Paper ID AP-SP0891

Modeling resting behavior on inter-urban expressways considering long-sustained rest with ETC data

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Abstract
This paper describes an analysis of the macroscopic resting behavior of expressway users using electronic toll collection (ETC) trip data. The authors have proposed, in previous papers, a macroscopic model framework of driver's total resting time during their trips based on the analysis of driver's total resting time calculated utilizing ETC trip data and vehicular detector data. This paper aims to analyze long-sustained resting behaviors of users, with a focus on estimation of total resting time distribution for expressway passenger cars in the proposed macroscopic model framework, using the ETC trip data. The results show that only 1.5% of small cars stay at rest areas for long-sustained resting (more than 2 hours), but long-sustained resting occupies more than 30% of the total resting time on expressways. Further analysis respecting their departure times and trip distances implied that long-sustained resting behaviors often resulted from drivers wanting to adjust their arrival time to their business opening hours. Based on this implication, we assumed that the resting behavior may be explained by combining two types of resting, 'normal resting' with a shorter time range and long-sustained resting with a longer range. The results of curve fitting the total resting time compound distribution indicate that the component ratios of long-sustained resting are 0.2 – 0.5, respectively from short to long distances, and those distributions of arrival times (i.e. desired exit times) consistently had their peak at around 5 AM irrespective of trip distance or departure time.

KEYWORDS:
Resting behavior modelling, Service area, Inter-urban expressway, ETC data

Introduction
In order to predict traffic flow state and congestion caused by a particular traffic operation scheme, we have been developing a mesoscopic traffic simulator that covers the entire inter-urban expressway network in Japan (1). With the expressway network topology getting more and more complex, traffic prediction based on conventional statistical analyses is becoming harder and harder because 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 behavior. From the seeds side, road operators are now motivated to utilize electronic toll collection (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 ETC data utilization can be found in the modeling of route choice behavior (2, 3). However, other types of driver behavior also need to be considered in our simulation model.

The resting behavior of expressway users is one of those that need to be considered. As trip distances on inter-urban expressways are relatively longer than those on urban expressways or surface streets, many drivers may have to take one or more breaks at service areas or parking areas during their trips. From the viewpoint of customer satisfaction, a smooth operation of service areas is a major concern of road companies. If the resting behavior is properly modeled in the expressway network simulator, it will be effective in estimating congestion at a service area and may help evaluate the effects of various countermeasures, such as improving parking lots, providing congestion information of service areas, recommending future resting plans via car navigation systems, etc., so as to mitigate traffic congestion at service areas or in the downstream section of service areas.

Though expressway companies have their own design manual of service/parking areas in which some parameters, such as the percentage of mainline traffic entering the areas and dwell time, or resting time, observed at sites are indicated (e.g. 4), the resting behavior of expressway users has not been made clear. In 1974, Tyler et al. evaluated highway travel and stopping patterns of California drivers for long trips of 100 miles or more, estimating statistical values of stopping intervals in both time and distance (5). The results showed that the median stopping interval for long-trip motorists was every 73 miles and 75 minutes, and the mean stopping interval was 81 miles and 85 minutes. King collected field data for 13 rest areas in five states of the US in the late 1980s to estimate models for predicting the percentage of mainline traffic that would use a rest area based on the distance between rest areas. This work found that traffic entering rest areas ranged between 5.5% and 17.7%, an average of 10.3%, and with average vehicle occupancy of 2.2 persons (6). Also in the late 1980s, Perfater studied rest area usage at eleven combination rest area and welcome centers in Virginia (7). Traffic counts and dwell times were recorded specifically at the sites, and rest area usage surveys were distributed to patrons. The results showed that an average of 12% of mainline passenger cars entered the rest area versus 23% of the mainline truck traffic. The percentage for trucks varied greatly, ranging between 10% and 40.6% depending on the site.

Recent studies conducted by Al-Kaisy et al. on data from 44 rest areas throughout the state of Montana (8, 9) showed that average rest area usage for different highway categories (high and low volume interstates and arterials) varied and traffic entering the rest area ranged between 8.4% and 12.3%. The average overall usage was approximately 10%, and the overall 85th percentile was around 15% of mainline traffic entering rest areas. The results showed that the mean dwell time at the three study sites ranged from 14 min 15 s to 23 min 20 s. When dwell times were examined by vehicle type, heavy vehicles recorded the longest mean dwell time, followed by recreational vehicles and then passenger cars. Examination of mean dwell times for short- and long-term parking found the short-term to vary from 8 min 37 s to 10 min 26 s and the long-term to vary from 4 h 41 min to 5 h 26 min.

In Japan, however, few previous studies (10-13) were found in this topic until recently, and those published were mostly based on observation data taken at specific service areas or of responses to questionnaire surveys. More recently, some analyses (14, 15) used probe data obtained from digital tachograph to study service/parking area choice behavior and parking dwell time of trucks on expressways. It seems insufficient to analyze resting behaviors through those approaches, relating the data collected with trip context and traffic conditions.

Recently, the authors have also been studying resting behavior of expressway users to employ the study results in their simulation model. In their preceding papers (16-18), they analyzed drivers' total resting time, estimated from ETC trip data and vehicular detector data, and found that a fraction of users tend to park at service/parking areas for longer than 2 hours. They also proposed a macroscopic model framework of drivers' total resting time during their trips based on the analysis results, assuming distributions of long-sustained resting time for different expressway entrance times and trip lengths of passenger cars and heavy vehicles.

This paper aims to analyze long-sustained resting behavior with a focus on estimating the total resting time distribution of motorists on expressway passenger cars in the proposed macroscopic model framework, using ETC trip data. Future research issues will also be addressed.

Outline of available data for analysis

ETC trip data and vehicular detector data are mainly used in the study to analyze the total resting time for each trip on the expressway network. The ETC trip data used in the study includes encrypted ID, vehicle type of toll payment, expressway entrance and exit interchange location, and their entering and exit times. Since the penetration rate of ETC-equipped vehicles on expressways in Japan is almost 90%, we are able to analyze service/parking area choice behavior and dwell time for most vehicles. In this study, travel time is calculated from ETC trip data, and driving time is estimated from vehicular detectors that are installed at a reasonable spacing (approximately 2 km in suburban area and one location between neighboring interchanges) along the route. The detector data is collected every 5 minutes. In such a way, total resting time of a particular trip is estimated by the difference between travel time and driving time.

Table 1. Trip distribution by weekdays/holidays and vehicle type (16)

Trip length	Weekdays (Passenger cars)	Weekdays (Heavy vehicles)	Holidays (Passenger cars)	Holidays (Heavy vehicles)
- 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 1 shows trip distributions for each vehicle type, on weekdays and holidays (16). 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 85th 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, trips of 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. Long trips of over 500km, however, take up less than 1% of passenger cars and 3% of heavy vehicles; and there are only a few long trips over 1,000km.

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

Analysis of resting behavior

The travel time of an ETC-equipped car (ETC car) can be calculated with the time difference between the time stamped at the departure and the arrival toll gate. As this travel time consists of running time on expressways and resting time at service areas, we may estimate the total resting time of the ETC car by subtracting the average running time from its travel time. The average running time is calculated as an accumulation of the travel times of sections along with the time-space trajectory departing at the same time and running at the mean speed of each detector coverage section as shown in Figure 1.

Obviously, the running time of each ETC car varies from the average running time, and it is consequent that calculation of resting time involves error coming from this discrepancy. Our preliminary investigation on the travel times of ETC cars for short range trips less than 50 km, showed that the magnitude of this error might be around +/- 15 minutes for every 100 km on average. Therefore, the estimated resting time can be negative when an ETC vehicle runs faster than the average and takes short rests, or does not rest at all. In this paper, however, we focused mainly on long-sustained resting behavior; so let us leave the estimated resting time with the error. Hereafter, we will simply refer to estimated resting time as ‘resting time’ but it will always mean ‘estimated’.

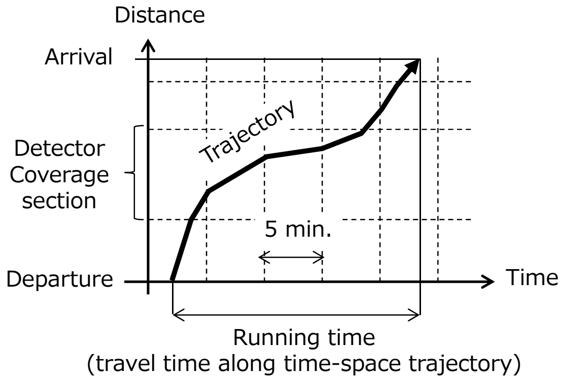

Figure 1. Calculation of average running time along time-space trajectory.

The bars in Figure 2 show the frequency distribution of resting time of small ETC cars, including passenger cars, vans, small cargo vans, etc., which travelled on expressways in November 2012, and of which trip distances were more than 50 km. The far left slot '<15 min.’ shows the number of trips with negative resting times. The curve in the figure denotes the cumulative share in total resting time for each slot. Although the total resting time for the left end slot became negative because of the estimation error mentioned above, let us omit the negative range in the right vertical axis, since those errors would be compensated in the accumulation to the longer resting times. It is remarkable in Figure 2 that the share of resting times longer than 60 minutes is only 6%, but the share in the total resting time is more than 60%. Furthermore, resting times longer than 120 minutes take up only 1.5% in appearance, but has more than 30% share in the total resting time.

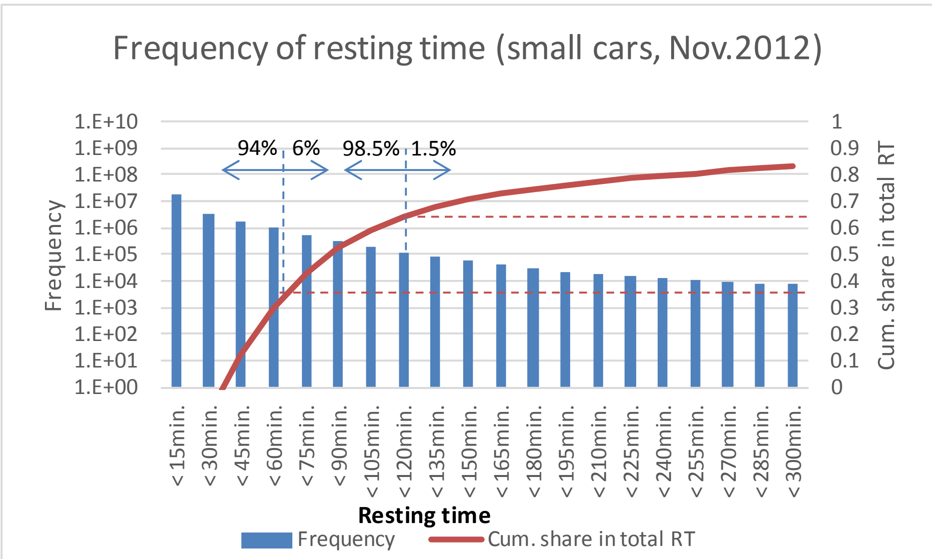

Figure 2. Frequency distribution of resting times of small cars.

In order to figure out what factor induces such long resting times, we have investigated the relationship between the departure (or entry) time and the arrival (or exit) time for ETC cars. Figure 3 compares the distribution of arrival hours with respect to each departure hour for ETC cars with trip distances between

100 km and 200 km and with resting times longer than 120 minutes (2 hours). If the resting behaviors were independent from the departure hours and consistent during the whole day, the peaks of the distribution would be regularly shifted 1 hour later for the subsequent departure hour. Such tendency is clearly found among distribution curves of departure hours between 4 PM and 8 PM, or 4 AM and 7 AM. However, they have a second peak in the early morning around 6 AM to 8 AM. Furthermore, the distribution curves of departure hours from 9 PM to 3 AM concentrate their peaks at around 6 AM.

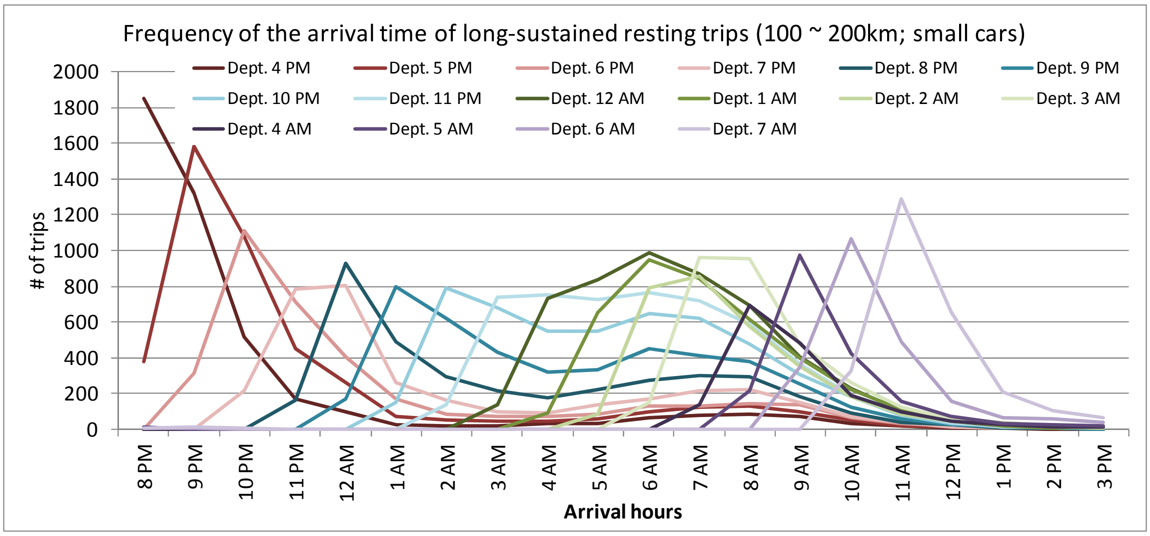

Figure 3. Frequency of the arrival time of long-sustained resting trips.

As this concentration of arrival hours in the early morning can be found in similar comparisons for other trip distances, it implies that some ETC cars take long resting time waiting to exit expressways at a certain time in the early morning, irrespective of their trip distances, to adjust their time of arrival to their business opening hours.

The frequency distribution for heavy vehicles has similar characteristics with more conspicuous leaning toward long-sustained resting time. In this paper, however, let us focus on the analysis and modeling of long-sustained resting behavior of small cars, since it reveals a clearer relationship than that of heavy vehicles with business opening hours as an element influencing resting time, explained hereafter. The issues in the modeling for heavy vehicles will be noted in the final section as our future work.

Modeling long-sustained resting behavior

Based on the above observation, an assumption arises that resting time will follow the compound distribution consisting of two components which have different motivations for resting. One may take, let's say 'normal resting', a relatively shorter resting time, to have a meal or to make a purchase, while another may take a longer resting time to adjust the arrival time to their business opening hours. Figure 4 supports this assumption, focusing on the arrival time distribution of ETC cars with trip distances of 100 km to 200 km that exit expressways between 3 AM and 11 AM. The cumulative frequency curves seem to converge when their departure hours are much earlier than their business opening hours, e.g. Dept. 12 PM to 7 PM. This convergence, likewise a logistic curve of which the peak is around 6 AM, can be found in similar comparisons for different trip distances. This may imply the existence of single desired arrival time distribution independent from trip distance and departure time. The other curves which departure hours are closer to business opening hours, e.g. Dept. 10 PM to 1 AM, are distorted from the convergence, mingled with 'normal resting' times.

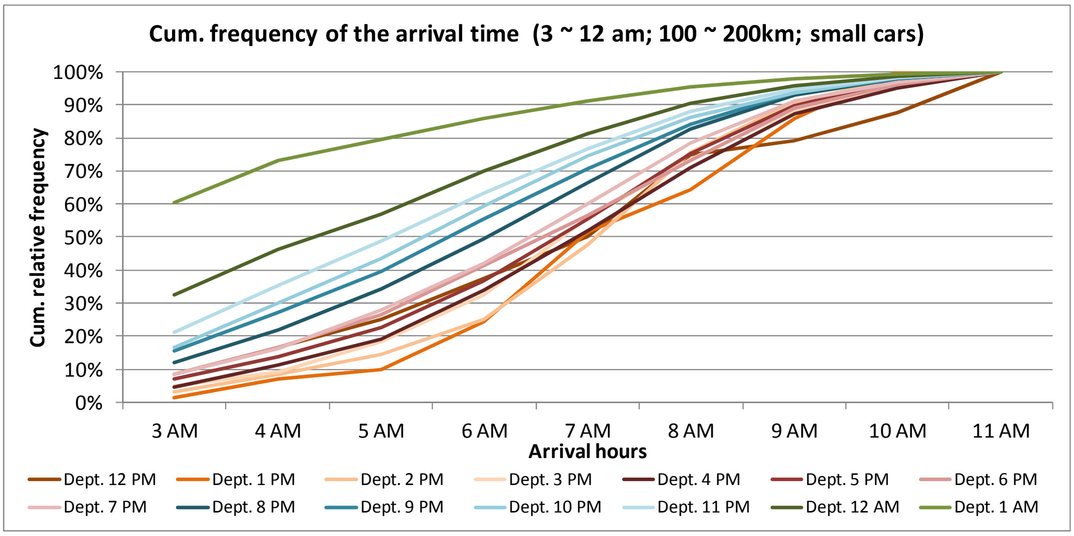

Figure 4. Cumulative frequency of the arrival time of ETC cars.

Now, let us introduce the following combination function $R_{dt}(x)$ of two cumulative Gumbel distributions to explain the appearance of resting time x;

$$R_{dt}(x)=(1-\alpha)\, F_1\,(x;\mu_1,\eta_1\,)+\alpha F_2\,(x;\mu_2,\eta_2\,) \tag{1}$$

where, $F_1\,(x;\mu_1,\eta_1\,)$: cumulative Gumbel distribution of normal resting,
$F_2\,(x;\mu_2,\eta_2\,)$: cumulative Gumbel distribution of long-sustained resting,
α : component ratio of long-sustained resting ($\in[0,1]$),
μ_1,μ_2 : offset parameters,
η_1,η_2 : scale parameters.

The numerical search using Microsoft Excel's solver (GRG non-liner search) was conducted for every 100 km in trip distance and every departure hour to find the best parameters giving the maximum likelihood. Figure 5 is an example of the estimated cumulative probability distribution function of resting time for ETC cars with trip distances of 400 to 500 km and departure times from 8 PM to 9 PM. The estimated compound distribution seems to well fit the cumulative relative frequency of the resting times of ETC cars. In this example, the component ratio of long-sustained resting (α) is 0.26 and its distribution peak given by the offset parameter (μ_2) is 297.4 minutes (almost 5 hours). Provided that an ETC car runs at 100 km/h on average and takes 4 to 5 hours to reach its destination without stopping, resting for 5 hours will mean that the car will exit the expressway at around 5 AM to 6 AM. The estimated characteristics of long-sustained resting seem to be consistent with the implication above.

Figure 6 shows the component ratios of long-sustained resting (α) when $\alpha>0.05$. The ratios for all distances gradually increase from evening and reach their peak at around midnight. At the peak time, the component ratios become 0.2 – 0.5 respectively from short to long distances.

Figure 7 shows the offset parameters of long-sustained resting distribution (μ_2) when $\alpha>0.05$. The offsets of all trip distances linearly decrease at almost the same rate with -60 minutes as departure time proceeds 1 hour, and move toward zero at around 5 AM. As the offset parameter of the Gumbel distribution gives its peak position, this means the distribution of long-sustained resting time consistently has its peak at around 5 AM. This is a bit earlier than the normal business opening hours, but could be regarded as margin for travelling on surface streets to the final destination.

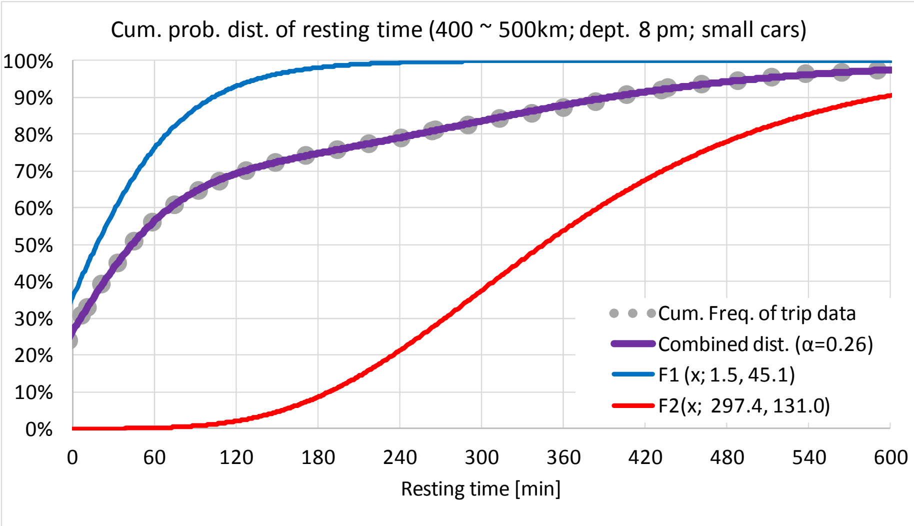

Figure 5. An example of the estimated cumulative distribution function of resting time.

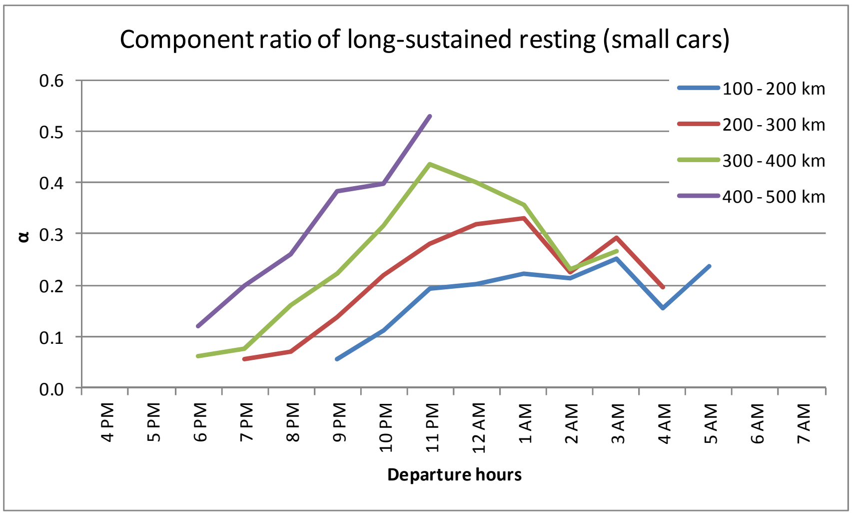

Figure 6. Component ratios of long-sustained resting.

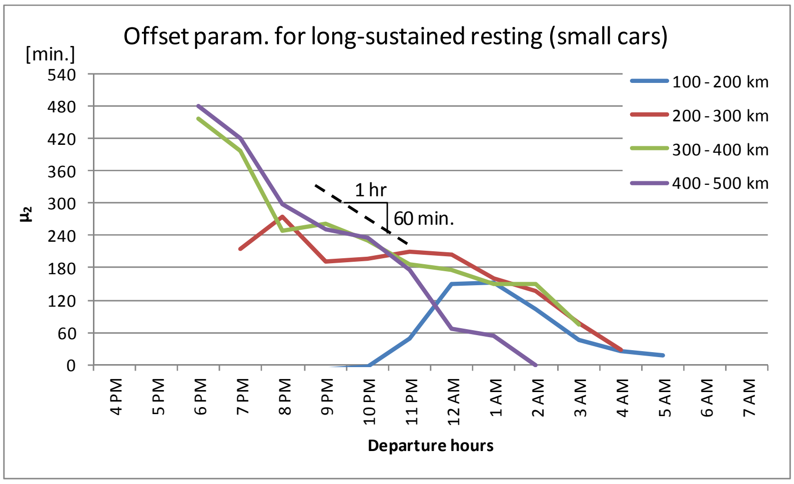

Figure 7. Offset parameters for long-sustained resting.

Figure 8 shows the scale parameters of long-sustained resting distribution (η_2) when $\alpha>0.05$. The scale parameters logarithmically decrease, while moving toward minimum at around 5 AM. As the larger scale parameter gives a wider spreading shape of the Gumbel distribution, this could be considered that the earlier departure ETC cars needed to anticipate the uncertainty in travel time, or had more freedom in their business opening hours.

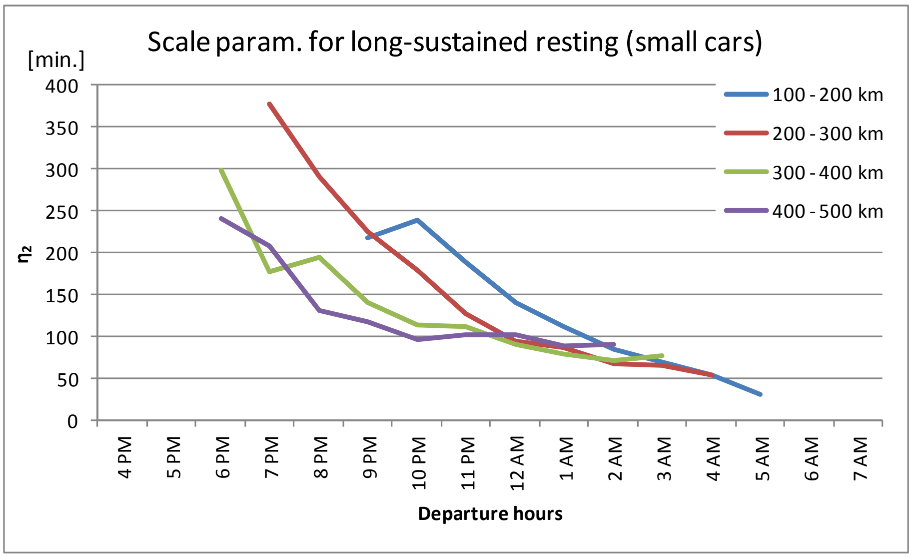

Figure 8. Scale parameters for long-sustained resting.

Conclusions and future work

In this paper, the resting behavior of motorists on inter-urban expressways in Japan was analyzed by using ETC data, as penetration of ETC is almost 90% of all trips, and traffic sensor speed data. The existence of trips with considerably long resting time was figured out in the preliminary observation. For small cars, the number of cars that take long-sustained resting, more than 2 hours, is only 1.5%, but long-sustained resting time occupies more than 30% of the total resting time on expressways.

The specific analysis, respecting their departure times and trip distances, implied that those long-sustained resting behaviors are the result of adjusting the drivers' arrival time to their business opening hours. Based on this implication, we assumed that the resting behavior would be explained by combining two types of resting, 'normal resting' with a shorter time range and long-sustained resting with a longer range. Then, numerical search was conducted to estimate the component ratios and their parameters of the Gumbel distributions. The estimated parameters indicated that the component ratios of long-sustained resting are 0.2 – 0.5, respectively from short to long distances, and those distributions of arrival times (i.e. desired exit times) consistently had their peak at around 5 AM, irrespective of trip distance or departure time.

In some cases, we estimated a very small component ratio of long-sustained resting. This means that the single peak distribution is more adequate than the compound distribution. Selecting a better model from single, double and triple combinations by using some information criteria, e.g. AIC (Akaike Information Criterion), will be tackled in our future work.

Furthermore, we focused on the resting behavior of small cars and left that of large vehicles as future work, since making an assumption of the compound distribution using two types of resting distributions was inadequate in some cases. From our observation, we have guessed that the third distribution would represent resting behavior taken to adjust arrival times to toll discount time zones, so that vehicles would qualify for toll discount. Similar estimation of the compound distribution of resting time of large vehicles needs to be done as well in the future.

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