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Preliminary analysis on resting behavior of expressway users with ETC data

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Abstract

This paper describes the preliminary analysis on the resting behavior of expressway users by using electric toll collection (ETC) data. For the sake of the impact assessment of various traffic management schemes, we have been developing a mesoscopic traffic simulator which covers whole inter-urban expressway network in Japan. The simulator takes account of the dynamic route choice behavior of drivers and, for the further step, is expected to model the resting behavior during their trips. For this purpose, ETC data of which penetration is almost 90% is one of valuable data sources. In this draft, the procedure of the analysis to estimate the resting duration from ETC data is outlined with its result. Some findings highlighting the distinct behaviors to be considered in the modeling are discussed.

Keywords: ETC data, resting behavior, inter-urban expressway service area.

Introduction

So far, we have been developing a mesoscopic traffic simulator which covers whole inter-urban expressway network in Japan[1]. With recent developments, the network topology is getting more complex, and traffic prediction based on statistical analysis is becoming harder and harder since it does not take into account the drivers' behavioral changes on the network. Looking at the issue from the seeds and needs perspective, there would be needs to develop a network traffic simulator dealing with traffic flow dynamics and driver behaviors. From the seeds side, road operators are now motivated to utilize ETC data collected every time a vehicle passes an ETC tollgate located at interchanges, since the penetration of ETC is almost 90% of expressway users nowadays. Fully using ETC data is expected to improve the accuracy of time-dependent O-D matrix which is mandatory in simulation studies.

Another expectation for the ETC data utilization can be found in the demand side modeling, which is also mandatory in network context. Some studies on route choice behavior have been achieved mainly by the expressway companies [2][3]. However, there would be other types of behavior which has to be considered.

The resting behavior of expressway users might be one of those that need to be considered. As the trip distances on inter-urban expressways are relatively longer than those on urban expressways or surface streets, many drivers may have chance to take one or more rests during their trips. From the view point of the customer satisfaction for expressway users, smooth operation of a service area is one of major concerns of road companies. If the resting behavior is properly modeled in the express network simulator, it will be valuable to estimate the congestion status of a service area and may help to evaluate the effects of various countermeasures, such as enhancement of parking lots, congestion information provision of a service area, recommendation on future resting plan via car navigation, etc.

However, few conventional studies[4] are found in this topic and mostly they are based on a surveillance data at a certain service area or on a questionnaire survey. It seems insufficient through those approaches to analyze the resting behavior relating with trip context and traffic conditions.

In this paper, the procedure of to estimate total resting duration from ETC data is outlined with its estimated results. Some findings highlighting the distinct behaviors to be considered in the modeling are discussed.

Feature of ETC Data from the Viewpoint of Resting Behavior Analysis

The ETC trip data used in the study includes encrypted ID, vehicle type of toll payment, expressway entrance and exit interchange, and their entering and exit time. Figure 1 describes the relationship of travel time, driving time and total rest time spent at service/parking areas. Here, travel time is calculated from ETC trip data and driving time is estimated from vehicular detectors that are installed at a reasonable spacing. In such a way, total rest time of a particular trip is predicted by the difference between travel time and driving time.

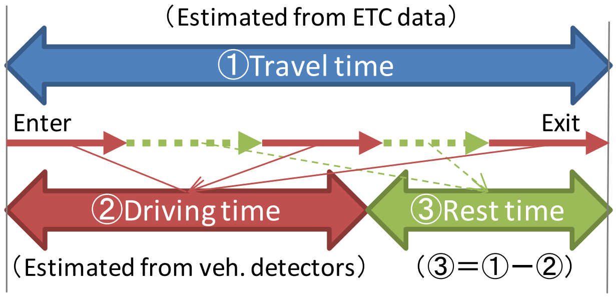

Figure 1 – Travel time, driving time and rest time of a trip on expressways

Though probe data giving continuous location and time every 200m can be used to predict detailed information of driver's resting behavior such as when and where and how long a vehicle makes a rest at service or parking areas and number of rests, the penetration rate of the ETC 2.0 on-board unit (OBU) is too low to be used for prediction of driver's resting behavior as a typical example. ETC trip data, however, are obtained from nearly 90% of the expressway users, and it can be used to estimate total rest time although it is difficult to understand vehicle's detailed resting behavior from the ETC data. With the accumulation of microscopic probe data, total rest time estimated from the ETC data can be used to check the accuracy of microscopic models formulated from probe data.

Analysis of Expressway Trips Based on ETC Data

The objective of this chapter is to understand actual situation about expressway trips such number of trips, trip distribution and travel time distribution and so on from the analysis of the ETC trip data, and also to make clear subjects in estimation of rest time. The data used for analysis is all the ETC data using the expressway network operated by all the three interurban expressway operators (NEXCO-East, Central and West) in one month in November of 2012. Two vehicle types, i.e. passenger car (PC) and heavy vehicle (HV) and weekdays and holidays judged by the expressway entering time were taken for trip analysis. A trip covering neighboring months was not included in the analysis. It is assumed in the study that a particular interchange pair always takes the shortest path.

Characteristics of Interchange-paired Trips

Table 1 describes trip related indices such as total monthly number of trips, average daily number of trips and also avg. trip distance, for weekdays and holidays and vehicle type. It is seen that more trips are made on holidays rather than weekdays. Similarly, heavy vehicles travel longer distance than passenger cars. In particular, passenger cars make more trips on holidays than on weekdays, whereas heavy vehicles take more trips on weekdays rather than on holidays. The average percentage of heavy vehicles is 23.5% on weekdays and 11.5% on holidays.

Table 2 shows the trip distributions for each vehicle type and weekdays and holidays. The percentage of trip distance below 50km is 71% on weekdays and 59% on holidays for passenger cars and 54-56 for heavy vehicles. The 85 percentile trip distance is approximately 80km on weekdays and 110km on holidays for passenger cars, and 140-150km for heavy vehicles. On the other hand, the trips of distance over 100km in which resting behavior is expected only account for 10.5% on weekdays and 18.3% on holidays for passenger cars, and 23-24% for heavy vehicles. The long trips of distance over 500km, however, takes up less than 1% for passenger cars and 3% for heavy vehicles; and there are a few long trips over 1,000km.

Table 3 shows as an example the relationship between trip distance and number of trips for passenger cars on weekdays. The trip distance of the interchange pairs of more than 1,000 vehicles per day is below 50km. The trips of distance over 100km in which resting behavior is expected only account for less than 1%.

Therefore, it is concluded from the viewpoint of resting behavior analysis that only a small number of trips are long distance trip during which resting behavior is expected. Rare trips account for a majority of trips and they are difficult to be analyzed from the sample size point of view.

Table 1 – Expressway trip related indices by weekdays/holidays and vehicle type

Trip indices	Weekdays (PC)	Weekdays (HV)	holidays (PC)	holidays (HV)
Total monthly number of trips (x1000)	51,085.7	15,931.5	25,991.3	3,364.4
Avg. daily number of trips (x1000)	2,432.7	758.6	2,887.9	373.8
Total vehicle kilometers traveled (million veh-km)	2,487.9	1,397.7	1,678.3	303.8
Avg. trip distance (km)	48.70	87.73	64.57	90.30

Table 2 – Trip distribution by weekdays/holidays and vehicle type

Trip distance	Weekdays (PC)	Weekdays (HV)	holidays (PC)	holidays (HV)
- 10km	11.0%	8.1%	7.7%	9.7%
- 20km	32.8%	24.1%	24.8%	23.5%
- 50km	70.8%	55.6%	59.1%	54.5%
- 100km	89.5%	77.4%	81.7%	76.0%
- 200km	97.1%	89.2%	94.6%	88.7%
- 300km	98.9%	93.4%	98.0%	93.3%
- 500km	99.8%	97.7%	99.7%	97.7%
- 1,000km	99.99%	99.9%	99.99%	99.8%
- 1,500km	99.9999%	99.998%	99.9999%	99.996%

Table 3 – Relationship between trip distance and number of trips (Weekdays, PC)

		Interchange-paired distance					
		- 10km	- 20km	- 50km	- 100km	- 200km	- 200km
No. of trips	1 car/month	8	10	24	237	3345	42386
	- 1 car/day	7	19	225	2195	18821	64110
	- 10 car/day	152	178	1165	6348	15366	9850
	- 100 car/day	550	840	3634	5604	3279	839
	- 1,000 car/day	330	908	2142	907	204	32
	1,000 - car/day	60	89	100	28	2	0

Travel Time Distribution

Travel time depends on vehicle type, day of week, expressway entry and exit time, purpose of travel, etc. Figure 2 shows as an example the relationship between expressway entering time and travel time for trips from Tokyo to Hamamatsu on weekdays for heavy vehicles. It can be seen from the figure that

- Heavy vehicles entering expressways late at night;
- There is variation in travel time. Considering driving speed of 80km/h, over 2 hour total rest time would lead to more than5 hour travel time.

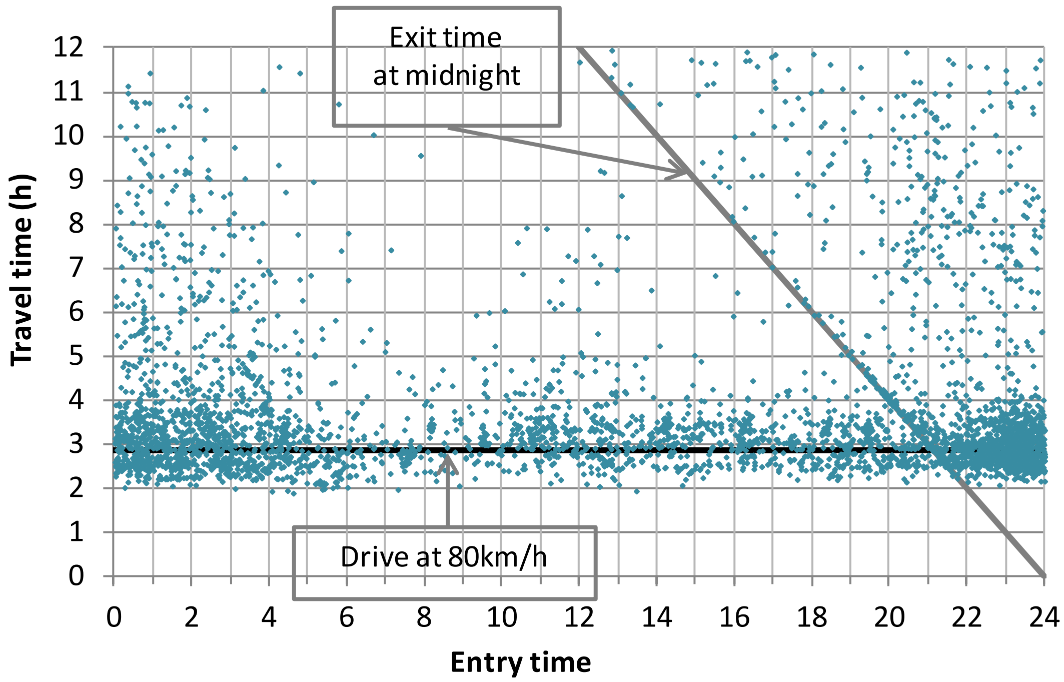

Figure 2 – Relationship between expressway entry time and travel time (Tokyo – Hamamatsu of Tomei Expressway, Weekdays, Heavy vehicles)

Analysis on Total Resting Time of Expressway Users with ETC Trip Data

Outline of the Analysis

The ETC trip data and the traffic detector data used for the analysis are collected on whole inter-urban expressways operated by the NEXCO. More than 126M ETC trips as shown in Table 4 were used for the analysis.

Table 4 – Number of ETC trip data in November 2012 [1000 trips/month]

	Weekdays	Holidays	Total
Passenger cars (PC)	67,937	34,132	102,070
Heavy vehicles (HV)	19,958	4,277	24,234
Total	87,895	38,409	126,304

The total resting time of each trip is estimated by subtracting the presumed running time from the travel time on the expressway. The presumed running time is calculated by accumulating the travel time along the time-space trajectory running at the average speed for each detector coverage section, as shown in Figure 3. In the case there are couple of possible paths for the trip, let us assume it takes the shortest distance path.

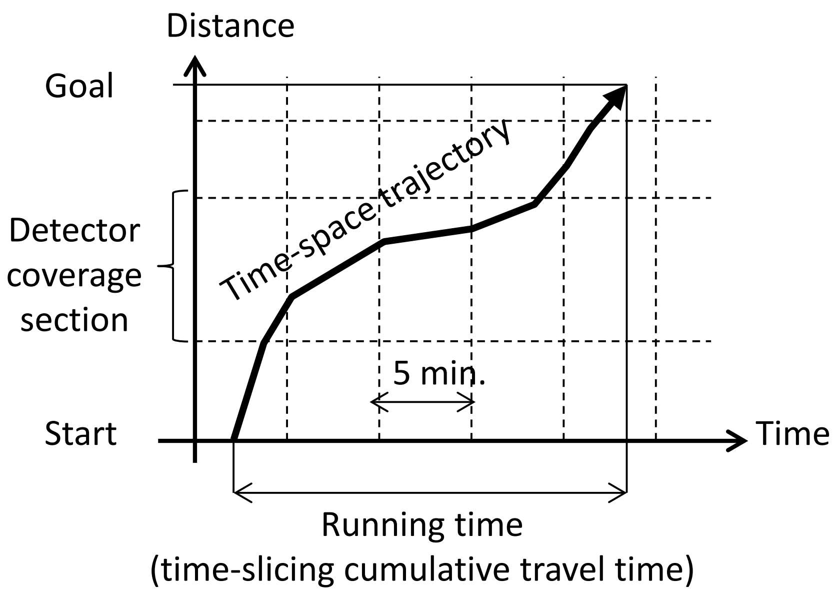

Figure 3 – Time slicing cumulative travel time

Distribution of the Estimated Resting Time

Figure 4 is the histogram of the estimated resting times of the HV trips of which distance is 320-330 km and exiting expressway during 6-7 AM on holidays. There are unneglectable numbers of negative resting times which come from the faster running speeds than the average. It is considered that there will be similar number of 'without-resting' trips with the slower running speeds in the positive side of the histogram. As those slower 'without-resting' trips are hard to be distinguished from the 'with-resting' trips, we should be careful to discuss the resting time shorter than 30 minutes.

There are not so many but remarkable numbers of resting time longer than couple of hours, sometimes more than one day. Those longer resting times would be spared for the sleeping during nighttime or the adjustment of exit time from the expressway, and should be treated separating from the majority of 'normal' resting times less than couple of hours.

To know the adequate range for such long resting times, let us focus on the shape of the cumulative relative appearance curve, the red line, in Figure 4. From the visual inspection, the curve less than 120 minutes seems to have the sigmoid shape and the curve more than 120 minute looks like linear slope. Similar feature in the curve shape can be found in the other distance range, let us hereby set the criterion for the long resting time at 120 minutes.

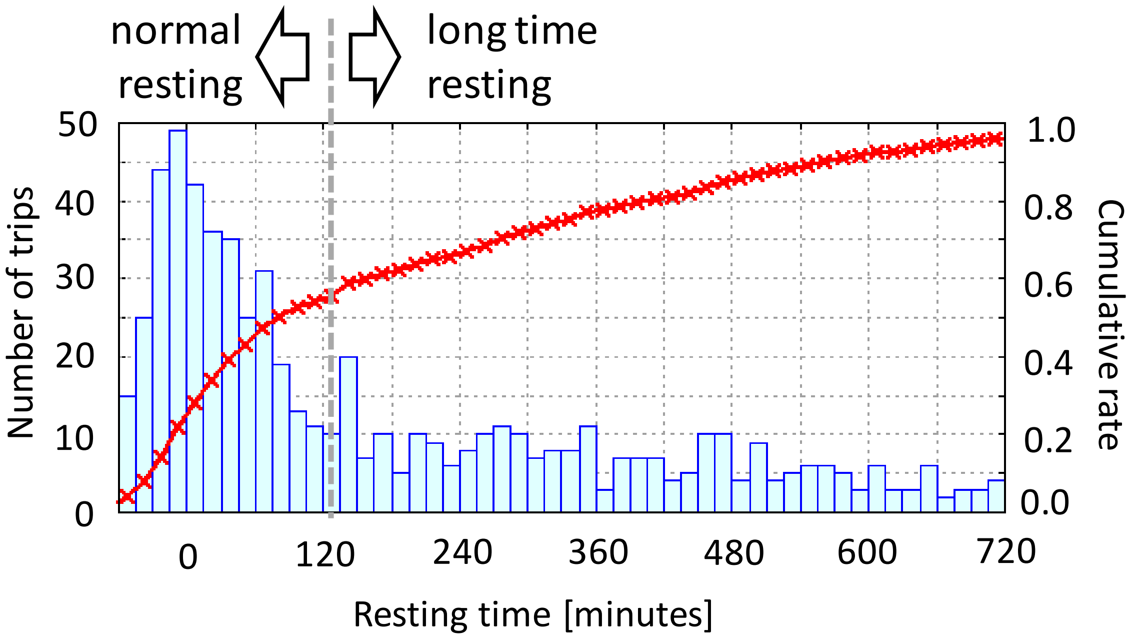

Figure 4 – Histogram of the estimated resting times (Holidays/HV/320-330km/exit during 6-7AM)

A Study on the Long Resting Behaviour

Figure 5 draws the colour contour map with 85 percentile of resting time for every 1 hour of the exit times and 10 km of the trip distance. The colour of the cell closer to red means the higher ratio of the long resting time for each cell. The pattern of the red cells which concentrate from 4 to 12AM attracts attention and it implies us two incentives to the exit time adjustment as follows.

The first incentive is to have toll discount for late night travels. In those days, the drivers who stay on the expressway during 23PM – 4AM could get the discount to the half of normal toll. We may recognize the concentration of the long resting times at around 23PM to 0AM and more than 300km, especially for heavy vehicles. This concentration would be the result of exit time adjustment of the drivers who could reach the destination before 23PM but took rest for a couple of hours. The longer distance trips would take enough margin to the uncertainty of their travel times and consequently had to take longer resting time for the adjustment.

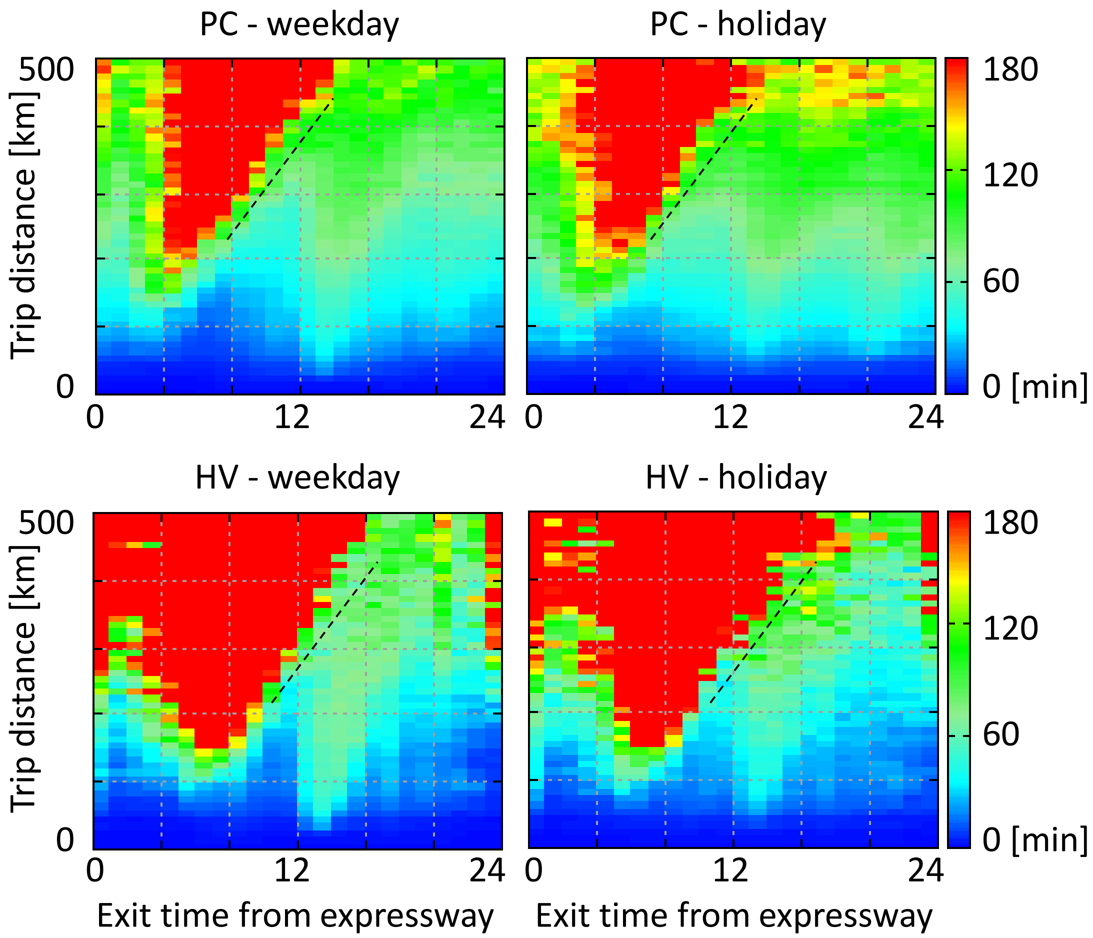

Figure 5 – Contour map with 85 percentile of resting times

The second incentive would come from the restriction of business opening hours. The reverse triangular shape of the red cells has the sloping edge in the morning hours. This distinctive feature can be explained as shown in Figure 6, which overlays the frequency distributions of the entry and the exit times of PC-weekday trips of which distances are 300-310 km and of which resting times are more than 120 minutes onto the color contour map of PC-weekday in Figure 5. The exit time distribution has the morning peak at around 7AM.

As the expected travel time without resting will be about 3 hours at the cruising speed 100kph, those trips exiting at around 7AM peak may enter the expressway at latest before 4AM, and consequently can have the toll discount. If only the first incentive is affecting, there is less attraction for drivers to shift their departure time earlier, and we may expect the similar peak at around 4AM in the entry time distribution.

However, such peak in the entry time distribution is found at around 11PM, 5 hours earlier than the expectation. This may suggest the restrictions on travel schedule by the business hours, meaning many travelers have to leave their origin places before the business closing time but cannot reach the destinations before the business opening time because of the unavailability of their business facilities.

There is another remarkable peak at around 3AM in the entry time distribution. This peak can be explained by the early departure time shift of the travelers who are motivated to have the toll discount.

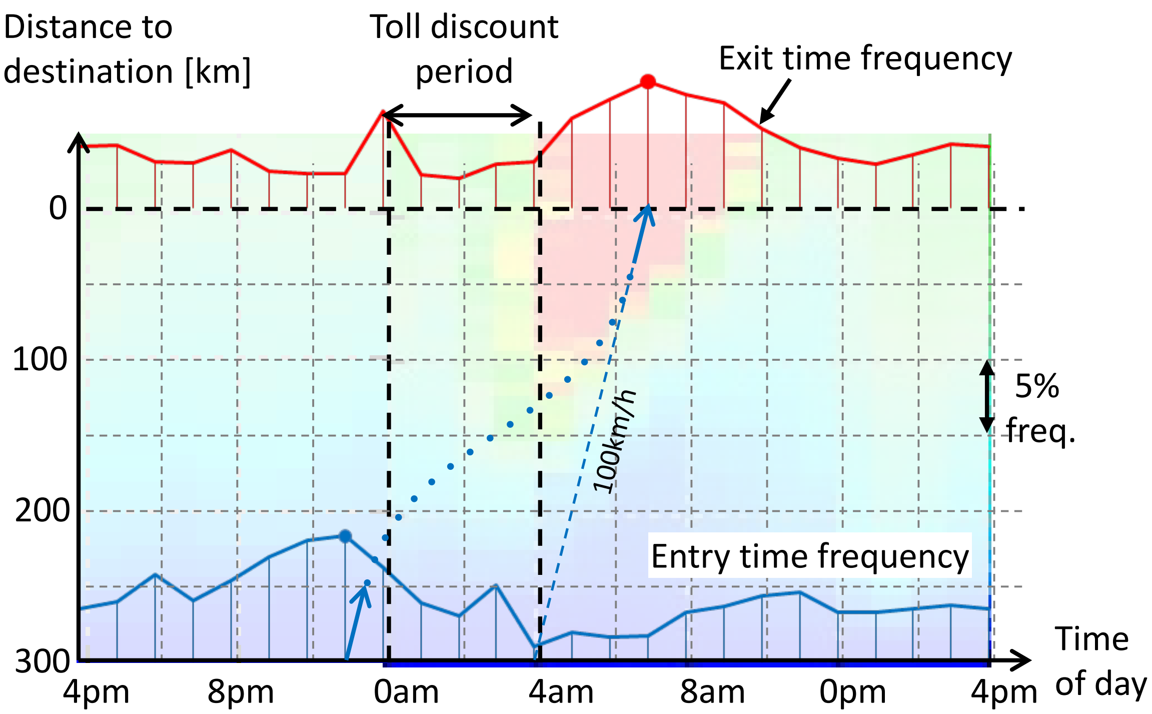

Figure 6 – The entry and the exit time restriction by the business hours

A Study on the Normal Resting Behaviour

The next focus moves on the 'normal' resting behaviour within 120 minutes which would be spent for repose, having meal, buying souvenirs, etc. Figure 7 shows the contour map of the proportion of the resting time more than or equal to 60 minutes and less than 120 minutes. Similarly to the early morning pattern in Figure xx, we may recognize the second reverse triangular shape with light blue to green colour in the early afternoon, and in case of PC-holiday, the third triangle can be found in the evening. Those patterns appearing at meal time reveal the resting behaviours for lunch and dinner. The reverse triangular shape may come from the reason that the longer trips tending to run far from their destination at meal time have more necessity to have meal at that time.

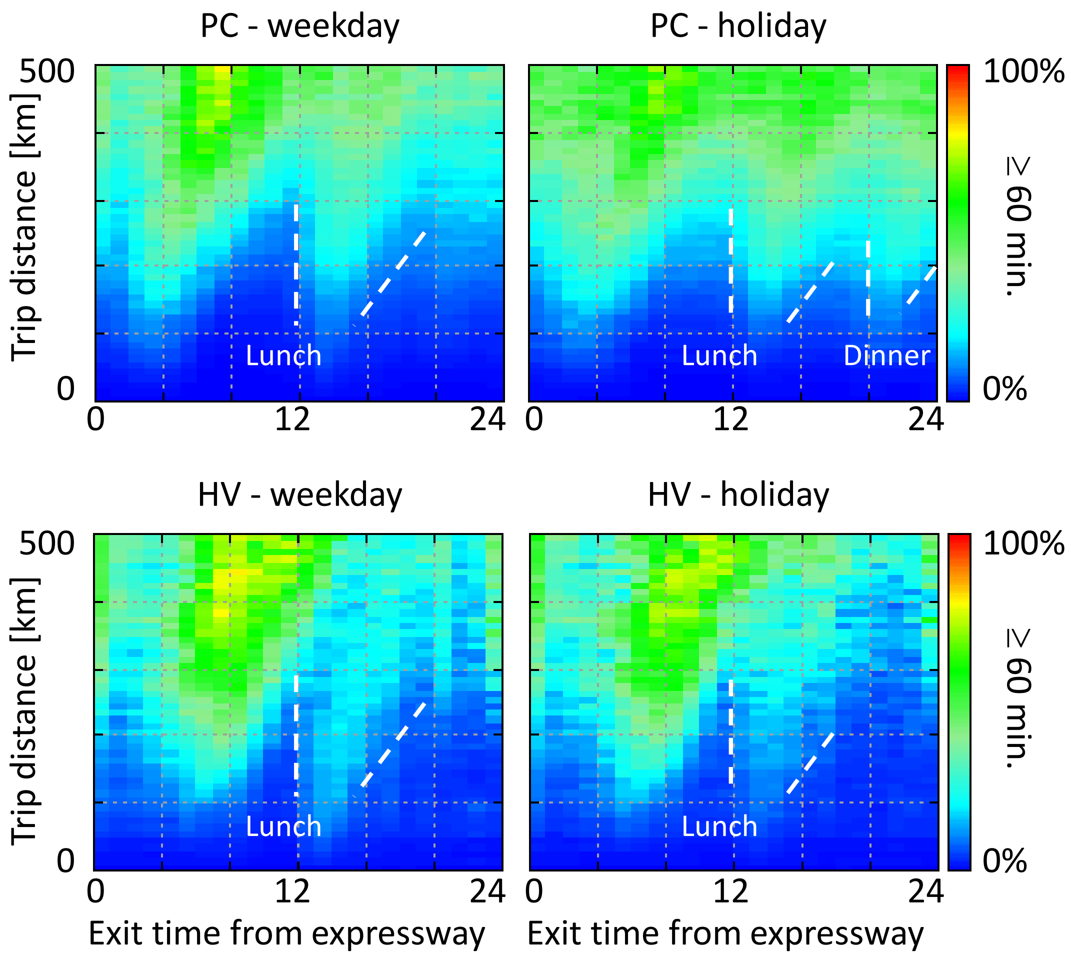

Figure 7 – Contour map of the proportion of the resting time > 60 min.

Conclusions and Future Works

In this paper, we have analyzed the resting behavior with the ETC trip data and the detector speed data. The study on the long resting time more than 2 hours suggests two incentives to have toll discount in the midnight and to postpone the exit time until business opening time. Another study reveals that the normal resting times less than 2 hours concentrate at around meal time. Our future works will identify the macroscopic model to predict total resting time on expressway.

References

1. Hirai S., J. Xing, R. Horiguchi, T. Shiraishi, M. Kobayashi (2015). *Development of a Network Traffic Simulator for the Entire Inter-urban Expressway Network in Japan*, Transportation Research Procedia Volume 6, pp285-296.

2. Yaginuma H., T. Ishida, T. Adachi, Y. Asakura, (2012), *An empirical analysis of traffic information provision and route choice behavior with large-scale data*. Proceedings of the 32nd Annual Conference of Japan Society of Traffic Engineers (in Japanese).
3. Ishida T., M. Fukase, H. Ishibashi, and H. Kiyomiya, (2013), *Analysis of route choice behavior on intercity expressways*, Proceedings of 33rd Conference of Japan Society of Traffic Engineers (in Japanese).
4. Matsushita, T., T. Kumagaya, Y. Nonaka, and T. Ishida (2011). *A basic analysis of expressway service area choice behavior*. Proceedings of Infrastructure Planning and Management, Vol.44,（CD-ROM）(in Japanese).