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Study of resting behavior on inter-urban expressways using ETC 2.0 probe data

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Abstract

Resting is a part of long drive to keep both drivers and vehicles relax and safe. The Nippon Expressway Companies (NEXCO) which operate the inter-urban expressways in Japan provide with two types of resting place, service areas (SA) and parking areas (PA). As for the operator, NEXCO is interested in the smooth operation and the fully utilization of SA/PAs through the informative guidance taking account of the drivers' resting behavior. However, there is less knowledge on the drivers' resting behavior during long drive and further investigation on this topic is expected. In order to explore the resting behavior on inter-urban expressways, we have been using ETC 2.0 probe data to extract individual resting behavior by tracking successive travel data on expressways. In this paper, we describe the procedure for the extraction of resting behavior from ETC 2.0 probe data, followed by the preliminary analysis of the resting behavior.

Keywords:

ETC 2.0 probe data, service area and parking area, resting behavior

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 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 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 studies[4] are found on 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 research, we aim to evaluate traffic measures regarding the use of SA/PA after incorporating resting behavior model in the traffic simulator. In our preceding research, we had analyzed the resting behavior on expressways using the ETC trip data and vehicle detector data. Nowadays, almost 90% cars on the expressways in Japan equip ETC on-board unit. However, because ETC trip data does not contain the information about time and location at a particular resting area unless DSRC antenna is installed, we have investigated the resting behavior such as total resting time with the ETC trip data, but we are not able to analyze the resting behavior at each SA/PA.

In order to make clear the individual resting behavior at each SA/PA during the travel on expressways, it is required to trace the individual car's position successively, i.e. probe data. In this paper, let us introduce, at first, the outline of 'ETC 2.0' probe data which is collected by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan. The procedure to identify the individual rest from the successive probe data will be described next, followed by the preliminary analysis of the resting behavior on expressways.

Outline of ETC 2.0 Probe Data

The ETC 2.0 probe data contains privacy-free individual vehicle's location and time for every 100 or 200m approximately. However, it does not contain the data within an area 500m or so from a point where the engine is turned off for personal information protection. One record of ETC 2.0 data contains the items as shown in Table-1.

Table 1- Items of ETC 2.0 probe data

Basic information	Vehicle ID (privacy free)
	Vehicle type and usage
	GPS time
	Trip number
	Serial number in a trip
	Road type (expressway, national road, etc.)
Additional information after map matching	Map matching flag (success/fail)
	Longitude and latitude
	Road section ID
	Direction
	Road operator code

ETC 2.0 probe data can be roughly divided into the basic information and the additional information after map matching. Regarding the basic information, the vehicle ID (hereinafter, simply referred as ID) corresponds to the serial product number of individual ETC 2.0 in-vehicle on-board unit but is daily scrambled with random number mask to protect the privacy of drivers. Therefore, the individual car trips within a day can be traced by the same ID, but overnight trips cannot be traced.

The same trip number is given to the data which are successively recorded within a short interval of distance. As this trip number is just provided for the convenience of data handling, let us note that the meaning of 'trip' is different from the conventional meaning in the context of travel behavior analysis. The trip number may change at the long gaps in the record interval, which may happen due to many causes such as the malfunctions in data transmission or data processing, the engine off and the resting at SA/PA, of course.

The additional information after map matching contains the result whether the map matching was successful or not, the position of a vehicle in longitude and latitude and the road operator code which can be used to distinguish expressways from other road types.

Extraction of Resting Behavior from ETC 2.0 Probe Data

To analyze the resting behavior at each SA/PA, it is necessary to identify the visiting time to and the leaving time from the SA/PA for each individual probe vehicle. Figure 1 shows a time-space trajectory diagram with the ETC 2.0 probe data recorded around the Ebina SA on the Tomei Expressway eastbound, on August 1, 2015. The black and white circles on the trajectories mean the changing points of the ‘trip numbers’ which are shown beside the circles. The purple dotted lines indicate the gaps more than 60 seconds breaking the continuity of the trip number. 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 traveling 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 center of SA/PA.

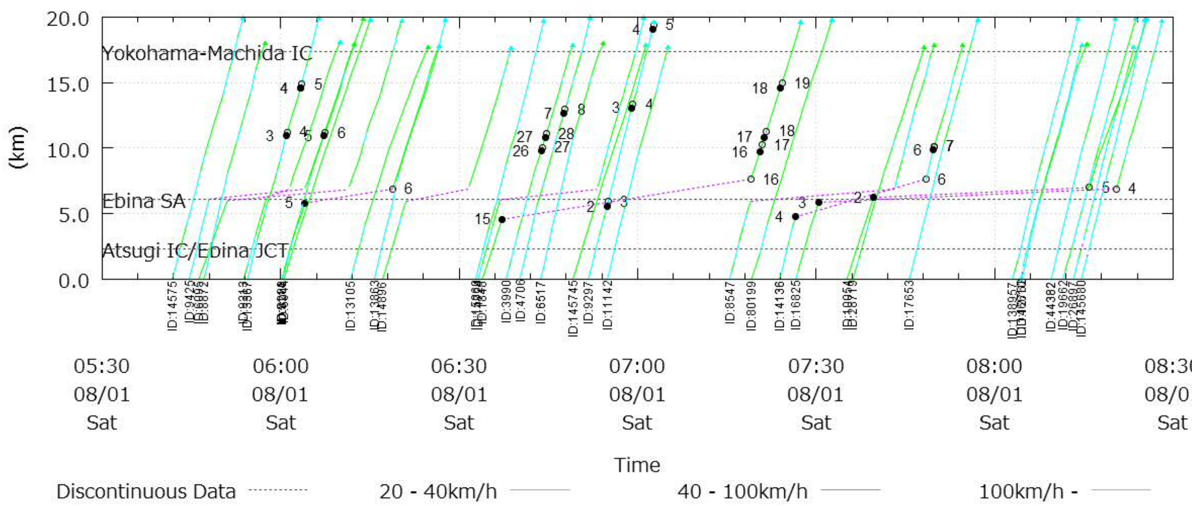


Figure 1 – Time-space trajectories around the Ebina SA on Tomei Expressway eastbound

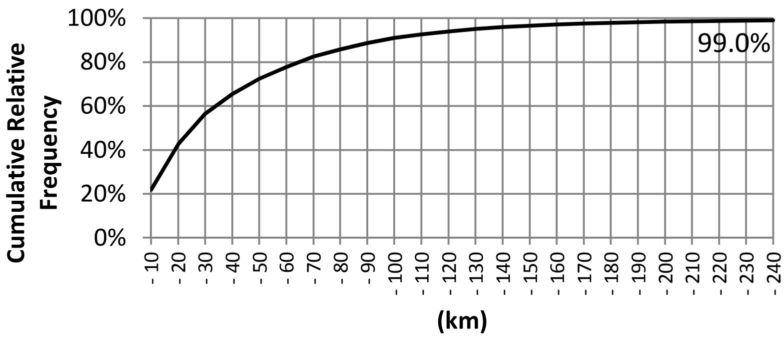
In order to understand the characteristics of resting behavior in conjunction with the trip context, it is required to identify the successive trip data from its entry interchange to its destination interchange. Unfortunately, it is not always guaranteed that the both trip ends are recorded in the ETC 2.0 probe data, and often starts or ends on the expressways somewhere in-between. In this paper, we had assumed the trip would start from the nearest interchange beforehand at the location of the first data and would end the nearest interchange afterward at the location of the last data.

Basic Statistics on the Identified Trips and the Resting Behavior

The procedure described above was applied to the ETC 2.0 probe data collected all over Japan from August 1-2, 2015. The number of extracted trips was 131,329. As for the vehicle type composition, 129,857 trips (98.9%) were of small cars, 1,470 trips (1.1%) were of large vehicles, and 2 trips (0.0%) were unknown. Hereafter, let us focus on the resting behavior of small cars.

Distribution of Travel Distance

The cumulative relative frequency of travel distance is shown in Figure 2. The cumulative share of the trips of which travel distances are less than 100 km reaches to 90%, and for less than 200 km it reaches to 99%. The mean, 85th percentile and maximum travel distances of trips were 47 km, 80 km and 714 km respectively. It should be noted that the another study by the authors[5] using different data source figured out slightly longer distribution on the travel distance on expressways, we have to remind the possibility that the travel distance estimated here might be shorter than the actual ones. This would come from the limitation of ETC2.0 data that as aforementioned the longer trip in nighttime could not be extracted on the whole when it ran over the midnight.

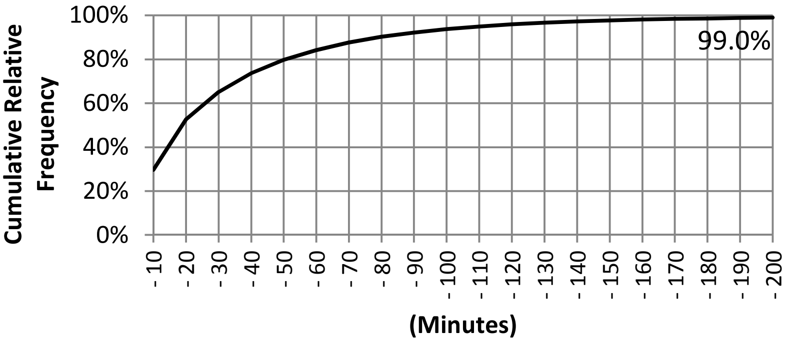


Mean	46.8
S.D.	49.5
Mode	10
85th percentile	80
Max	720

Figure 2 - Distribution of travel distance of small cars

Distribution of Travel Time

The cumulative relative frequency of travel time is shown in Figure 3. The cumulative share of the trips of which travel time is less than 90 minutes reaches to 90%. The mean, 85th percentile and maximum travel times were 38 min, 70 min and 772 min (nearly 13 hours) respectively.



Mean	38.4
S.D.	41.6
Mode	10
85th percentile	70
Max	780

Figure 3 - Distribution of travel time of small cars

Distribution of the Number of Resting

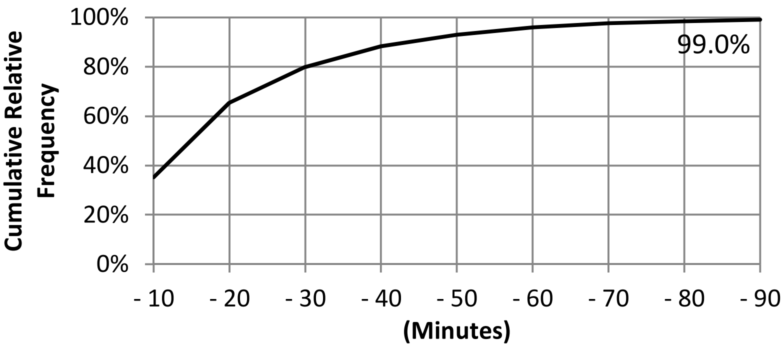
The cumulative relative frequency of the number of resting is shown in Figure 4. The 18,057 trips of small car were accompanied with one resting or more, accounting for nearly 15%. About 11% of trips took one resting and nearly 3 % took twice.

Mean	0.2
S.D.	0.5
Mode	0
85th percentile	0
Max	10

Figure 4 - Distribution of the number of resting of small cars (N=129,857)

Distribution of the Resting Time

The cumulative relative frequency of resting time is shown in Figure 5. The average resting time at SA was 22.9 min, while at PA was 15.9 min. The mean, 85th percentile and maximum resting times were 25 min, 40 min and 128 min respectively.



Mean	24.8
S.D.	18.1
Mode	10
85th percentile	40
Max	130

Figure 5 - Distribution of resting time of small cars (N=129,857)

Stopping Rate at SA/PA

Table 2 shows top 10 SA/PAs which have highest stopping rate calculated with the number of resting vehicles divided by the total number of passing and resting vehicles at the SA/PA. As for the reference, the observation values which came from the on-site survey conducted on the holidays in 2013 by NEXCO were listed in the table. The stopping rates calculated from the ETC 2.0 probe data are almost the same as previous observation results.

Table 2 - Stopping rate of small cars at SA/PA

SA/PA Name	Expressway Name	Inbound				Outbound			
		Resting (Cars)	Passing (Cars)	Stopping Rate (%)	(Observation Value*) (%)	Resting (Cars)	Passing (Cars)	Stopping Rate (%)	(Observation Value*) (%)
Ebina SA	Tomei	353	1,678	17.4	21.1	347	1,596	17.9	23.1
Dangozaka SA	Chuo	402	861	31.8	22.6	244	892	21.5	24.2
Ashigara SA	Tomei	203	1,044	16.3	19.9	262	893	22.7	21.0
Gozaisho SA	Higashi-Meihan	170	776	18.0	15.0	130	988	11.6	15.9
Hasuda SA	Tohoku	116	1,122	9.4	16.6	173	886	16.3	18.4
Enakyo SA	Chuo	153	507	23.2	28.7	131	423	23.6	27.1
Tsuchiyama SA	Shin-Meishin	99	554	15.2	22.6	157	469	25.1	28.5
Miyoshi PA	Kanetsu	108	920	10.5	22.2	140	895	13.5	16.2
Nishinomiya-Najio SA	Chugoku	96	1,183	7.5	11.2	147	1,132	11.5	11.7
Moriya SA	Joban	150	818	15.5	23.2	86	486	15.0	20.0

*All Vehicle Type

Relevancy between Travel Distance and the Number of Resting

The relevancy between the travel distance and the number of resting is shown in Figure 6. It seems that the number of resting increases with the travel distance.

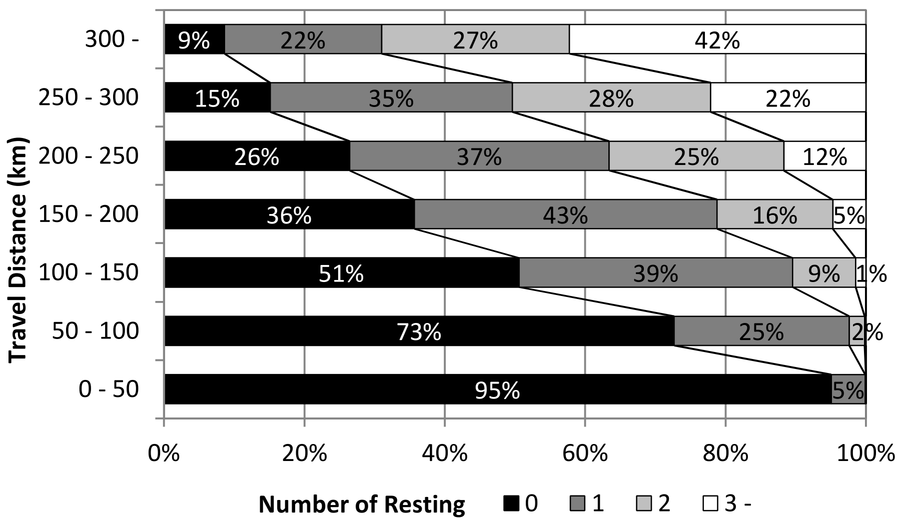


Figure 6 – Relevancy between total travel distance and number of resting (N=129,857)

Relevancy between Travel Distance and Total Resting Time

Figure 7 shows the share of total resting time by travel distances. It seems that resting time increases in proportion to the travel distance. The share of total resting times less than 60 minutes gets more than 80% in total for travel distance less than 300km, and the share for trips of over 300km accounts for 34%.

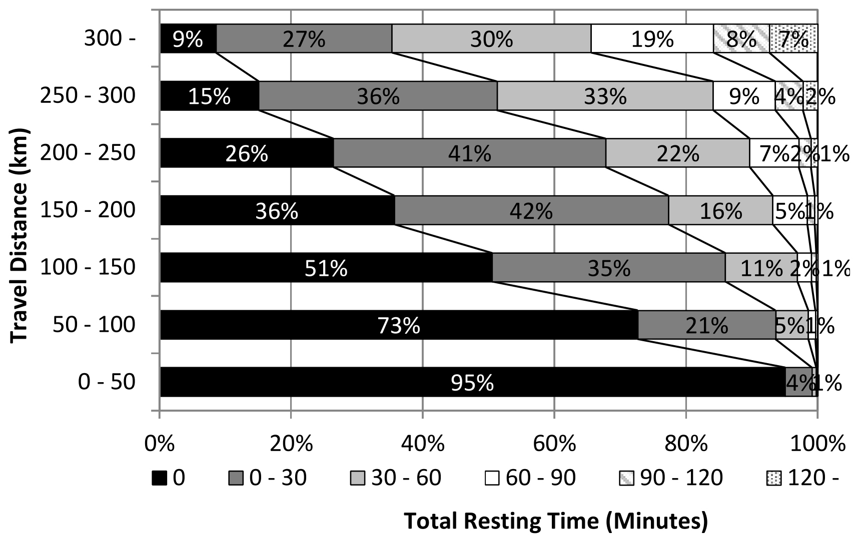


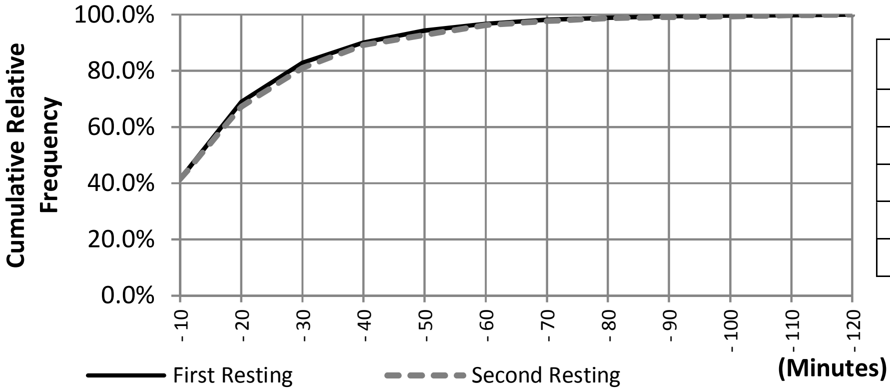
Figure 7 – Relevancy between total travel distance and total resting time (N=129,857)

Difference between the first and the second rests

Figure 8 shows the cumulative relative frequency of resting time of the first and the second rests respectively. The both curves of the first and the second rests seem almost the same. The mean, 85th percentile and maximum resting times of the both rests were 23 min, 40 min and 120 min respectively.

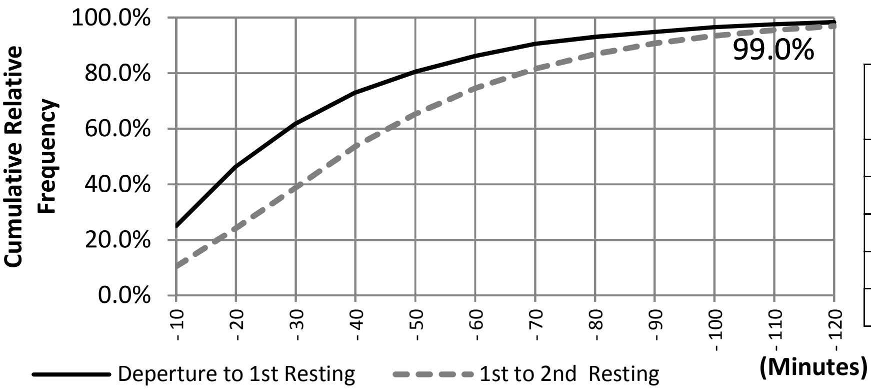
Figure 9 shows the distributions of running times from the entry of an expressway (referred as '0') to the first resting and from the first to the second resting. The running time before the 2nd resting is longer than that before the 1st resting. The mean, 85th percentile and maximum running times were 36 min, 60 min and 240 min respectively before the 1st resting, and 49 min, 80 min and 230 min respectively before the 2nd resting. These running times are almost within 2 hours.

Similarly, Figure 10 shows the driving distance from the entry to the first resting and from the first to the second. The running distance before the 2nd resting is longer than that before the 1st resting. The mean, 85th percentile and maximum running distances were 49 km, 90 km and 370 km respectively before the 1st resting, and 73 km, 120 km and 340 km respectively before the 2nd resting. It seems that vehicles which get the first rest within 100 km accounts for 90% approximately of trips. Those which get the second rest within 150 km also accounts for 90% approximately.



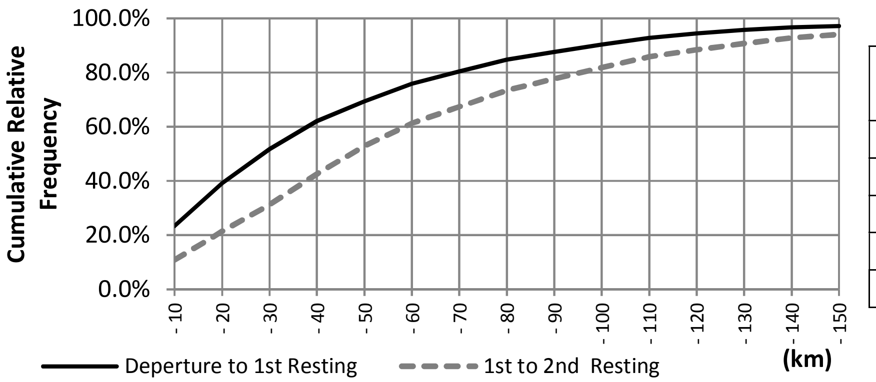
	1st resting	2nd resting
Mean	23.0	23.8
S.D.	17.0	18.2
Mode	10	10
85th percentile	40	40
Max	120	120

Figure 8 – Distribution of resting time (N=2,986)



	Before 1st resting	Before 2nd resting
Mean	35.7	49.4
S.D.	29.2	32.4
Mode	10	40
85th percentile	60	80
Max	240	230

Figure 9 – Distribution of running time (N=2,986)



	Before 1st resting	Before 2nd resting
Mean	49.2	72.8
S.D.	42.8	49.5
Mode	10	20
85th percentile	90	120
Max	370	340

Figure 10 – Distribution of running distance (N=2,986)

Conclusion

In this paper, we have studied the procedure for the extraction of resting behavior from ETC 2.0 probe data. Preliminary analysis on the resting behavior was conducted in respect to resting time distribution, relevance between travel distances and resting times, etc. The analysis results show that ETC 2.0 probe data could be a good traffic data for traffic state prediction and so on although there are still several points to be improved in the future. We can know from a limited amount of data that expressway users' resting behavior such as the percentage of mainline traffic entering the service/parking areas during their trips, trip length, travel time, resting time and running time/distance between successive rests, which will be used to model resting behavior in the next step.

For our future works, behavioral modeling on the resting behavior with disaggregated approach will be tackled base on the results of this analysis. The implementation of the resting behavioral model into traffic simulator is our future work as well.

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