DEVELOPMENT OF AN ALGORITHM OF AUTOMATICALLY SETTING CRITICAL SPEEDS ON URBAN EXPRESSWAYS

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ABSTRACT

The purpose of this study was to develop an algorithm of automatically setting critical speeds that discriminated in real-time between congested and uncongested traffic flow in road sections of urban expressway networks through the use of traffic detector data. A method of binarizing images was applied to set critical speeds on scatter-grams of traffic volume and speeds in combination with a kind of edge enhancement. This algorithm was evaluated in comparison with an existing one that used the threshold selection method by Otsu. In addition, this algorithm was validated with traffic detector data of the Tokyo Metropolitan Expressway Networks.

INTRODUCTION

As for most of the urban expressways in Japan have very complex networks and are still expanding now. In the Metropolitan Expressway which is the representative of the urban expressway, the traffic volumes reach about 1.17million vehicles per day[1]. This is equal to the population of the ordinance-designated city in Japan. In this way, in the situation that many vehicles move a complicated network, it is thought that the traffic condition of the whole network is affected by the outbreak of the phenomenon that traffic capacity and traffic demand change. Therefore, it is effective to decide a concrete traffic policy such as the traffic

information providing and so on before it happens with the quick detecting and the prediction of the traffic condition in the future. On the other hand, on urban expressways in Japan, traffic volume and speeds are collected, for instance, every five minutes by vehicle detectors that are installed at intervals of about a few hundred meters. In recent years, real-time systems for predicting short-term traffic conditions based on macroscopic traffic simulation models using the detector data has been developing to support traffic information and control systems[2][3].
It is indispensable to adjust the model parameter of the simulation elaborately so that the prediction precision of this system may improve. The method of automatic setup and update for the model parameters such as the traffic capacity of the bottleneck, the merging ratio of a junction and the relationship between traffic volume and density of a road section are researched.

A bottleneck with this system defined as the section on the lower reaches of the continuing traffic jam section most. The function is judged dynamically in this system from the real-time vehicles detector data was added.

And merging ratio at junction is calculated for only the situation that the both of upstream links from junction are congested. Therefore, it is said that the accurate discriminant of the traffic situation (saturated flow or non-saturated flow) is essential.

Generally, the definition of traffic congestion in urban expressway in Japan is below:

- 20 km/h : heavy congestion (saturated flow)
- 20km/h-40km/h: congestion (non-saturated flow)

This definition is used for the traffic information in Japan. However, this definition is not determined based on from the point of view of traffic engineering but based on the sense of drivers. In fact, the definition cannot discriminate accurately saturated flow. Therefore, it is believed that the definition is not suitable for the calibration of the parameters of traffic simulation in real time.

It is not practical to initialize critical speeds manually because there are about three thousand detectors installed, for instance, on the Tokyo Metropolitan Expressways. Moreover, the critical speeds have to be continuously updated because of time-varying characteristics of detectors. Therefore, we developed an algorithm of automatically setting critical speeds based on detector data.

EXISTING METHOD AND PROBLEMS

In existing studies, the study to estimate the threshold to judge traffic congestion from the characteristic of traffic flow at each detector can be found. For example, the Otsu method in image processing field is used by a research by Akahane et. al.[4][5] The method by Akahane et. al. creates a histogram from accumulated detector data first, and divide the data into 2groups by a threshold. If the variation between two groups are maximum and the variation in each group is minimum, the threshold is the best boundary to detect traffic congestion. Figure 1 shows the calculation result of the detection of traffic congestion among a section. We can find the good results and a bat result (with dashed line).

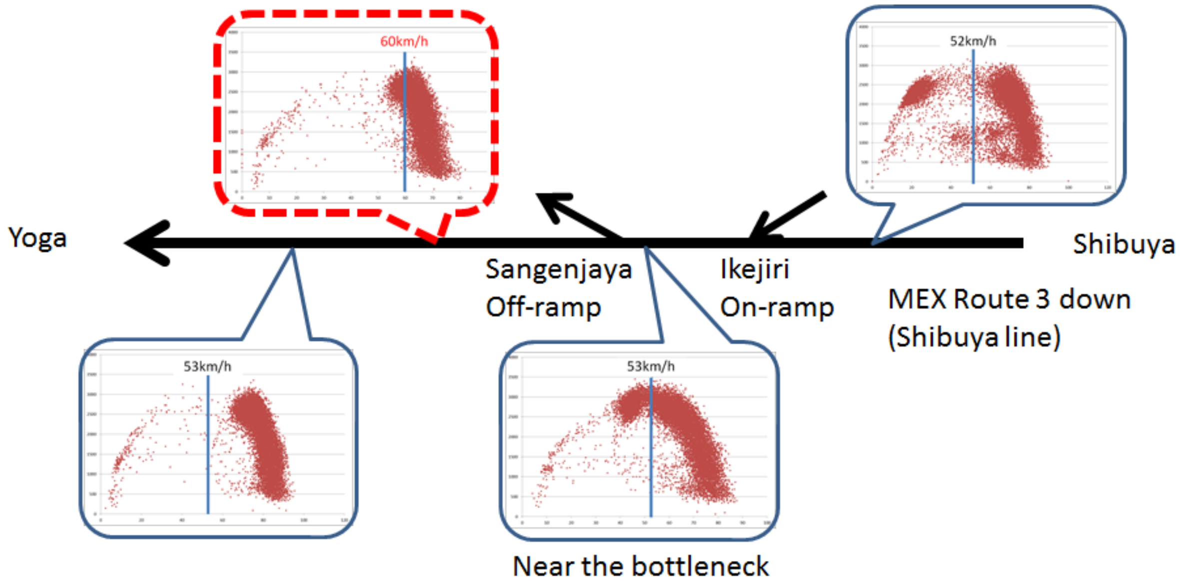


Figure 1 A discriminant result of the Otsu method

The detector point with low accurate estimation of threshold is located at the downstream side of bottleneck. And the most of the data is the situation in unsaturated flow. In this situation, threshold is estimated in the area of unsaturated flow

METHODOLOGY

Kittler Method

In the previous section, we discuss about the discriminant method using the Otsu method[5]. Some issues are found to estimate suitable threshold. Therefore, we tried the Kittler method and compared with the Otsu method. The Kittler method from image processing field is also an estimation method to determine threshold.

The Kittler method is an estimation method of threshold to minimize the average indiscriminating rate under the assumption that a gray value in target area and a gray value in the background area are accede to normal distribution. In this study, we take place gray value as speed to estimate the threshold for the discriminant of congestion.

Here let k denote the threshold of the discriminant of congestion, and let C_1 denote the class of unsaturated flow and C_2 denote the class of saturated flow. We assume that the distribution of speed C_1 and C_2 are accede to normal distribution. Then the average indiscriminating rate P_ε is calculated below:

$$\begin{aligned} P_\varepsilon &= 1 - \sum_{g=1}^{k} f(C_1 \mid g)p(g) - \sum_{g=k+1}^{L} f(C_2 \mid g)p(g) \\ &\leq 1 - \sum_{g=1}^{k}[1 + \log f(C_1 \mid g)]p(g) - \sum_{g=k+1}^{L}[1 + \log f(C_2 \mid g)]p(g) \\ &= \omega_1(k)\log\left(\frac{\sigma_1(k)}{\omega_1(k)}\right) + \omega_2(k)\log\left(\frac{\sigma_2(k)}{\omega_2(k)}\right) \\ &\quad + \frac{1}{2}(1 + \log(2\pi)) + \sum_{g=1}^{L} p(g)\log(p(g)). \end{aligned} \quad \cdots(1)$$

Where,

P_ε : Average incorrect identification

g : Observed speed [km/h]

$f(C_1|g), f(C_2|g)$: Distribution of observed speed with conditions

$p(g)$: Normalization histogram speed g

L : Max calculation time [km/h]

σ_1, σ_2 : Standard deviations

$\omega_1 = \sum_{g=1}^{k} p(g), \quad \omega_2 = \sum_{g=k+1}^{L} p(g)$

If the constant term of the equation (1) is cut, the standard value $J(k)$ is calculated as the follows:

$$J(k) = \omega_1(k)\log\left(\frac{\sigma_1(k)}{\omega_1(k)}\right) + \omega_2(k)\log\left(\frac{\sigma_2(k)}{\omega_2(k)}\right) \quad \cdots(2)$$

Kurita et. al[6]. described the equation (2) the standard to minimize the entropy E with conditional average. Therefore, we apply the value when the entropy E of the equation (3).

$$E = -\sum_{j=1,2}\sum_{g=1}^{L} f(C_j \mid g)\log\left(f(C_j \mid g)\right)p(g). \quad \cdots(3)$$

Figure 2 shows the result of the discriminant with the Kittler method at a detector point that the boundary to discriminate with the Otsu method cannot estimate in high accuracy. In our validation, it may say that the Kittler method is more suitable than the Otsu method.

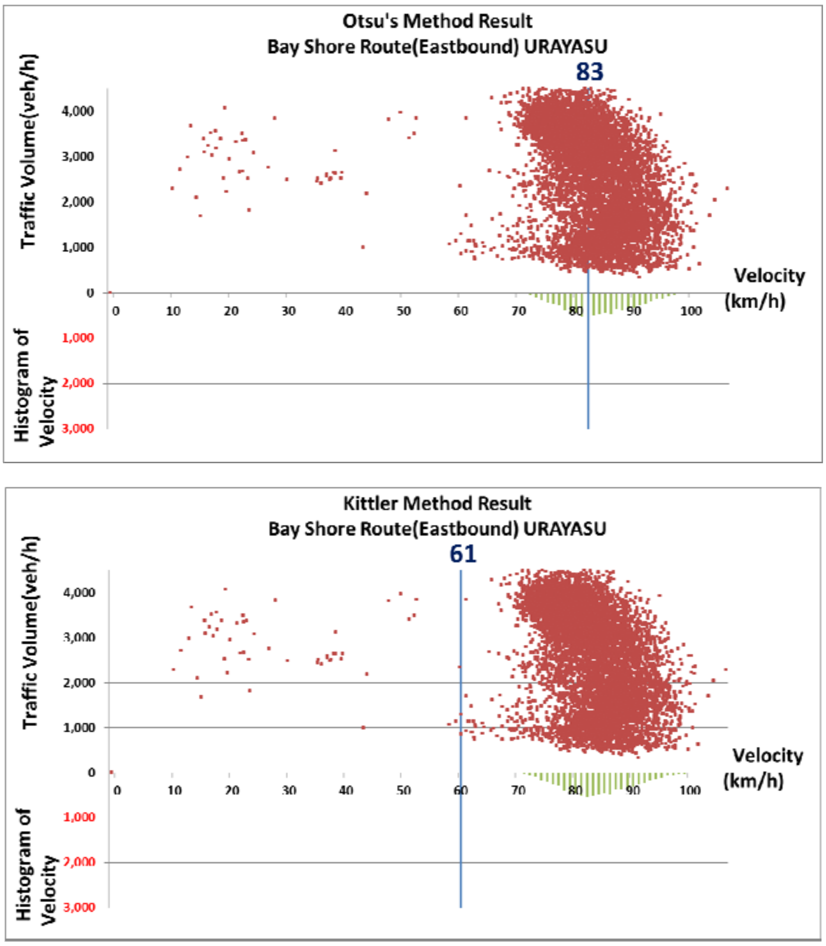
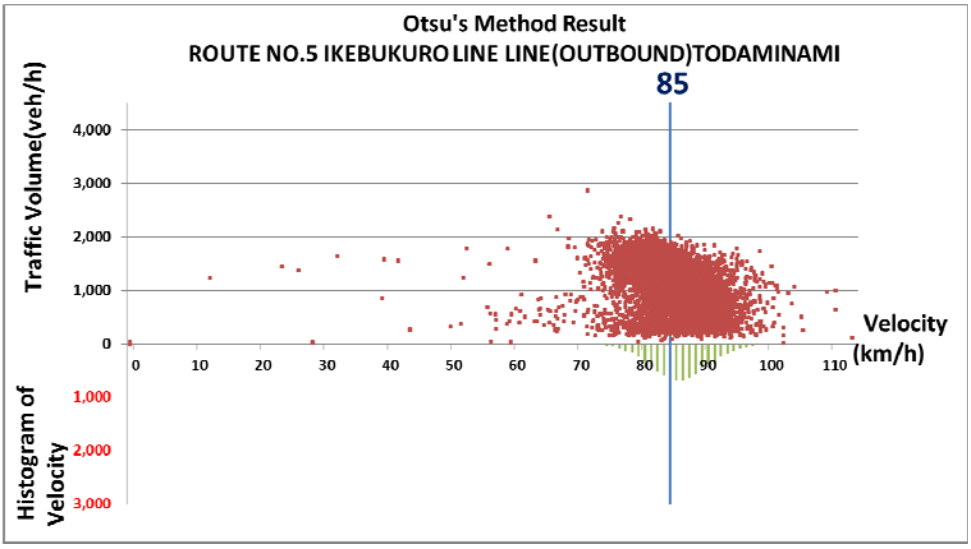


Figure 2　Comparison between Otsu Method and Kittler Method {Bay Shore Route(Eastbound) URAYASU}

Figure 3 shows the result with unexpected estimation of the threshold at another detector point. The both method cannot estimate the suitable threshold. The point which has the suitable result is found with the situation that the traffic volume has varied quite a bit. Therefore, we focused on the appearance frequency of the detector data and developed the strategy to understand the characteristics of traffic flow. To say simply, if a Q-V plot in an area that the appearance frequency is low, the plot is excluded. On the other hand, if a Q-V plot in an area the appearance of frequency is high, the plot is not excluded.



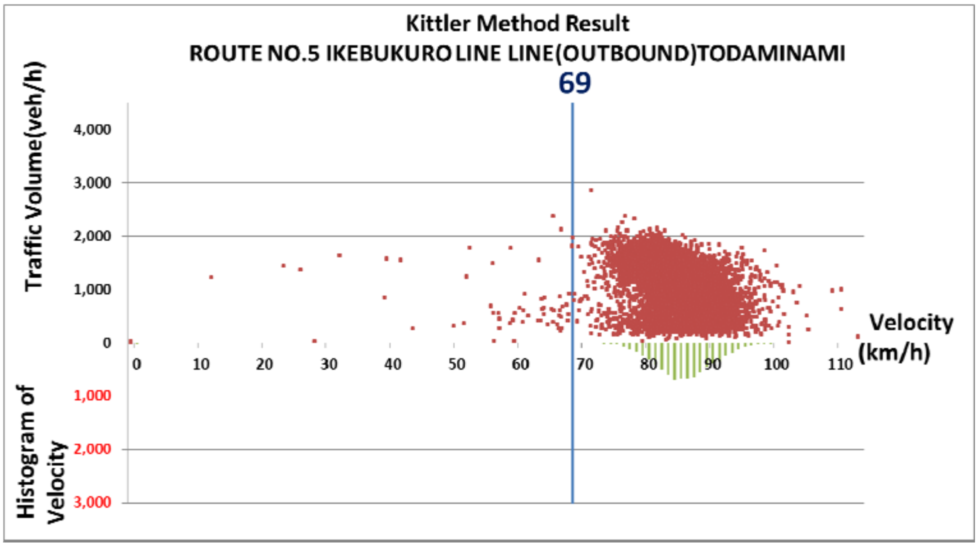


Figure 3 The result with unexpected estimation
(top: with the Otsu method, bottom: with the Kittler method)

The application of the edge reinforcement method to the discriminant algorithm

The distribution of detector data on Q-V diagram has some high concentrated areas and some low concentrated areas. From the existing researches, it is concerned that he low concentrated areas effects to reduce the accuracy of the discriminant result. On the other hand, it is also concerned that the accuracy of the discriminant is reduced by cutting the detector data which is not saturated flow in low concentrated area such as downstream link of bottleneck . Therefore, we arranged the data cleansing process below:

In this session, we describe the algorithm in detail as follows:

- Collected detector data are cleansed and plotted on scatter-grams of traffic volume and speeds(Q-V diagrams).
- The plots on the Q-V diagrams are divided into speed ranks at intervals of 1km/h.
- The plots in meshes where frequencies are less than 30% of the peak in each speed ranks are removed.

Figure 4 shows the result of the pre-processing the data above mentioned. The right- and left-hand side diagrams illustrate plots before and after processing individually.

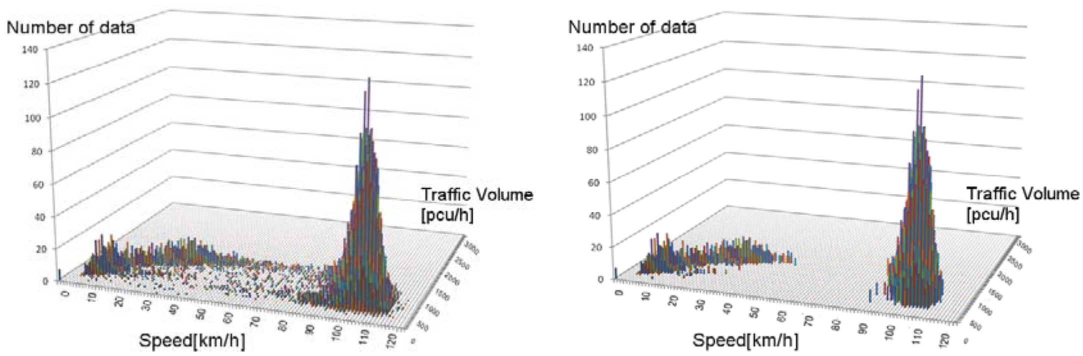


Figure 4 the result by edge treatment (Q-V diagram, before(left)/after(right))

Using edge reinforcement method, the detector data which effects to reduce the accuracy of the discriminant of the boundary on Q-V diagram can be cut out as shown in Figure 5. And the distribution of saturated flow area and non-saturated area is clarified.

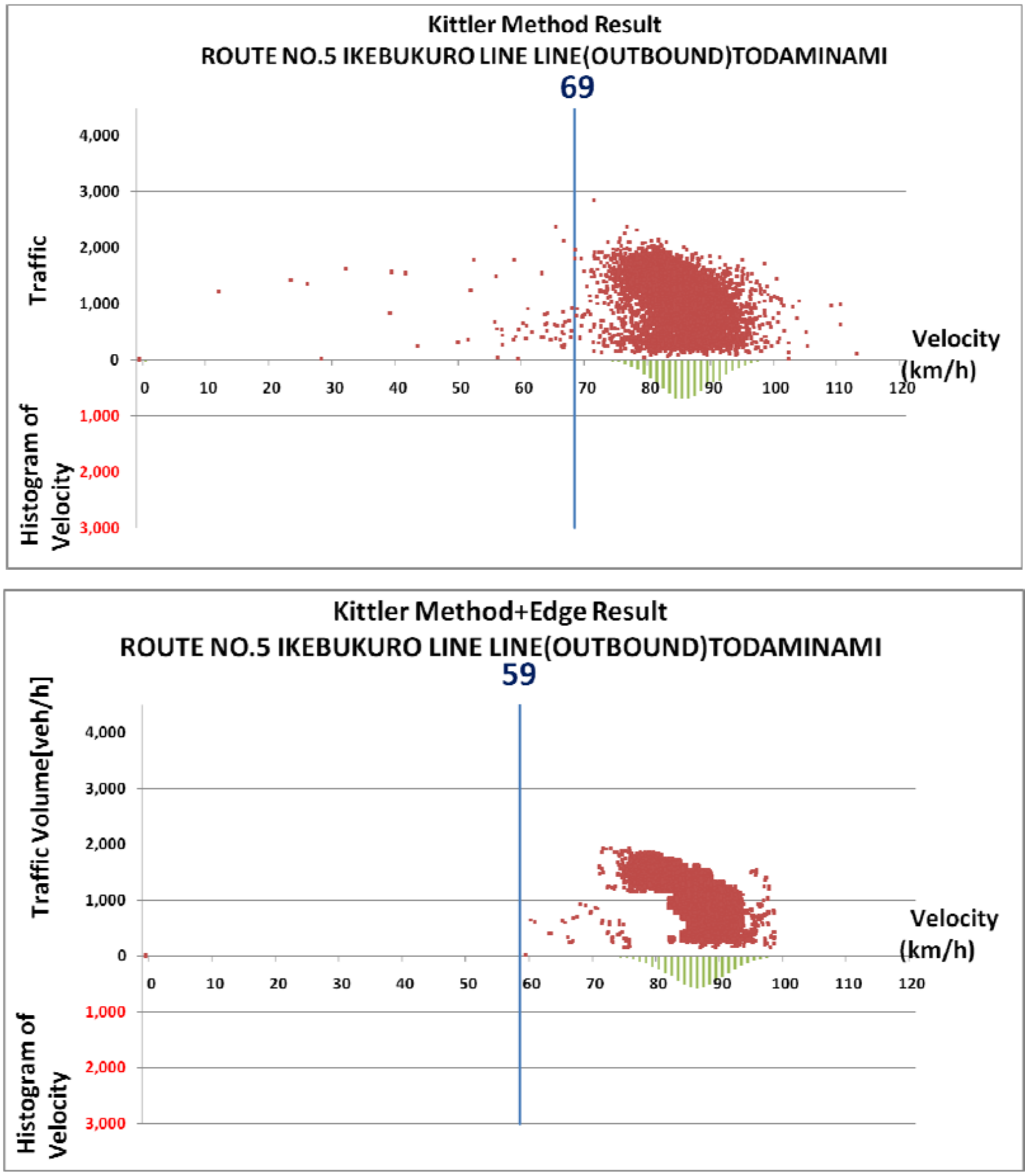


Figure 5 The result by edge reinforcement using detector data (before(top)/after(bottom))

COMPARISON WITH EXISTING METHOD

In this study, we compared the result of the algorithm based on edge reinforcement method, the algorithm based on the Kittler method and the algorithm using the Otsu method. Figure 6 and Figure 7 show the comparison results. From the visual comparison, it is said that the estimated thresholds by the existing algorithms using the Kittler method and the Otsu method have a trend to slant to the congestion area on the Q-V diagram at the detector point that the congestion is rarely detected. On the other hand, the algorithm using edge reinforcement method outputs the suitable results.

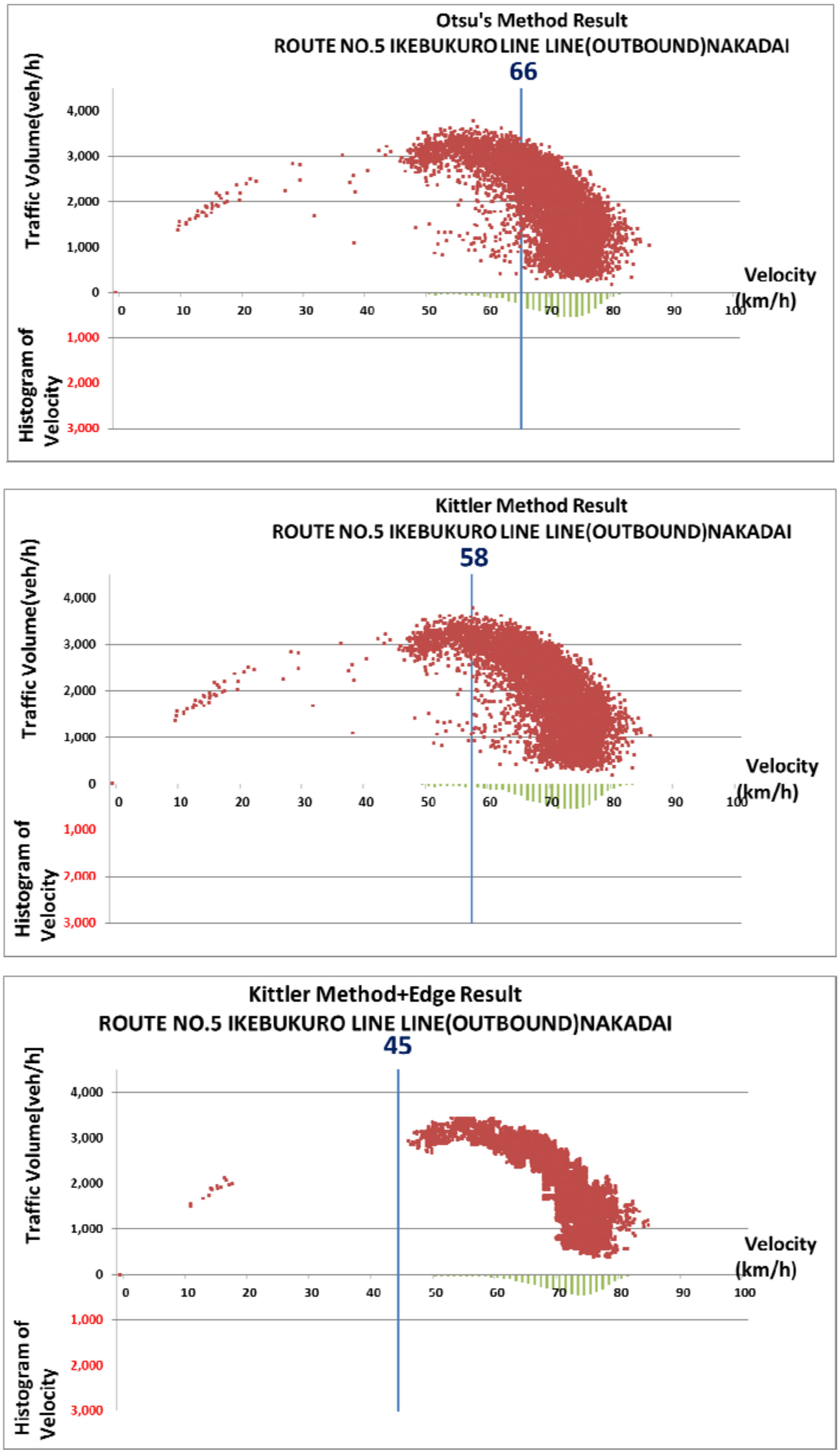


Figure 6 Comparison with existing method 1.
(Otsu method(top)/Kittler method(middle)/Kitter+Edge(bottom))

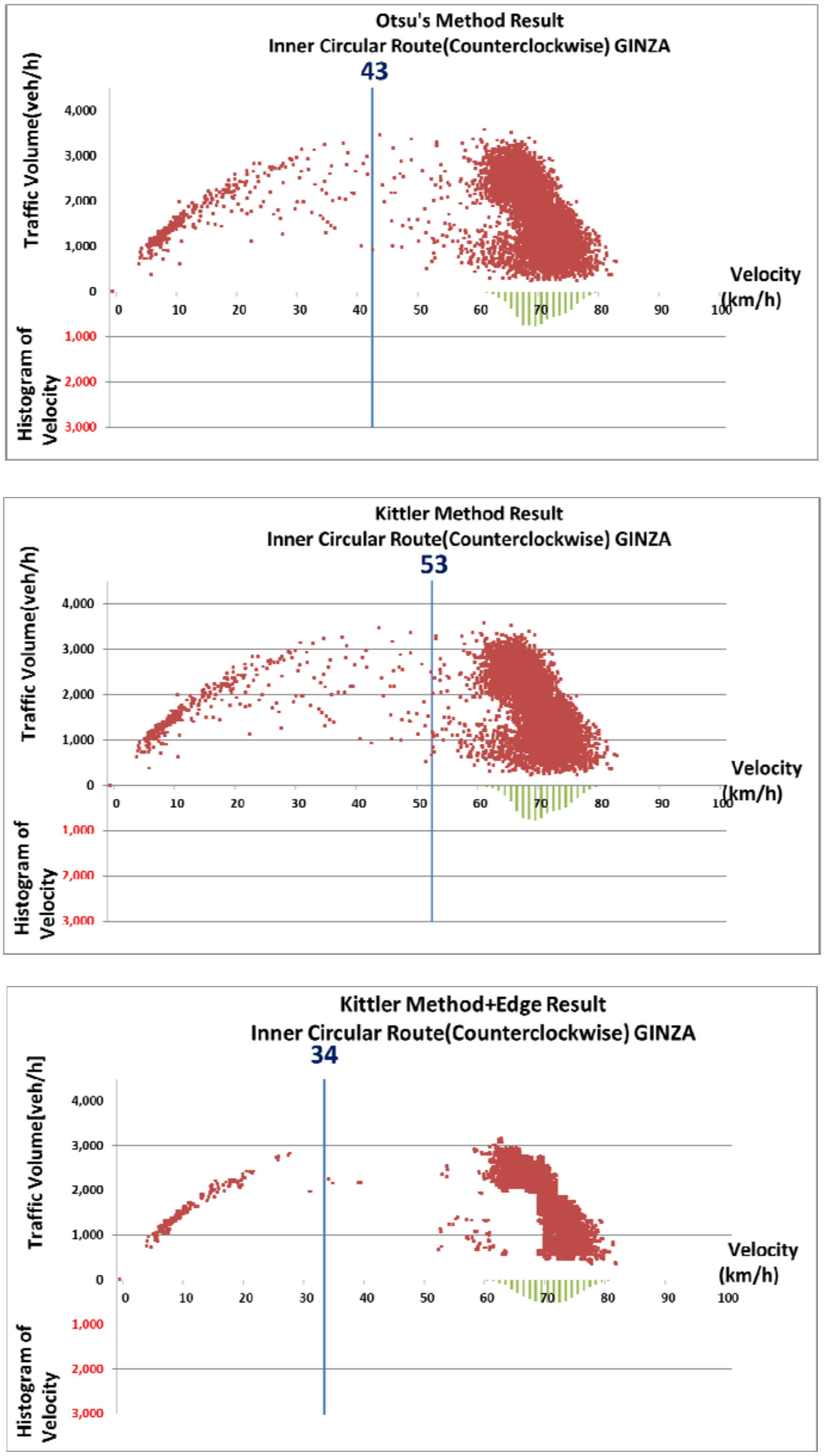


Figure 7 Comparison with existing method 2.
(Otsu method(top)/Kittler method(middle)/Kitter+Edge(bottom))

FUTURE WORKS

As the future works, we evaluate the discriminant algorithm applying to the all detectors in MEX and we confirm the applicability from the result. On the other hand, we survey the cause at the detector point that the discriminant result is not suitable. After the survey, we conduct a study on the refinement of our method.

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