation of parameters of traffic simulation for assessment of measures against congestion
- (iii) Road design not to reduce road potential because of feed back to road design.

9. References

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