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Analysis of resting behaviour of inter-urban expressway users with ETC2.0 probe data

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Abstract

To assess measures associated with rest areas, such as making rest areas more attractive by improving commercial facilities and parking lots or providing information on congestion of rest areas, it is necessary to analyse the behavioural changes of expressway users. Of the various behaviours, those at rest areas have not been studied very much so far. In this study, we aim to develop a resting behaviour model of inter-urban expressway users, apply the model into our expressway network traffic simulator, and evaluate the effectiveness of traffic measures associated with rest areas and mainline, e.g. by encouraging users to take an early break or by having drivers spend more time at rest areas when traffic is congested on downstream mainline. This paper reports on creating a database of resting behaviours of expressway users using ETC2.0 probe data, and on the analysis of the resting behaviours using the database.

1. Introduction

Three inter-urban expressway operators in Japan have carried out various measures concerning expressway rest areas (service area (SA) and parking area (PA)) to provide better services: making rest areas more attractive by rearranging parking spaces; renovating restrooms, shops, restaurants and other facilities; and providing real-time traffic information on mainline and at rest areas to ease congestion at rest areas. It may also be possible to control traffic to ease congestion on mainline by prompting users to stay at upstream rest areas longer to avoid the congestion.

To evaluate the rest area related measures, it is needed to predict how the trip behaviours (the sequence from entry of the expressway network to exit) of users change with the application of the measures.

Of the trip behaviours, only a limited number of studies have been carried out on resting behaviour, which comprises rest area selection behaviour and stay time behaviour: e.g. the study on short stays at rest areas by Shiino et al. (2011) and the study on how drivers select rest areas by Matsushita et al. (2011). Since 2015, Seya et al. (2015), Mouri et al. (2015), Yamada et al. (2015) have conducted the studies on rest area selection behaviour of expressway users. But the behaviour of users has not been analysed systematically.

Currently, we are developing an Expressway Network Simulator (ENS) to evaluate various traffic measures taken on expressway network (2015). The ENS is designed to reproduce the trip behaviour of each vehicle and is equipped with a route choice behaviour model, for selecting routes depending on the traffic condition on each route, but it does not include a resting behaviour model. By incorporating a resting behaviour model into the ENS, it will be possible to evaluate the effectiveness of rest area related measures for each rest area and a single route, and for the entire network. In addition, we expect to improve the accuracy of the ENS by making it possible to reproduce trip behaviour which is closer to the actual behaviours of users.

In the study, we aim to build a resting behaviour model of inter-urban expressway users, based on the analysis of resting behaviour using various traffic data. We also aim to apply the model in the traffic flow simulator and use it to evaluate traffic flow improvement measures related to rest areas for each route and for the entire expressway network. In a previous paper (Hirai et al., 2016), the authors did a macroscopic analysis of trip behaviour focusing on the stay time at rest areas by combining data from ETC (electronic toll collection), used by 90 percent of expressway users, and vehicle detector data. A macroscopic resting behaviour model (Hirai et al., 2015, 2016) was formulated from the findings. Because ETC data provides only expressway entry and exit data and does not give the number and location of breaks the users took, details of resting behaviour are not yet analysed.

To analyse rest area selection behaviour and stay time behaviour, data on each vehicle that includes route data is necessary. So, the authors used trip history data included in the probe data of the newly introduced ETC2.0 system to analyse the actual resting behaviour. This paper reports the findings of the basic analysis of resting behaviour.

2. Outline of ETC2.0 probe data

The so-called ETC2.0 probe data is used in the study, which is output from an ETC2.0 service becoming increasingly popular in Japan (Saji et al., 2014). It includes vehicle type, time, latitude and longitude. Data is recorded every time a vehicle moves 200 m or 45 degrees, from the point where the previous data was recorded. But data within approximately 500 m from where the engine was turned on or off is not recorded from the viewpoint of personal information protection. Table 1 shows items included in the ETC2.0 probe data.

Table 1: Typical trip history data items of the ETC2.0 probe data

Trip history data	Operation ID 1
	Vehicle type & use
	GPS time
	Trip no.
	Serial no.
	Road type code
Added data after map matching	Matching flag
	Matching latitude, longitude
	Entry/Exit node
	Inbound, outbound code
	Road operator code

It should be noted that, to protect personal information data, identification number allocated to each ETC2.0 on-board equipment is shuffled every day from the viewpoint of personal information protection, and each equipment is given a separate consecutive number, or Operation ID 1" (hereinafter ID). By gathering data for each ID, the movement of a particular vehicle for one day can be collected. Since the ID changes when the date changes and the engine is turned off, data on trips of overnight or multiple days for a vehicle is basically difficult to grasp from the ETC2.0 probe data.

When using the ETC2.0 data, if there is a continuity of a trajectory data in space-time diagram collected from the same ID arranged in chronological order, the collection of the data is referred to as a "trip" (the meaning is different from the earlier mentioned "trip behavior"). When it is judged that, for some reason, the data discontinues, in other words if there is a big difference in the time or distance between one recorded datum and the next, the consecutive number is changed, and this number is called a "trip number." In addition, a serial number is given to the data in each trip.

The added data after map matching include "matching flag" which indicates whether map matching was successful or not, "matching latitude and longitude" which are the latitudes and longitudes of vehicle location after map matching, and links (entry/exit nodes) of the digital road map (DRM) and their attributions (inbound/outbound code and road operator code).

3. Extracting resting behaviours and generating trip behaviour data

3.1. Grasping the characteristics of vehicle trajectories around rest areas in time-space diagram

To understand the resting behaviour for each ID, it is necessary to identify whether the user visited the rest area to take a break or just passed through, and also to get the information of the rest area, time, date and the length of the stay.

Figure 1: Vehicle trajectories in time-space diagram taken near Ebina SA on the Tomei Expressway (1 August 2015)

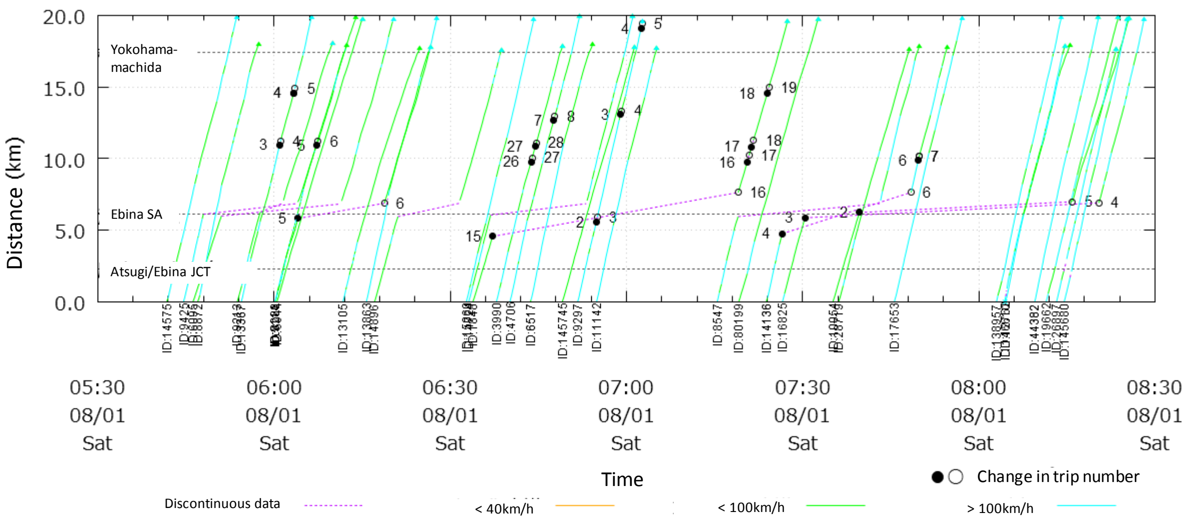


Figure 1 shows vehicle trajectories in time-space diagram for each ID taken in the inbound direction of the Tomei Expressway around the Ebina SA, on 1 August 2015. The marks ● & ○ on the trajectory indicate points where the trip number changed. The number beside them is the "trip number." The dotted purple line indicates places where the trip number has changed or where the "serial number" is discontinuous (interruption point). These longer gaps seem to express the resting at SA/PA, but could appear at any place far from SA/PAs for some reason, e.g. the slow speed travelling in traffic jam. Therefore, let us here set up the criteria to identify the gap corresponding to the individual resting as follows:

- of which the trip numbers at both ends are different;

- of which the time interval is more than 180 seconds;

- of which the positions at both ends are within 500m from the centre of SA/PA.

Below, we will define an interruption point as “a section between two points where the time difference is more than a fixed amount,” and will extract resting behaviours by determining whether the interruption point is close to a rest area or not.

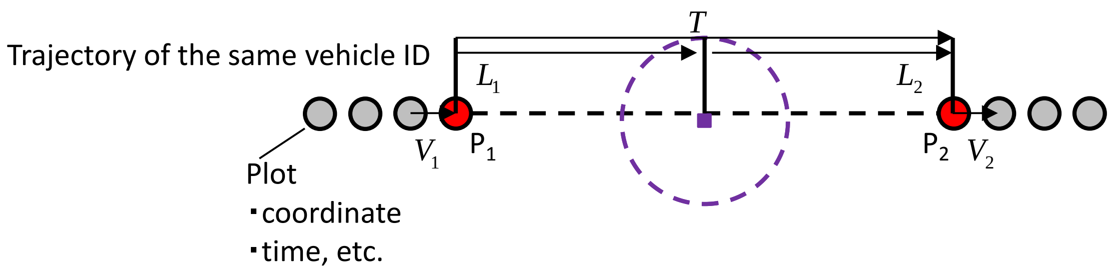
3.2. Extracting resting behaviours

3.2.1. Determining whether an interruption point is close to a rest area or not

In extracting resting behaviours, interruption points are used to determine whether they are located close to a rest area or not. As explained earlier, when a user takes a break at a rest area, the probe data on the upstream and downstream side of the rest area is not recorded. Therefore, we laid down a fixed radius around a rest area (rest area zone) for judging whether a vehicle stopped at or passed by a rest area. If the rest area zone is too large, it may include nearby ICs and JCTs, and vehicles leaving or entering the expressway may be erroneously judged as vehicles taking a break.

In this study, the radius of the rest area zone was set basically at 500m. Each zone was adjusted so that it does not include a nearby IC or JCT. If rest areas on both directions are a bit far from each other, the zone was set so that it includes both of them. As an example, the relation between rest area zones and interruption points are shown in Figure 2. The two interruption points or either of them may be included in the rest area zone.

Figure 2: Relation between rest area zone and interruption points



3.2.2. Determination of resting behaviors considering vehicle speed

Once resting behaviour is determined at a rest area, resting time is estimated from the information of location and time of the upstream and downstream interruption points with the following formulas.

$$RT = T - (T_1 + T_2) \tag{1}$$

$$T_1 = \frac{L_1}{V_1} \times 3{,}600 \tag{2}$$

$$T_2 = \frac{L_2}{V_2} \times 3{,}600 \tag{3}$$

where,

RT: estimated resting time (sec);
T: time span between interruption points P_1 and P_2 (sec);
T_1: estimated running time from P_1 to the centre of the rest area zone (sec);
T_2: estimated running time from the centre of the rest area zone to P_2 (sec);
L_1: straight distance between the centre of the rest area zone to P_1 (km);
L_2: straight distance between the centre of the rest area zone to P_2 (km);

V_1: average vehicle speed between P_1 and the immediately upstream point (km/h);
V_2: average vehicle speed between P_2 and the immediately downstream point (km/h);

3.3. Generating trip behaviour database

Next, we generate trip behaviour database from entry to exit of expressway network to grasp actual trip behaviour that includes resting behaviour.

3.3.1. Generating entry data

When probe data of a vehicle does not include expressway data on the upstream side of the IC, it was judged that the vehicle entered the expressway from the IC in question, and the time the initial data was recorded as the time that the vehicle entered the expressway. When data was recorded in between ICs, the immediately upstream IC was considered as the IC of entrance, and the time the data was recorded was understood as the time of entrance.

3.3.2. Generating exit data

When expressway data on the downstream side of the IC does not exist, it was judged that the vehicle exited from the IC in question, and the time the last data was recorded was considered as the exit time. When the data was lost in between ICs, the immediately downstream IC was considered as the exit IC, the time of the data loss was considered as the exit time.

3.3.3. Generating resting data

To generate resting data, resting behaviour around the rest area was determined by using the method described in Section 3.2. The time of the final data recorded at the point of interruption P_1 plus the running time T_1 from P_1 to the centre of the rest area zone was determined as the vehicle's entrance of the rest area. Similarly, the time of the initial data recorded at the point of interruption P_2 minus the running time T_2 from the centre of the rest area zone to P_2 was determined as exit time. The time difference between the entrance and exit time of a rest area was defined as resting time as defined in formulas (1)-(3).

4. Analysis of resting behaviours

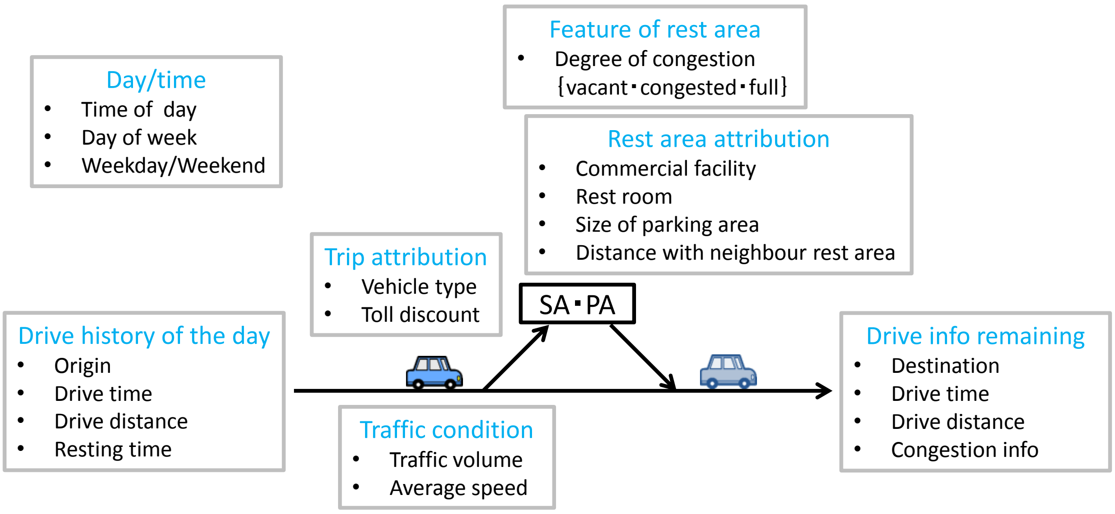
Based on the procedures described above, the trip behaviour database made for the entire expressway network in Japan is used to analyse the resting behaviour of expressway users. Since the ETC2.0 probe data at the time of analysis mainly covered small cars with almost no trucks, the target vehicle type of this paper is therefore focused on small cars.

4.1. Factors assumed to influence resting behaviours

Figure 3 shows various types of factors which are assumed to influence resting behaviours of expressway users. Of the factors shown in the figure, travel time and distance to and arrival time at a rest area may be taken from the trip behaviour database. In addition, travel time and distance from the rest area to his or her destination exit and attribution of the rest area such as the type of commercial facilities and size of parking lots may also affect rest area choice behaviour (passing/stopping) and resting time of expressway users.

Aiming to model resting behaviour, the paper analysed the actual resting behaviour, considering the possibility of using the explanatory variables and dependent variables in the resting behaviour model by using the trip behaviour database.

Figure 3: Factors assumed to influence resting behaviour

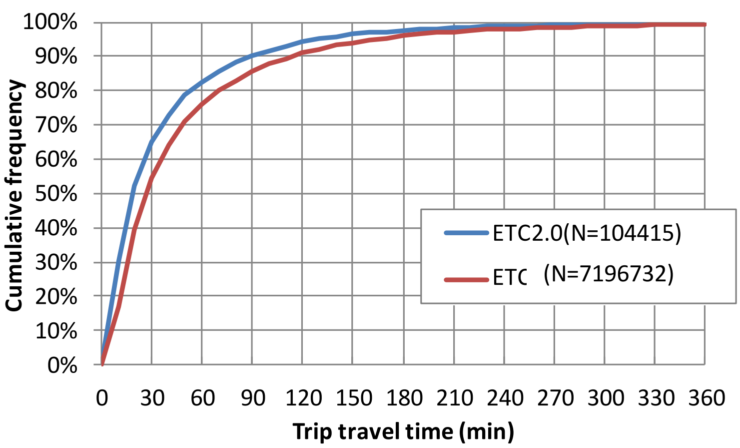


4.2. Trip travel time, number of rests and resting time per break

The trip behaviour database was generated from a nationwide trip history data collected between 1 and 2 August 2015, using the procedures described in sections 3.2 and 3.3. The number of trip behaviour data extracted was 105,504. As for the type of vehicles, there were 104,415 small vehicles (99%), and 1,088 large vehicles (1%). According to traffic statistics (EHRF, 2015), average daily number of vehicles using expressways in August 2015 was 5.4 million, and average penetration rate of equipped ETC2.0 on-board units was approximately between 1% and 2%.

Figure 4 shows trip travel time distribution from entries to exits estimated from ETC2.0 probe data and ETC trip data. The latter was obtained from electronic toll collection trip data comprising a pair of entry and exit ICs for each vehicle and covered almost 90% of total vehicles using expressways in Japan. Trip travel time estimated ETC2.0 probe data is a bit smaller than that from ETC trip data because vehicle ID changed after midnight once engine was turned off and overnight long trips were omitted in ETC2.0 probe data. Nevertheless, the two travel time distributions are more or less the same. The 85-percentile trip travel time was 70 min. 90% travelled 90 min or under, and 772 min was the longest trip time. It should be noted that the trip time distribution includes resting time.

Figure 4: Trip travel time distribution of trip behaviour (small cars)



The trip distance was 100 km or under for about 90% of the trips, and 99% were 200 km or under. The maximum trip distance was 714 km. On the other hand, from an early study conducted by the authors (Hirai et al., 2016), the cumulative ratio of the number of trips per trip distance taken from ETC data of November 2012 shows that 81.3% of small cars travelled less than 100 km on holidays, and 94.6% travelled less than 200 km. As can be seen, short trips were observed more in this study from ETC2.0 probe data.

Figure 5 shows the distribution of the number of breaks during a trip. Of the 104,415 trips of small cars, 84.1% did not take any breaks; 12.9% took only one break, and only about 3% of the trips took multiple breaks during their trips. As for the resting time distribution shown in Figure 6, the average resting time per break was 25.2 min and 85% of the trips took a break of less than 37 min.

Figure 5: Distribution of number of breaks (small cars)

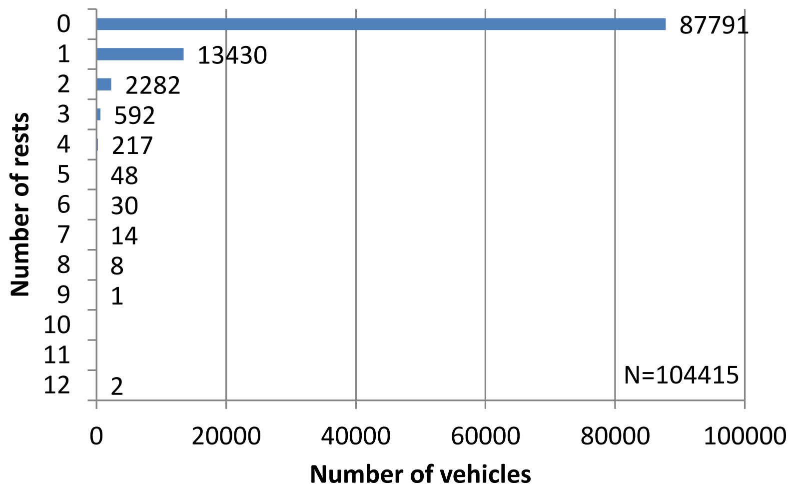
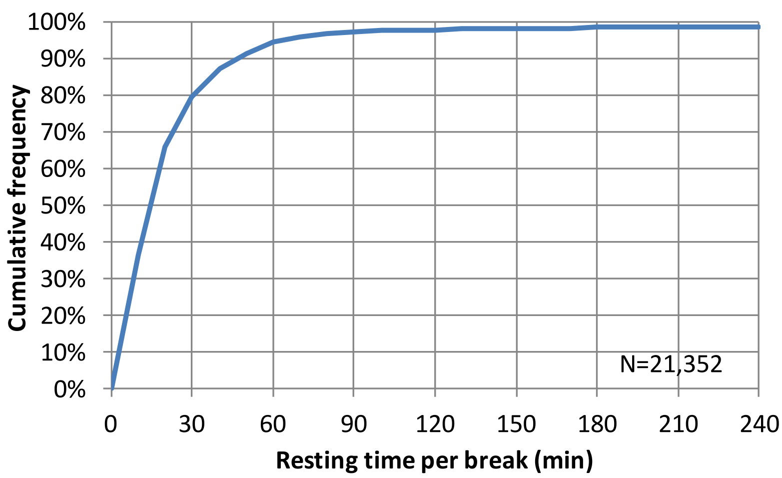


Figure 6: Distribution of resting time (small cars)



The top 10 rest areas (SA/PA) where small vehicles stopped by to have a break are shown in Table 2. The rate of rest area visits is defined as the percentage of mainline traffic that stop by a rest area. As seen in the table, maximum rate of rest area visits is as much as about 30%.

Table 2: Rate of rest area visits (small cars)

SA/PA	Expressway	Inbound			Outbound		
		# of vehicles visited	# of vehicles passed	Rate of rest area visits	# of vehicles visited	# of vehicles passed	Rate of rest area visits
Ebina SA	Tomei	353	1,678	17.4%	347	1,596	17.9%
Dangosaka SA	Chuo	402	861	31.8%	244	892	21.5%
Ashigara SA	Tomei	203	1044	16.3%	262	893	22.7%
Gozaisho SA	Higashi-Meihan	170	776	18.0%	130	988	11.6%
Hasuda SA	Tohoku	116	1122	9.4%	173	886	16.3%
Enakyo SA	Chuo	153	507	23.2%	131	423	23.6%
Tuchiyama SA	Shin-Meishin	99	554	15.2%	157	469	25.1%
Miyoshi PA	Kanetsu	108	920	10.5%	140	895	13.5%
Nishinomiya-Nashio SA	Chugoku	96	1183	7.5%	147	1132	11.5%
Moriya SA	Joban	150	818	15.5%	86	486	15.0%

4.3. Relations between trip distance and number of breaks and total resting time

Next, we analyse the relations between trip distance and number of breaks and total resting time. Figure 7 shows the relation between number of breaks and trip distance. Typically, the number of breaks increases as trip distance increases. On the other hand, a fraction of vehicles have no breaks for trip distance over 200 km, and about 6% do not even have a break for trip distance over 300 km. Therefore, it is necessary to take measures against these long trip users driving with no break as it is well known that it is better to have a break every one and a half to two hours.

Figure 7: Relation between number of rests and trip distance (small cars)

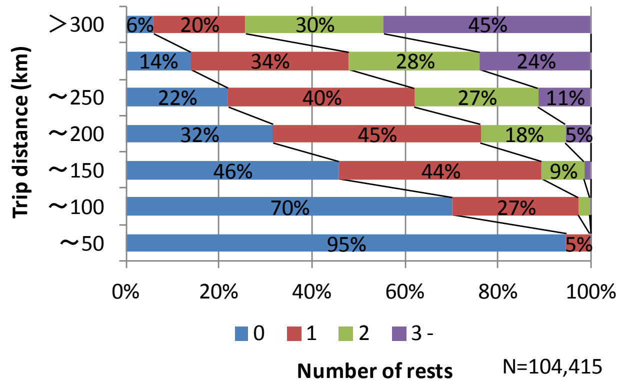


Figure 8: Relation between total resting time and trip distance (small cars)

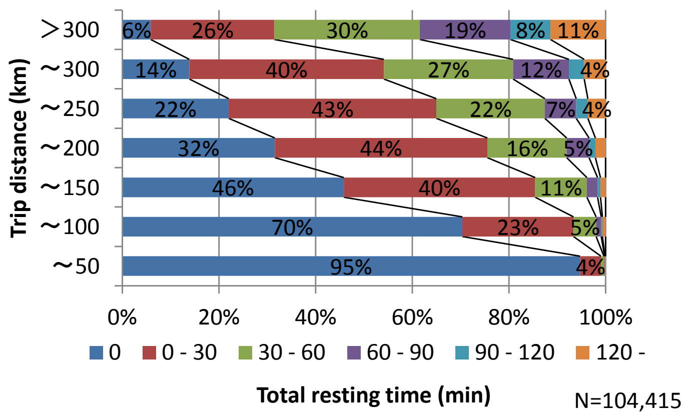


Figure 8 shows the relation between total resting time and trip distance. The total resting time is proportional to trip distance. When the trip distance is under 300 km, more than 80% of the total resting time is 1 hour or under.

4.4. Difference between 1st break and 2nd break

Figure 9 shows the cumulative frequency distribution of resting time of the 1st and 2nd break in trip behaviours where the users took more than 2 breaks. As can be seen from the figure, the lengths of the two breaks are about the same. Figure 10 compares the drive time from entry to 1st break and from 1st to 2nd break. We can see that the percentage of vehicles running longer between the 1st and 2nd break is higher. On the other hand, the percentage of vehicles running shorter between the 1st and 2nd break is smaller compared to the drive from entry to the 1st break. This is because the drive distance to the 1st break does not include the distance before entry to expressway. In both cases, the drive time is, for the most part, within 2 hours as usually advised for expressway users.

Figure 9: Distribution of resting time (small cars)

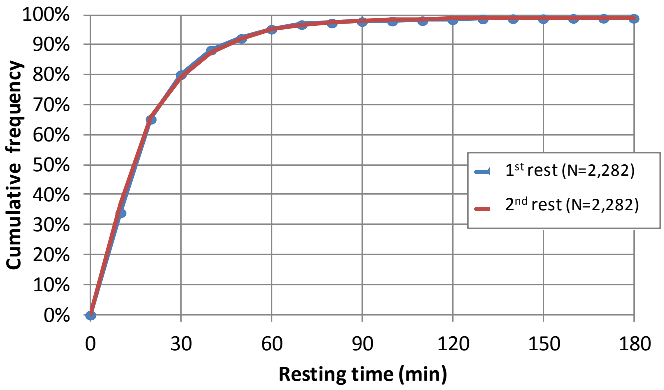
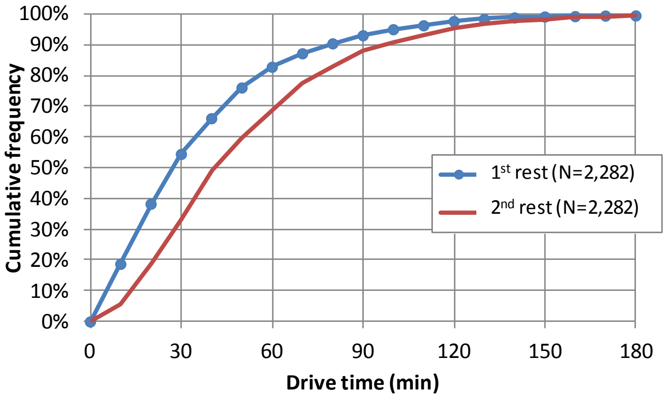


Figure 10: Distribution of continuous running time (small cars)



4.5. Difference in resting behaviour per time of day and type of rest areas (SA/PA)

Next, we calculate the total number of vehicles stopping at a rest area to take a break and total resting time per time of day. To include the differences in size and available facilities at SAs and PAs in the calculation, those for the two types of rest areas were calculated separately. The results are shown in Figure 11 (total number of vehicles taking breaks), Figure 12 (total resting time) and Figure 13 (mean and standard deviation σ of resting time).

Figure 11: Total number of vehicles stopping at rest areas per time of day and type of rest area (small cars)

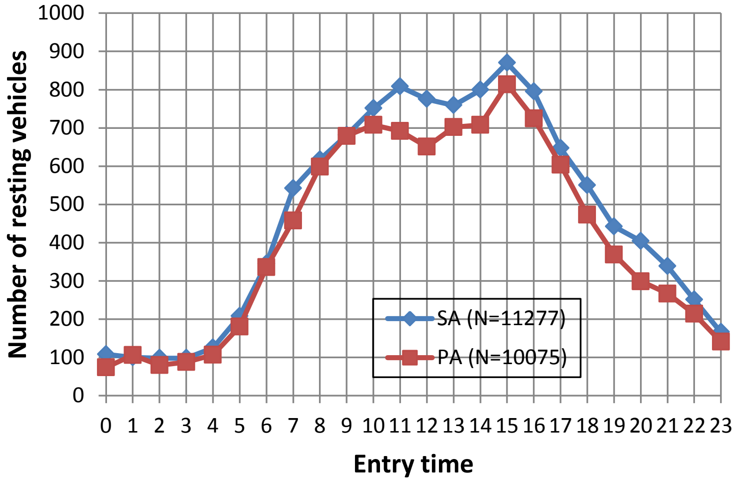


Figure 12: Total resting time of vehicles per time of day and type of rest area (small cars)

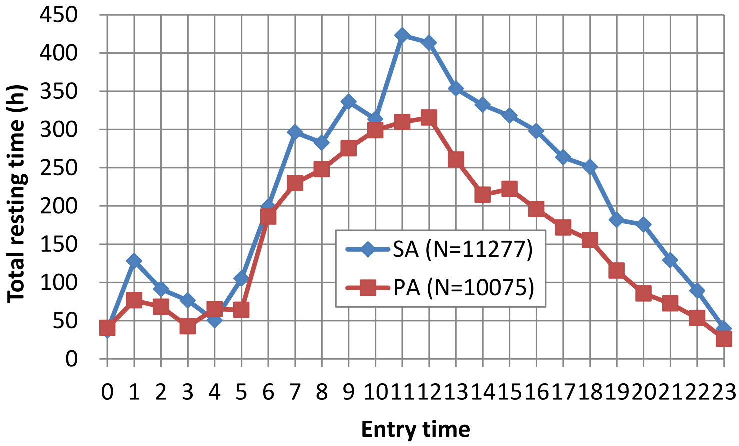
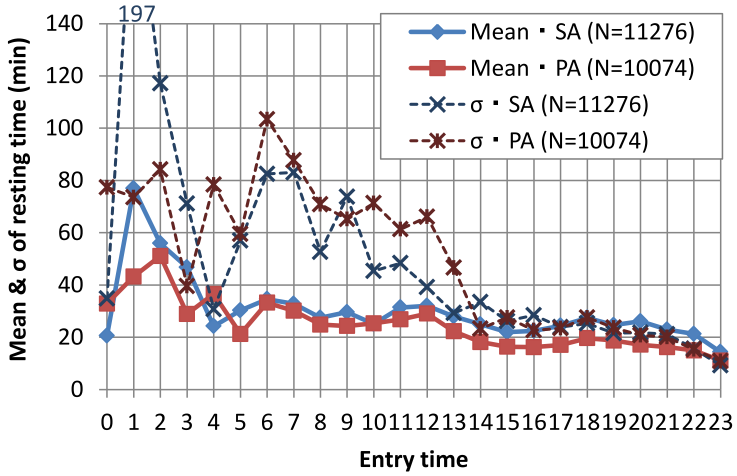


Figure 13: Mean and standard deviation of resting time for a vehicle per time of day and type of rest area (small cars)



The total number of vehicles taking breaks at SAs and PAs had their peaks between 3 pm and 4 pm. In the morning, that at PAs reached its peak between 10 am and 11 am. As for SAs, the peak was observed between 11 am and noon. The difference in the two types of rest areas is assumed to be caused by the availability of restaurants and other commercial facilities at SAs. In the afternoon, the peak for both SAs and PAs was observed between 3 pm and 4 pm.

On the other hand, the peak of total resting time was observed between 11 am and noon at SAs and between noon and 1 pm at PAs, which shows that irrespective of the difference of availability of restaurants and other commercial facilities at SAs and PAs, expressway users took a longer break for lunch than any other time of day. However, there was no much difference in the mean resting time between SAs and PAs. They decreased from early midnight through to late night. The standard deviation of resting time was much larger from midnight to noon than from noon to midnight. It also varied largely from midnight to noon.

5. Conclusions

This study used trip history data of the ETC2.0 probe data to create a database of the resting behaviours of individual vehicles, and analysed the actual resting behaviours of expressway users. Though the data collected only for 2 days (1 & 2 August 2015) was analysed here, the ETC2.0 probe data is accumulated day by day in the ETC2.0 Probe Data Utilization System, so it is possible to carry out similar studies using the probe data collected for a longer period.

On the other hand, in the trip history data, there are some uncertainties in the timing of the data recordings and added data. Therefore, data cleansing and improvement in the method to determine resting behaviour may be needed for further examination.

Our future tasks are to further improve the accuracy in determining resting behaviours and conduct analysis on data taken for a longer time. In addition, we plan to develop a resting behaviour model applying the findings of this study, which will be incorporated into an expressway network traffic simulator developed by the authors. Thus the integrated traffic simulator is able to evaluate effectiveness of traffic operation schemes of traffic congestion mitigation related with mainline and rest areas.

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