AN ANALYSIS OF URBAN FREIGHT TRANSPORT BEHAVIOR USING A PROBE CAR SYSTEM– A CASE STUDY OF THE KEIHANSHIN AREA IN JAPAN

Takayoshi Yokota, Advanced Transport Logistics (Hanshin Expressway),
Department of Urban Management, Kyoto University
(C-1, Kyoto Daigaku Katsura, Nishikyo-ku, Kyoto-shi,615-8530, Japan)
Tel:+81-383-3140, E-mail:tyokota@kiban.kuciv.kyoto-u.ac.jp

Dai Tamagawa, Advanced Transport Logistics (Hanshin Expressway),
Department of Urban Management, Kyoto University
(C-1, Kyoto Daigaku Katsura, Nishikyo-ku, Kyoto-shi,615-8530,Japan)
Tel:+81-383-3140, E-mail:d-tamagawa@kiban.kuciv.kyoto-u.ac.jp

ABSTRACT

The paper presents the results and findings obtained from a probe car survey in the Keihanshin area, Japan, which was conducted during October 2009. In this survey, 300 trucks from 21 different transport operators participated. The results show that short trips from major cities like Osaka, Kobe, and Sakai that have less than 10 km straight-line distance have low average straight-line velocity below 20 km/h. They also show that drivers tend to prefer highways if travel distance becomes longer, and once they decide to use highways, they keep to their routes including using the highways despite travel time substantially varying. These findings will contribute to constructing a freight vehicle behavior model.

Keywords: Urban freight transport, Probe car system, Highway, Case study

*1 Keihanshin: Japanese second largest urban area consisting of Kyoto, Osaka, and Kobe with population roughly 17 million.

INTRODUCTION

Freight vehicle behavior and how traffic conditions satisfy freight drivers' expectation have not been adequately studied in Japan. For instance, how they respond to traffic congestion, how many trips they take, and so on are not precisely known. Existing data based on responses to questionnaires is useful to grasp the overview of the freight traffic demands, but one can hardly guess the individual movements of a freight vehicle from these aggregate data. We will be able to expect much better information if we can obtain individual freight vehicle movement data. Transport will be categorizable into passenger transport and freight transport. The latter is solely undertaken by trucks in urban areas, and improving efficiency is its main issue. Unfortunately, in Japan, very few studies have been done on the freight traffic actual behavior. Among several approaches to the goals of the research, we set the twofold objectives:

1) Identify the freight traffic flow from macroscopic viewpoints, that is, which ODs are dominant, which road are mainly used by trucks, and how the travel velocity is.

2) Identify the freight traffic drivers' behavior when they encounter different traffic conditions.

There are some reports about the economic activity from the logistics standpoint in Keihanshin. However, it is quite difficult to use these data for the above two objectives because they are highly aggregated data. Picking up specific freight traffic phenomenon or individual vehicle behavior from those reports is almost impossible. Hence, to clearly extract more specific traffic characteristics of trucks and to study individual driver's behavior, we conducted a probe car survey from October 1 to 31, 2009, in which almost 300 trucks belonging to 21 different transport operators participated. If one wants to do a survey on freight traffic characteristics, one way is using the data of traffic sensors installed on highways and arterial roads. The electronic toll collection (ETC) system might be a candidate for the travel time sensing apparatus, but it is not a system designed for traffic surveys and can only measure toll roads. The automatic vehicle identification (AVI) system based on license plate number recognition can also measure travel times, but the systems are installed at very few spots and are not sufficient to grasp the actual area-wide traffic conditions. Other sensors such as infra-red beacons and ultrasonic sensors, which are described in T. Yokota (1999), can be used in public traffic information systems. However, they cannot satisfy the needs of our research because none of them can measure an individual vehicle's travel time and route. On the other hand, the GPS based probe car technology can report and record every trajectory of trucks with sufficient resolution (e.g. every single second) that satisfies our needs. Hence, we decided to do a probe car survey of trucks. However, the success of the probe car survey heavily depends on whether we could choose trucks that represented the characteristics of the entire population of trucks in Keihanshin because the probe cars are a limited sample.

THE SURVEY USING A PROBE CAR SYSTEM

A probe car survey was conducted with 300 trucks that mainly traveled within the Keihanshin area during October 2009. To be as consistent as possible with the results of a previous survey, we tried to monitor diverse types of goods, origins, and destinations. The probe data are a set of time series that consist of unique id, time stamp, latitude, and longitude.

Literature Review

Various studies have analyzed traffic flow using probe cars. M. Sravi (2002) proposed a data cleansing and trip end identification method, but the technology used is only for buses and taxies. Whether the technology is applicable to freight vehicles is not clear. S. Kitamura (2003) proposed a method for analyzing how taxis detour around traffic from their probe data. T. Miwa (2004) discussed the modeling of route choice behavior of taxies from probe data. T. Yokota (2007) described the travel time estimation and prediction method on the basis of probe car data. Most of these existing studies using probe cars mainly focus on taxies, busses, and passenger vehicles, meaning freight vehicles have been barely studied.

Several studies have been done, however, concerning the trip chains or tours of commercial vehicles. J. Holguin-Veras (2005) discussed the trip chain behavior of commercial vehicles and estimated the probability of the trip purpose with respect to the vehicle category and the number of trip chains, average number of stops, and length of trip chains from the data on the basis of travel diaries in Denver. M. Figliozzi (2007a) formulated a tour model and analyzed the impact of congestion with respect to different conditions. He also categorized tours into three classes based on the average distance per stop and the percentage of the time spent driving with an example of empirical tour data in Sidney. M. Figliozzi (2007b) also proposed a set of continuous approximation models for four different types of tours. Using the models he discussed the likely impact of policy or network changes.

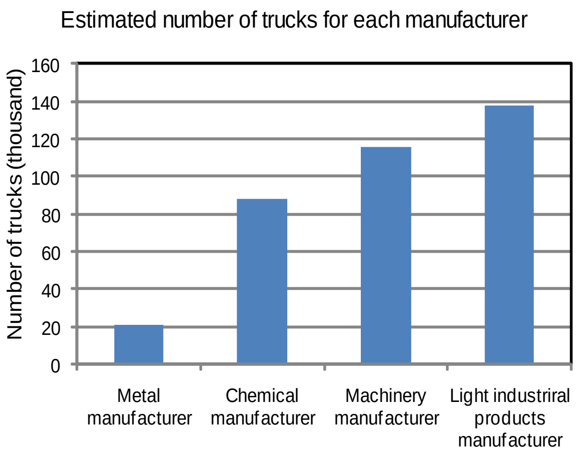
S. P. Greaves (2008) introduced the probe-data-based analysis of commercial vehicle tour data and described his pilot survey in Melbourne. He also discussed potential applications such as O-D matrices estimation and constructing trip length distributions. However, this pilot survey studied few vehicles (30 trucks) and was not intended to obtain unbiased results.

Selection of the probe cars

This section describes how we chose the kinds of trucks as probe cars. At first, we decided the target number of trucks for this survey. To obtain unbiased data that can represent the real conditions of freight transport in Keihanshin, as many trucks as possible should be gathered, but the budget for this survey was limited. In considering the budget, the maximum number of trucks for this survey was calculated to be 300 vehicles. This volume is 0.1% of the total number of trucks in Osaka Prefecture except for *kei* cars (smaller automobiles such as vans and pickup trucks), so we cannot say this volume is large enough. Therefore, we examined the number of trucks for each type of goods and each area in Keihanshin that was estimated in the survey of urban freight transport in the Keihanshin area conducted by several local governments in 2005, and we set a target number of trucks for each type of goods and each area to eliminate spatial and goods type biases. For the sake of brevity the words “2005 survey” are used instead of “the survey of urban freight transport in the Keihanshin area conducted by several local governments in 2005” herein. Figure 1 shows the number of trucks for each type of manufacturer and the rate of the number of trucks for each area in Keihanshin according to the 2005 survey, and it also shows the target number of trucks for each type of goods and each area. Manufacturers of light industrial products use almost twice as many trucks as chemical manufacturers. Also, metal manufacturers use much fewer trucks than the others. In considering all this, we set the target number of trucks for light industrial goods and for machinery and metal industrial goods to be twice as many as that for chemical industrial goods. As for the number of trucks in each area, we set the target number for outside Osaka Prefecture that is smaller than the real number. Osaka prefecture has many more vehicles, including trucks, and more traffic congestion than other prefectures. Therefore we emphasized Osaka Prefecture and set a large target number of trucks.

We selected 27 companies with the help of the Osaka Trucking Association and Japan Institute of Logistics Systems, and asked for their cooperation. In selecting the companies, we did not set targets for company size because it was quite difficult to fit the target while adjusting types of goods and truck area, but we tried to diversify the company size. Tables 1 and 2 show the result of the selection. We could assemble trucks from 21 companies of various sizes. However, types of goods considerably differed from the target. This is because many trucks carried various kinds of goods in one delivery, or different kind of goods day by day, and many trucks could not be categorized into any of the categories we prepared. Also, we could not survey many trucks carrying machinery or metal industrial goods. The main reason was that the value of those goods was large, so shippers did not want to disclose any information about their freight schedule for security reasons.

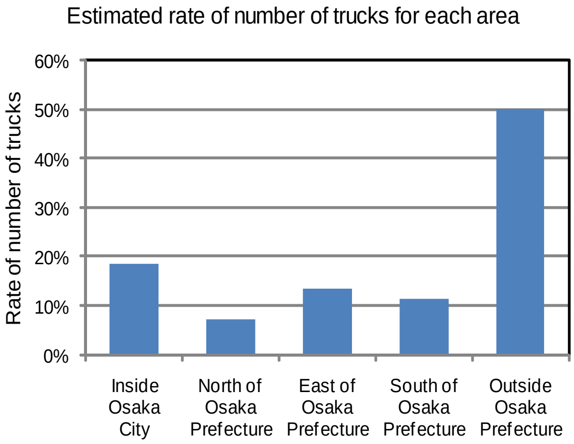
About types of goods



Target number of trucks for each goods (vehicles/day)

Chemical industrial goods	60
Machinery and metal industrial goods	120
Light industrial goods	120

About areas trucks leave



Target number of trucks for each area (vehicles/day)

Inside Osaka City	90
North of Osaka Prefecture	30
East of Osaka Prefecture	60
South of Osaka Prefecture	60
Outside Osaka Prefecture	60

Figure 1 Selection Policy of Kinds of Freight and Area

Table 1 Selection Result of Kinds of Freight and Area

Actual number of trucks for each goods (vehicles/day)

Chemical industrial goods	24
Machinery and metal industrial goods	30
Light industrial goods	196
Others	50

Actual number of trucks for each area (Vehicles/day)

Inside Osaka City	136
North of Osaka Prefecture	25
East of Osaka Prefecture	35
South of Osaka Prefecture	60
Outside Osaka Prefecture	44

Table 2 Results of Selection of Trucks in Detail

		Target number of trucks	Carrier	Freight area					Actual number of trucks		Types of goods	
				Osaka City	North Osaka	East Osaka	South Osaka	Outside Osaka			goods	Category
Truck departure area	Osaka City	90	A	■	■	■	■	■	15	136	Paint	3
			B				■	■	6		Sundries, Stationary	3
			C	■	■	■	■	■	40		Daily necessaries, Chilled food	3
			D	■	■	■	■	■	10		Various	4
			E	■	■	■	■	■	30		Beverage	3
			F	■	■	■	■	■	10		Various	4
			G	■	■	■	■	■	15		Various	4
			H	■	■	■	■	■	10		Sundries	3
	North Osaka	30	D	■	■	■	■	■	10	25	Various	4
			G	■	■	■	■	■	5		Various	4
			I	■	■			■	10		Food and beverage	3
	East Osaka	60	J	■				■	10	35	Office equipment	3
			K	■	■	■	■	■	18		Auto parts	2
			L	■	■	■	■	■	3		Food	3
			M	■	■	■	■	■	4		Material of petrochemicals	1
	South Osaka	60	N		■			■	10	60	Petrochemicals	1
			O	■			■	■	5		Machinery	2
			P	■			■		30		Sundries	3
			Q	■			■	■	5		Electric appliance	2
			H	■	■		■	■	10		Gas	1
	Outside Osaka	60	M	■	■	■	■	■	16	44	Interior material	3
			R	■	■	■	■	■	5		Housing material	3
			S	■	■		■	■	6		Beverage	3
			T	■	■	■	■	■	15		Food (frozen, chilled)	3
			U				■		2		Electronic component	2

■ : Freight area

Category
1: Chemical industrial goods
2 : Machinery and metal industrial goods
3 : Light industrial goods
4 : Others

ACQUIRED PROBE DATA

Figure 2 illustrates the amount of obtained probe data. Each set of probe data is represented by each 10 by 10 km mesh, called second mesh, which is defined in Japan Industrial Standard JIS X0410. We obtained more than three million probe data in highest probe density mesh. Almost 270 out of 300 trucks contributed to the probe survey on weekdays while the number decreased on Saturdays, Sundays, and a national holiday (October 12) as illustrated in Figure 3. Furthermore, as Figure 4 shows, the total daily mileage was approximately 40 thousand kilometers on weekdays, while it decreased to about 10 thousand kilometers on Sundays and the national holiday.

These probe data consist of 2-second-interval positional data. As a solution to one of the objective 1,that is, to identify ***which road are mainly used by trucks*** we defined about 20 by 20 m cells and counted the number of probe data that fell into corresponding cells. We obtained dense cells, into which many probes fell, and sparse cells, into which very few probes fell. This density (or frequency) map or traces of the probe data gives a road map of the trucks, as is show in Figure 5. The high-frequency cells (more than 30 probes in a month) are drawn in blue, and sparse and low-frequency cells (at least one probe in a month) in gray. We can see that the blue roads cover the major roads for trucks in the one-month survey. For comparison, the highways and the national roads of the region are shown in Figure 6.

We extracted stop points by the fact that most trucks stop for at least 600 seconds to load and unload goods. The number of trip end points that satisfy the criteria is about 2,000 in one day, which means that each truck has 7.4 trip end stops including a starting base, in other words, 6.4 stops on average. It is interesting to compare this result to other cases in different cities. In Denver case ,J. Holguin-Veras (2005) says that the commercial vehicles make an average 5.6 stops a day. Similar study results can be found for Amsterdam 6.2 stops, city of Calgary 6.0 stops, and Melbourne 12.2 stops in S. P. Greaves (2008). In spite of the different countries and cities, the average numbers of stops are moderately close with the exception of Melbourne case. The distribution of the number of stops is shown in Figure 7. The yellow pins on the Google Earth picture in Figure 8 show the stops in trip chains of trucks.

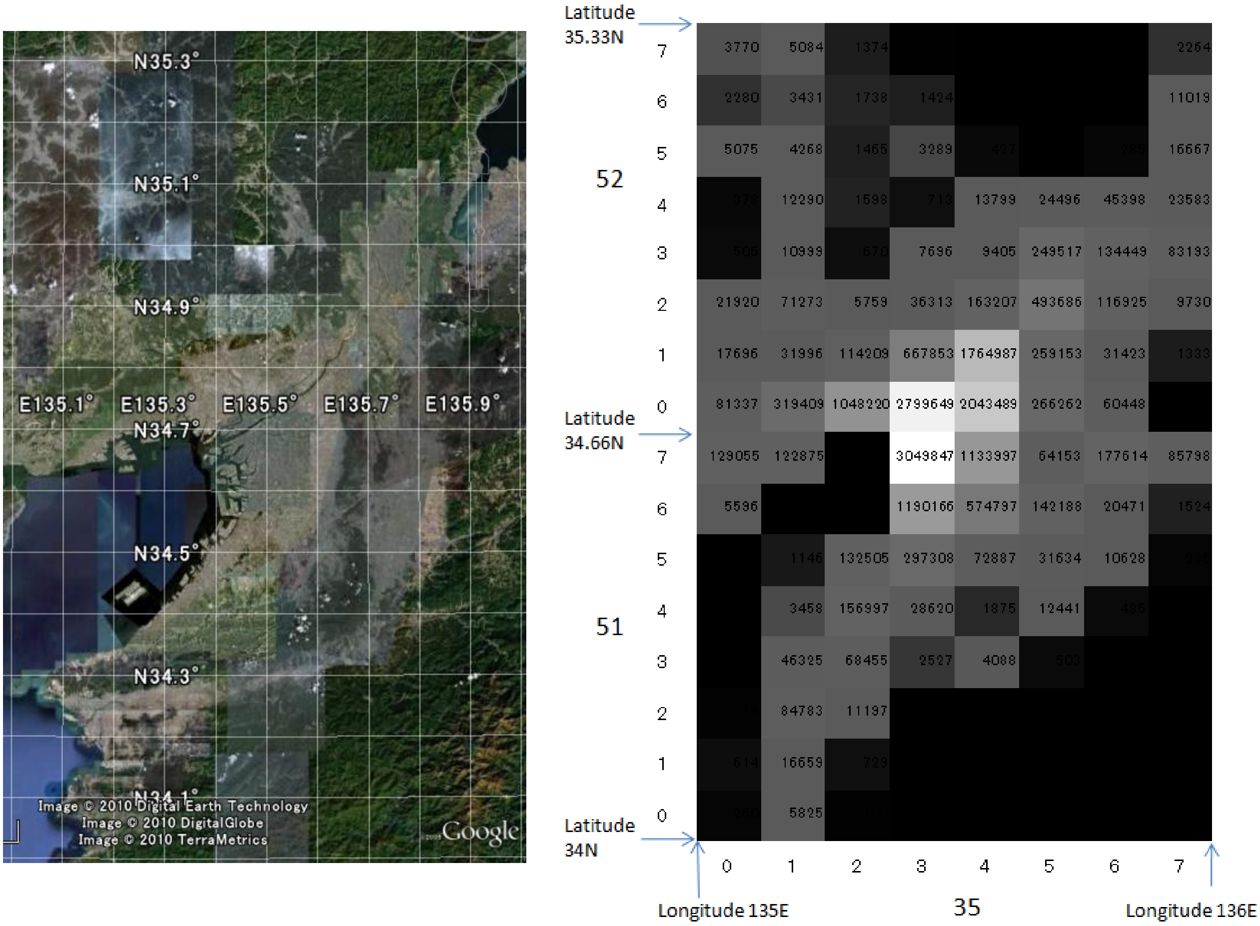


Figure 2 Acquired Probe Data from October 1 to 31, 2009

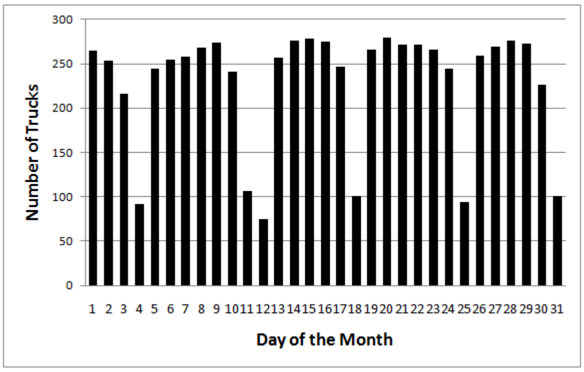


Figure 3 Number of Trucks

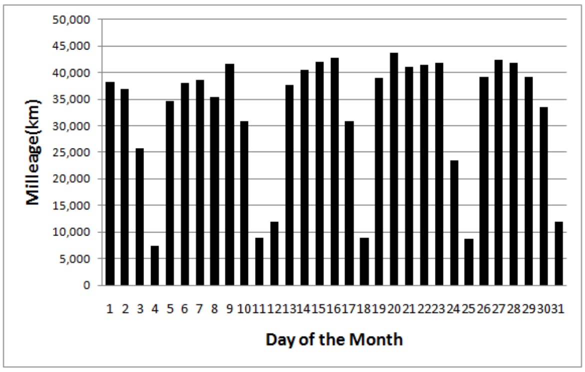


Figure 4 Total Mileage of Trucks

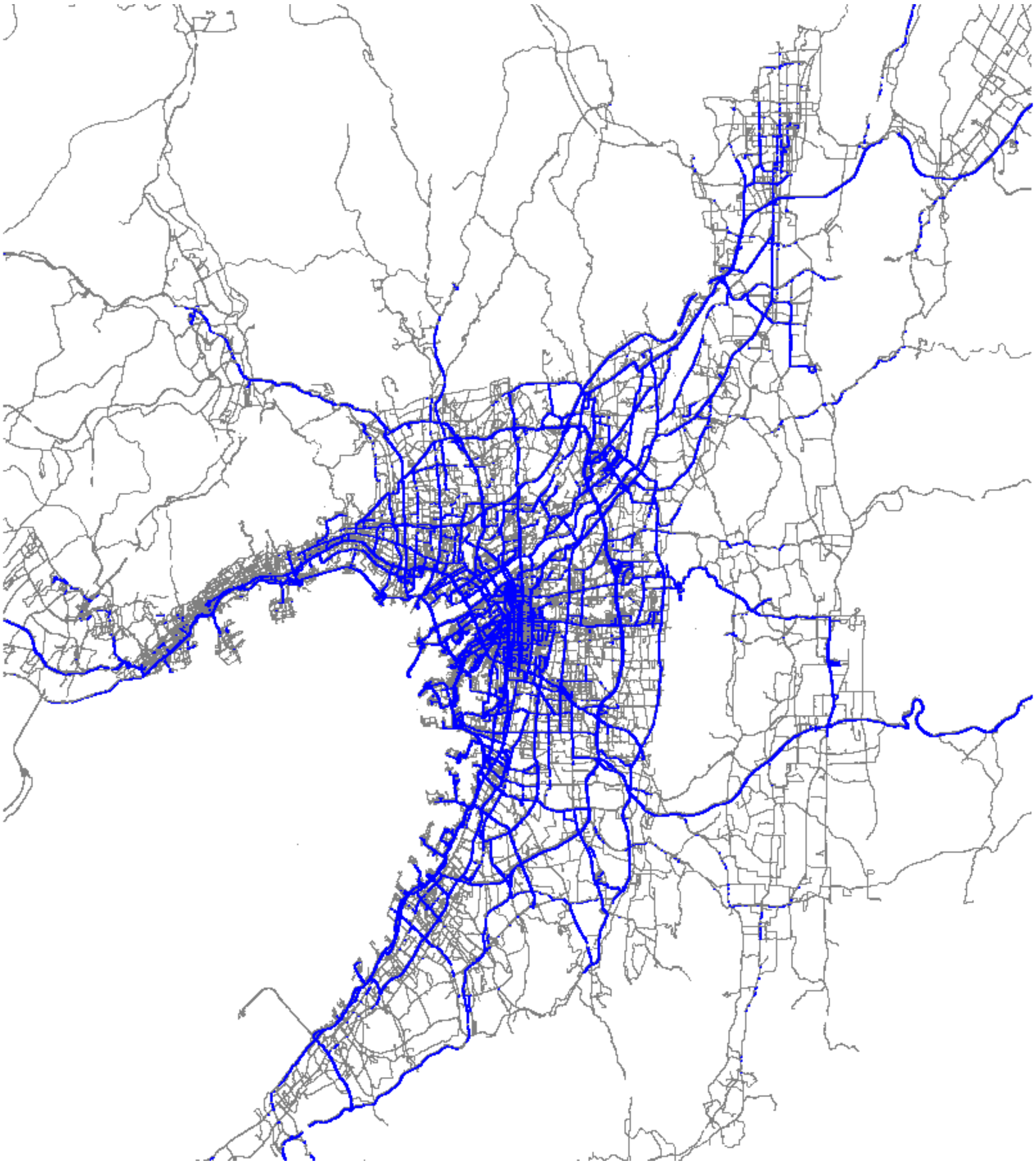


Figure 5 Roadmap drawn using truck probe data.
Blue roads indicate high-frequency road cells (more than 30 probes a month)
Gray roads indicate low-frequency road cells (at least one probe a month)

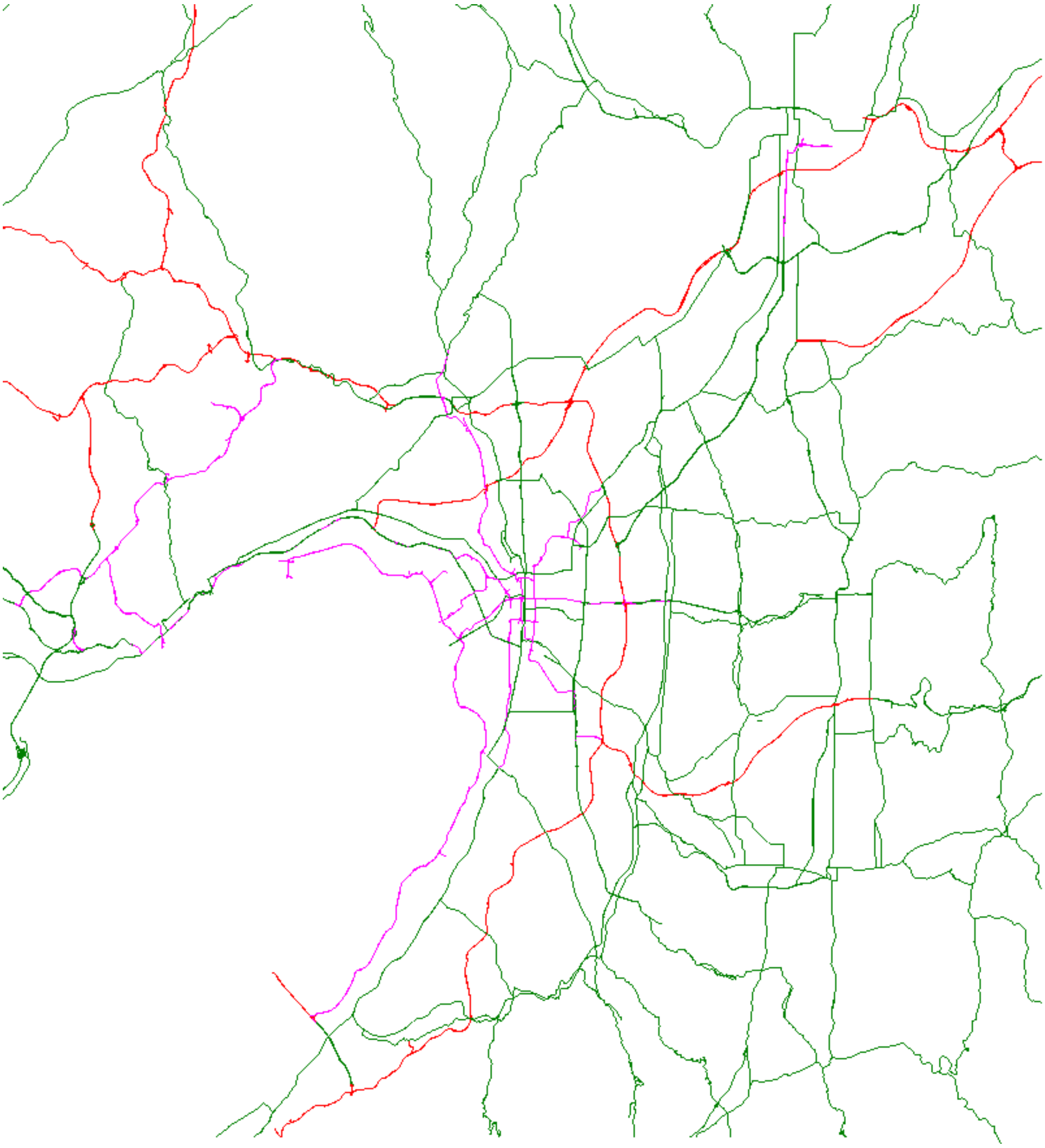


Figure 6 Highways and National roads in Keihanshin Area
Red and purple roads indicate highways. Green roads indicate national roads.
(Digital roadmap data: Copyright ©2010 Sumitomo Electric Industries Ltd.)

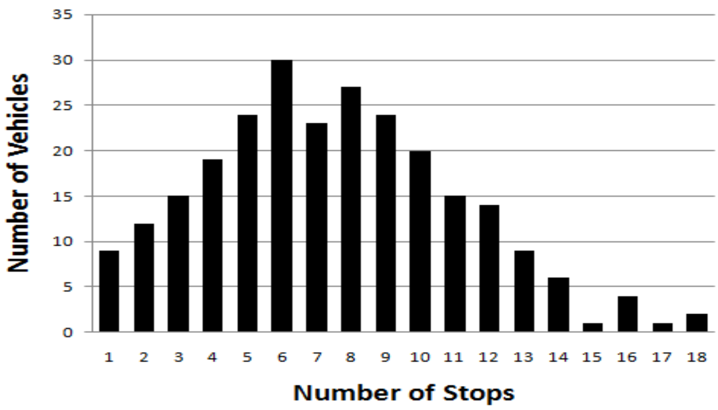


Figure 7 Distribution of Number of Stops (population 255 trucks) Tuesday, October 13, 2009

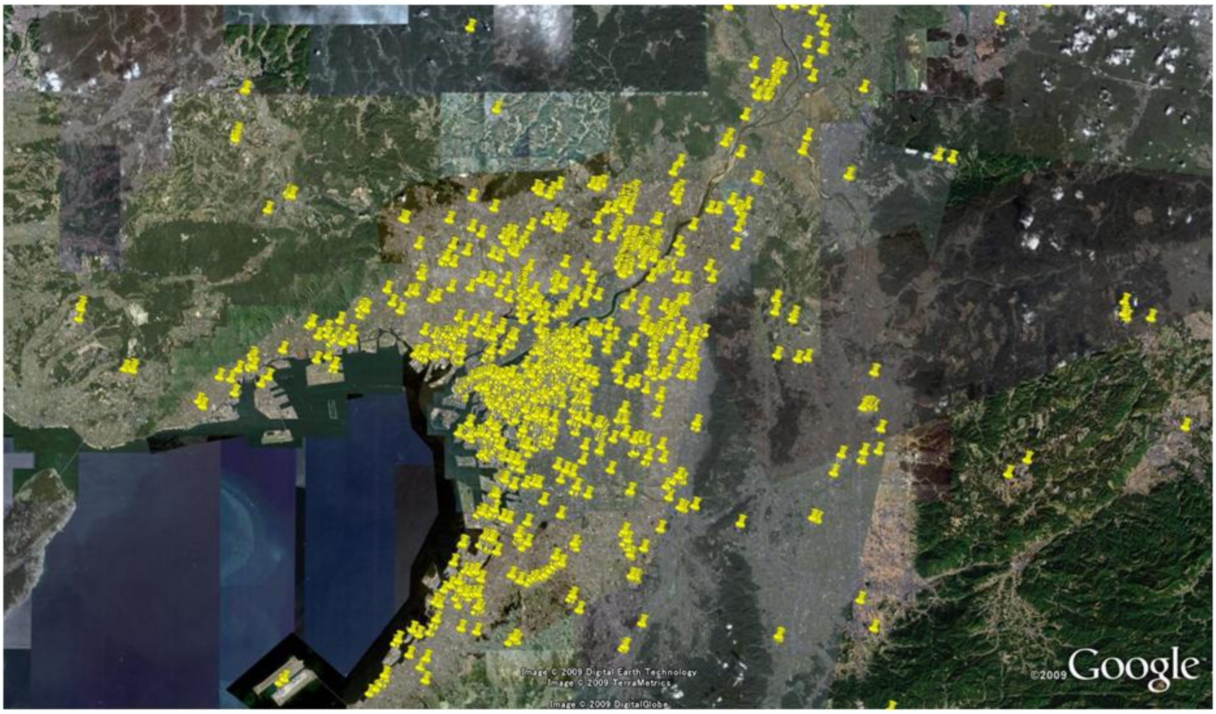


Figure 8 Estimated Trip Ends

Consistency of the acquired probe data with the 2005 survey

Before we start further analysis, we need to see if the probe data is consistent with the traditional data. For this purpose, we compared the probe data with the 2005 survey data from the trip characteristics viewpoint. Figure 9(a) and (b) show the distribution of the trip distance of all trips we gathered in the one month probe survey. Figure 9(a) is a linear scale graph, while Figure 9(b) is a logarithmic scale graph. The distribution of the straight-line trip distance can be approximated quite accurately by an exponential distribution of Eq. (1). The R^2 value is 0.9495. Figure 11 shows the accumulated contribution of the straight-line trip distance.

$$yt = 27{,}451e^{-0.0952x} \qquad (1)$$

where x: straight-line trip distance (km)
yt: number of trips

From the definition of the exponential distribution the mean value of the straight-line trip distance and the standard deviation are 10.5km. (The inversed value of 0.0952). From Figure 11, 95% tiles of all trips are within 35 km. In addition, more than a half of all trips (58.4%) are within the range of 10 km. As reference data, we tried to estimate the similar profiles from the 2005 survey. This survey used data from 11,227 companies from the 58,000 companies that had at least 10 employees, which is almost 6 percent of all companies in the Keihanshin urban area. Figure 10(a) and (b) show the distribution of the amount of freight in tons/day from Osaka Prefecture estimated from the report of the 2005 survey, which was based on collected questionnaires. Since the response rate of the survey was not high, the survey report is an estimate. The distribution of the freight is spread rather wider than that of the probe survey in Figures 9(a),(b). The distribution can be approximated by an exponential function of Eq. (2).

$$yf = 105{,}488e^{-0.0518x} \quad (2)$$

where x: straight-line trip distance (km)
yf: amount of freight (tons/year)

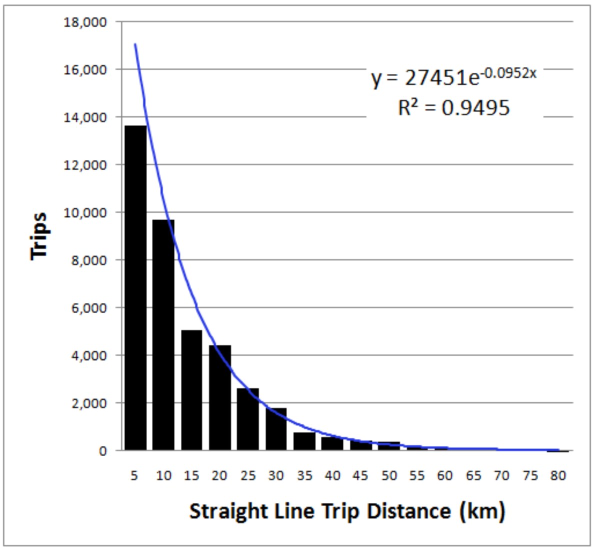


Figure 9(a) Distribution of Straight Line Trip Distance from Truck Probe Data

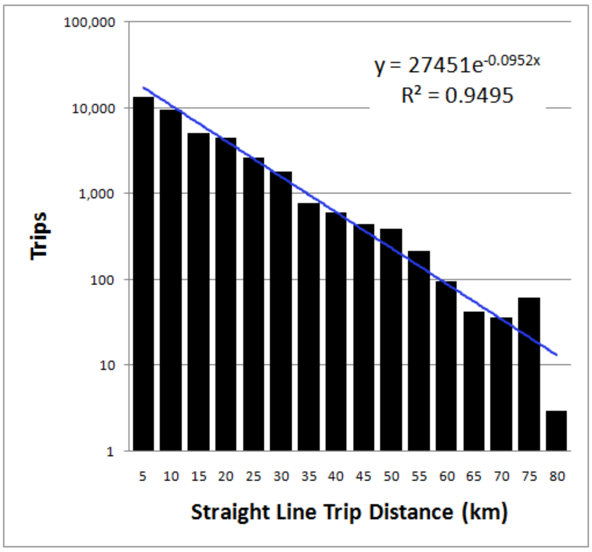


Figure 9(b) Distribution of Straight Line Trip Distance from Truck Probe Data (Log Scaled)

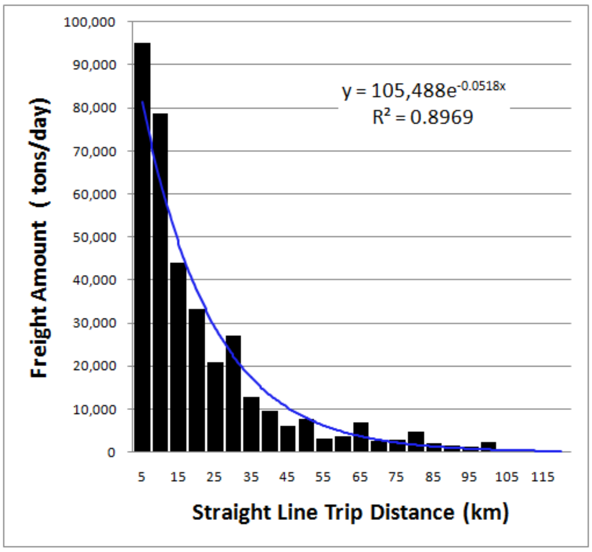


Figure 10(a) Distribution of Freight Amount (estimated from the 2005 survey)

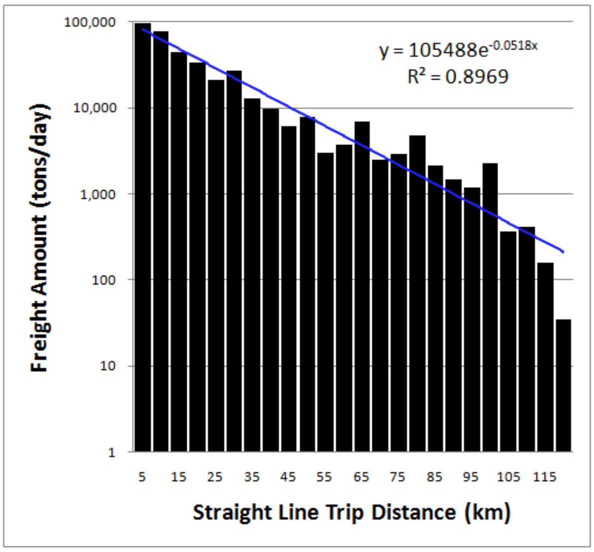


Figure 10(b) Distribution of Freight Amount Estimated from the 2005 survey(Log Scaled)

The R^2 value is 0.8969. The mean value of the straight-line trip distance and the standard deviation are 19.3 km. (The inversed value of 0.0518). This is almost twice as large as the average value obtained by the probe survey. From Figure 12, 95% tile of all freight is within 65 km. The difference of the 95% tile distance between the amount of freight and trips may be due to the following reasons.

1) The longer the trip, the bigger the vehicle and the heavier the freight.
2) The probe survey and the 2005 survey were conducted four years apart in possibly different economic conditions.

We assume that the economic conditions are almost the same. To examine the first reason, we calculated the ratio of the two profiles, that is, the profile in Figure 9(a) divided by the profile in Figure 10(a). The dimension of the profile is trips/(tons/day), the results after normalization are shown in Figure 13.

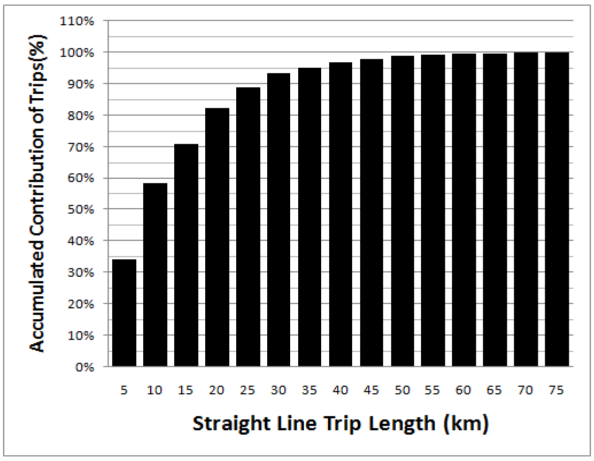


Figure 11 Accumulated Contribution of Trips from Truck Probe Data

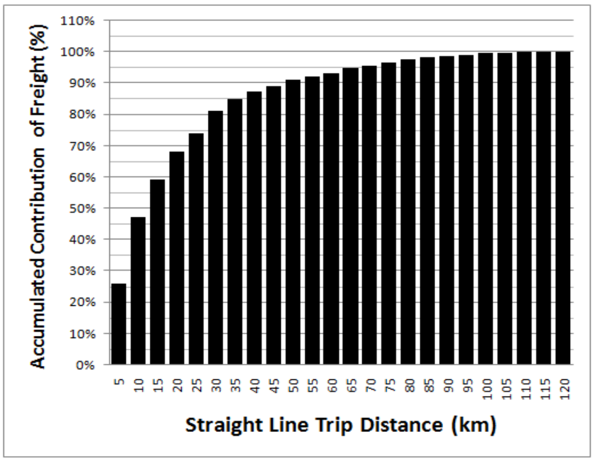


Figure 12 Accumulated Contribution of Freight from the 2005 Survey

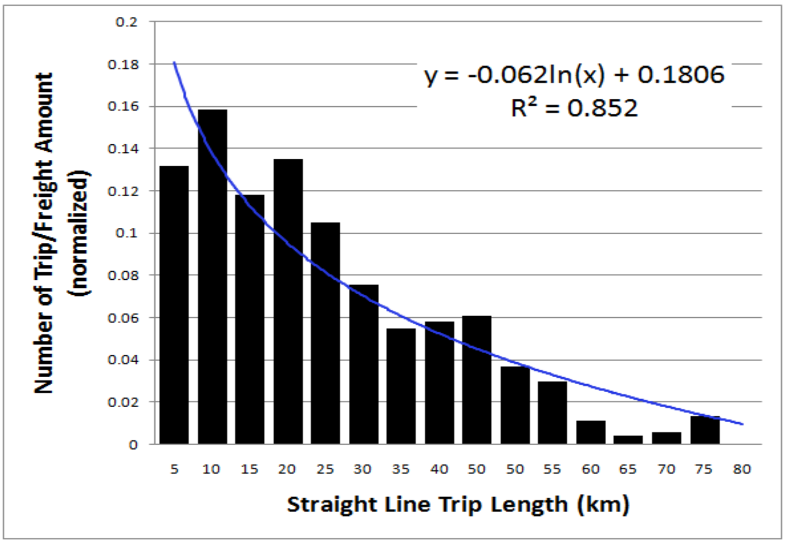


Figure 13 Ratio of Number of Trips and Freight Amount

From this result, we can see that the ratio gradually decreases as the distance of the trip increases just like we assumed; that is, the longer the trip, the bigger the vehicle and the heavier the freight. We do not have enough information to estimate the absolute value for the ratio at this moment. Hence the result is a qualitative one. The distribution can be approximated by a logarithmic function.

$$y = -0.062\ln(x) + 0.1806 \qquad (3)$$

where x:straight-line trip distance (km)
y: ratio of the amount of freight (thousand tons/year) to the number of trips (normalized)

This result shows the possibility of the reason 1) 's validity and more precise study should be done in the future work.

Consistency of the trip origins

We divided the region into 2 by 2 km meshes as bases for comparing the trip origins between the probe survey and the 2005 survey. The reason we set the mesh size to 2 by 2 km is based on the fact that the average distance between adjacent lamps on highways is about 2 km. The total number of the trips is 42,891 according to all trip data. We organized the trip data in accordance with the 2x2-km mesh of trip origins and sorted them in accordance with the number of trips .The largest number of trips from one origin is 1,812. The distribution of the number of trips can be approximated by an exponentially decaying function in Figure 14. The R^2 value is 0.9852. The accumulated contribution is shown in Figure 15. 80% of all trips are covered by 100 high ranked trips, 90% of all trips by 180 high ranked trips, and so on.

We consulted the 2005 survey. From this survey, one can find out the freight demand at city and town level. The distribution of the amount of freight with respect to the rank is shown in Figure 16. In this survey, the number of trips is unknown. The profile in Figure 16 can also be approximated by an exponential function. However, the R^2 value is 0.8736, which is less than that of Figure 14. The reason it closely follows the exponential distribution is still unknown. The positions of high ranked origins of trips are investigated to evaluate the travel velocities. Figure 18 shows the high-ranking origins according to the 2005 survey, and Figure 19 the high ranking origins according to the probe survey. From these results, we can say that the higher-ranking origins are concentrated in Osaka, Sakai, and Kobe. Taking account of the limitation of spatial resolution, we can conclude that the results in Figure 19 are consistent with those of Figure 18 in a sense that origins are centered on Osaka, Kobe, and Sakai.

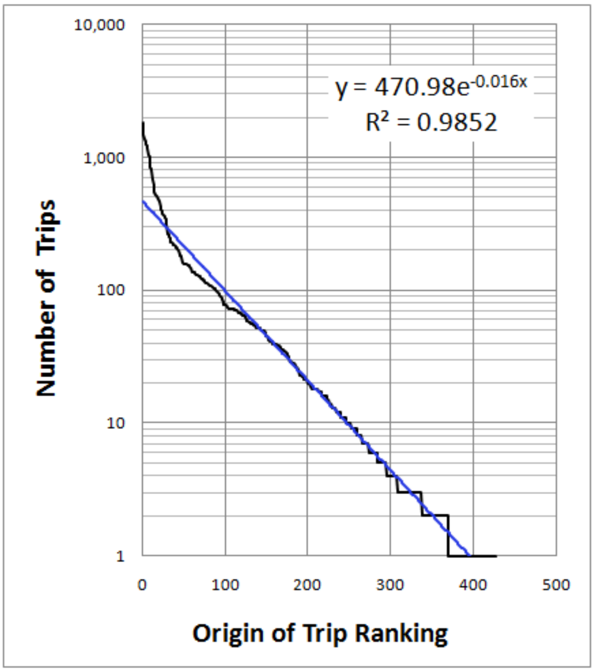


Figure 14 Trip Distribution Ranking from Truck Probe Data

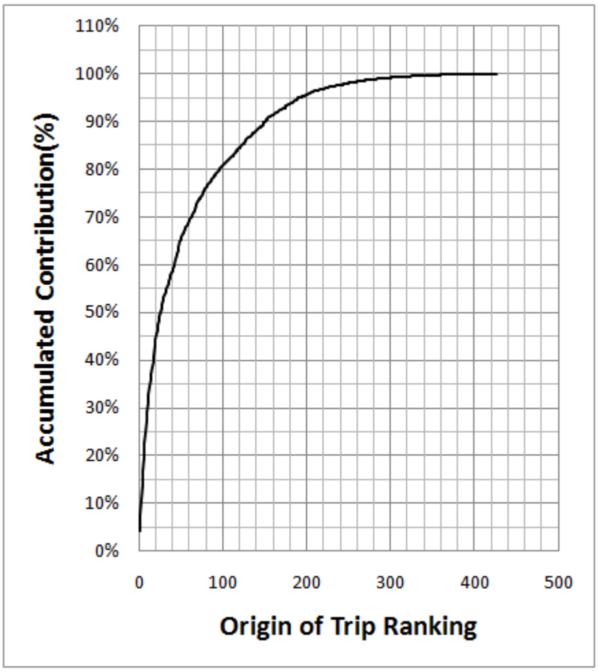


Figure 15 Accumulated Contribution Distribution from Truck Probe Data

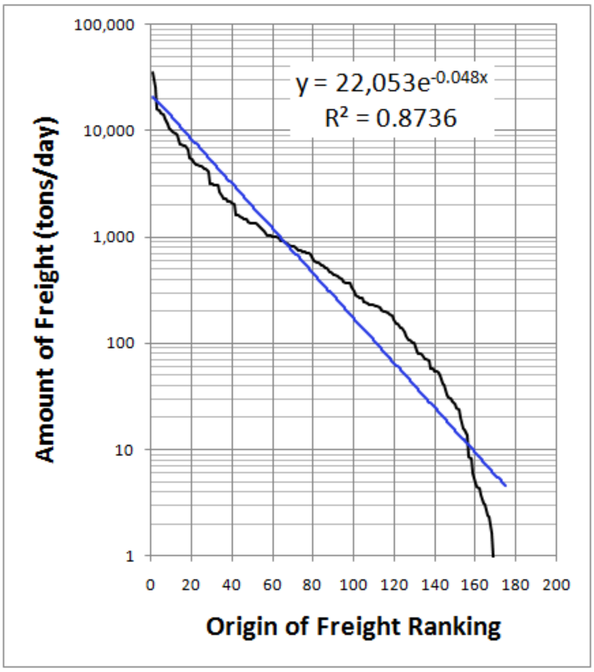


Figure 16 Amount of Freight Distribution Ranking from the 2005 Survey

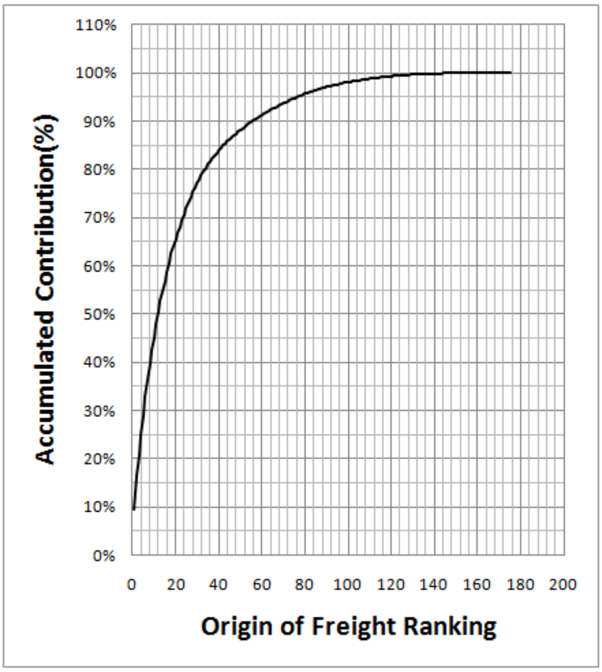


Figure 17 Accumulated Contribution of Amount of Freight from the 2005 Survey

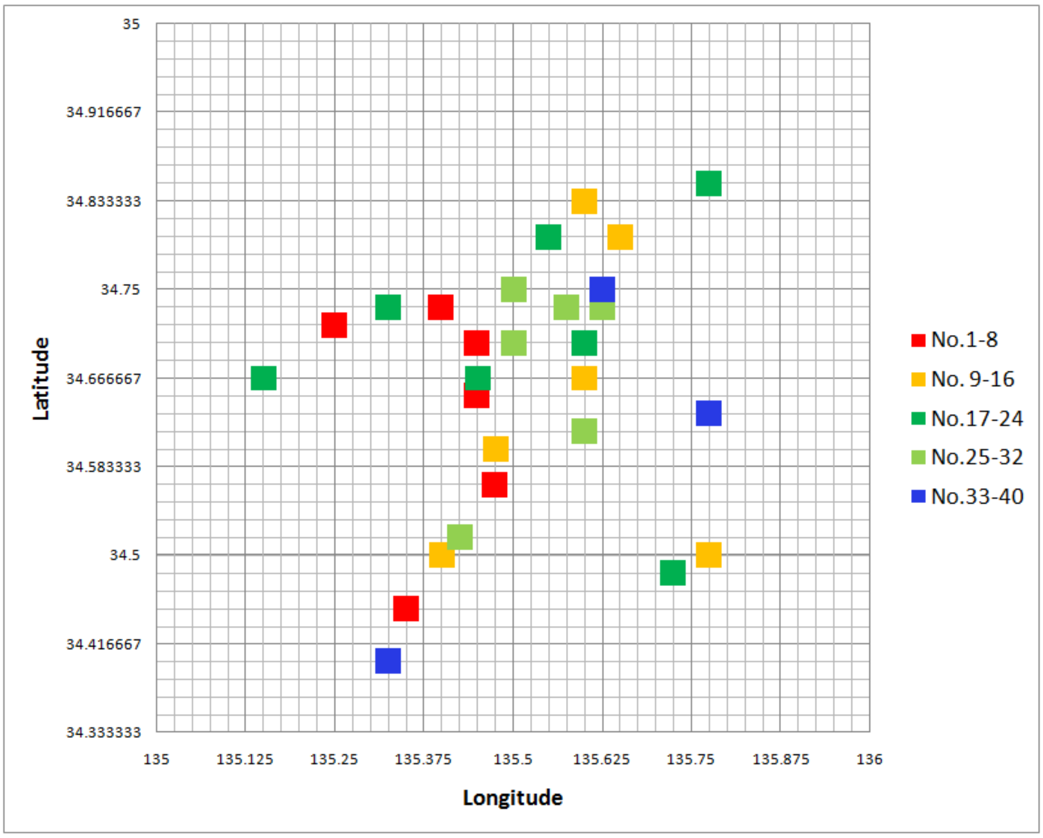


Figure 18 High Ranked Origins from the 2005 Survey

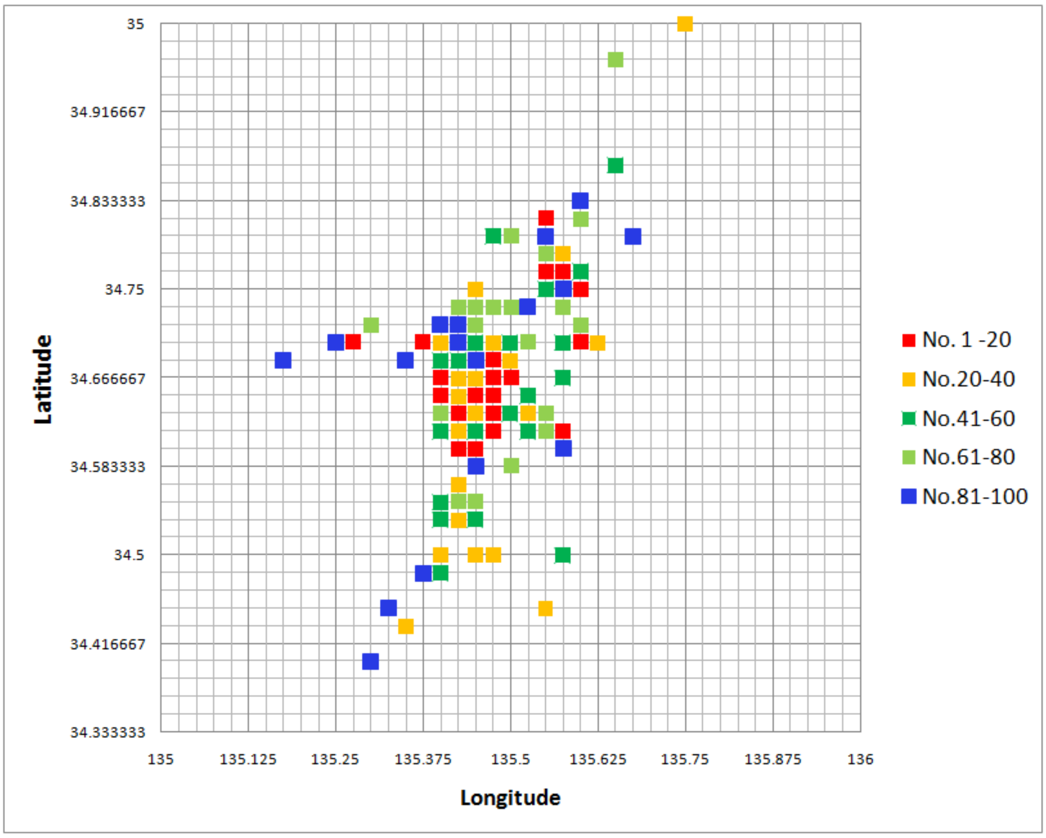


Figure 19 High Ranked Origins from Truck Probe Data

ANALYSYS OF STRAIGHT-LINE VELOCITY FROM MAJOR ORIGINS

Since our first objective of the research is: ***1) Identify the freight traffic flow from macroscopic viewpoints, that is, which ODs are dominant, which road are mainly used by trucks, and how the travel velocity is.,*** we analyzed the probe data to obtain the travel times of trips from major origins. The straight-line velocity distribution from major origins ,Osaka, Kobe, and Sakai are calculated because they contribute greatly in the Keihanshin area, but of course any origins can be examined. Each straight-line velocity is calculated for each trip data, and they are illustrated in Figures 20, 21, and 22 in different colors. Black meshes show the origin meshes. It is commonly seen that if the distance of the trip is within 10-20 km the straight line velocity is often shown in red (less than 10 km/h), which is quite low. Moreover, as Figure 22 shows, the straight-line velocity from origins in Sakai to Osaka is quite low.

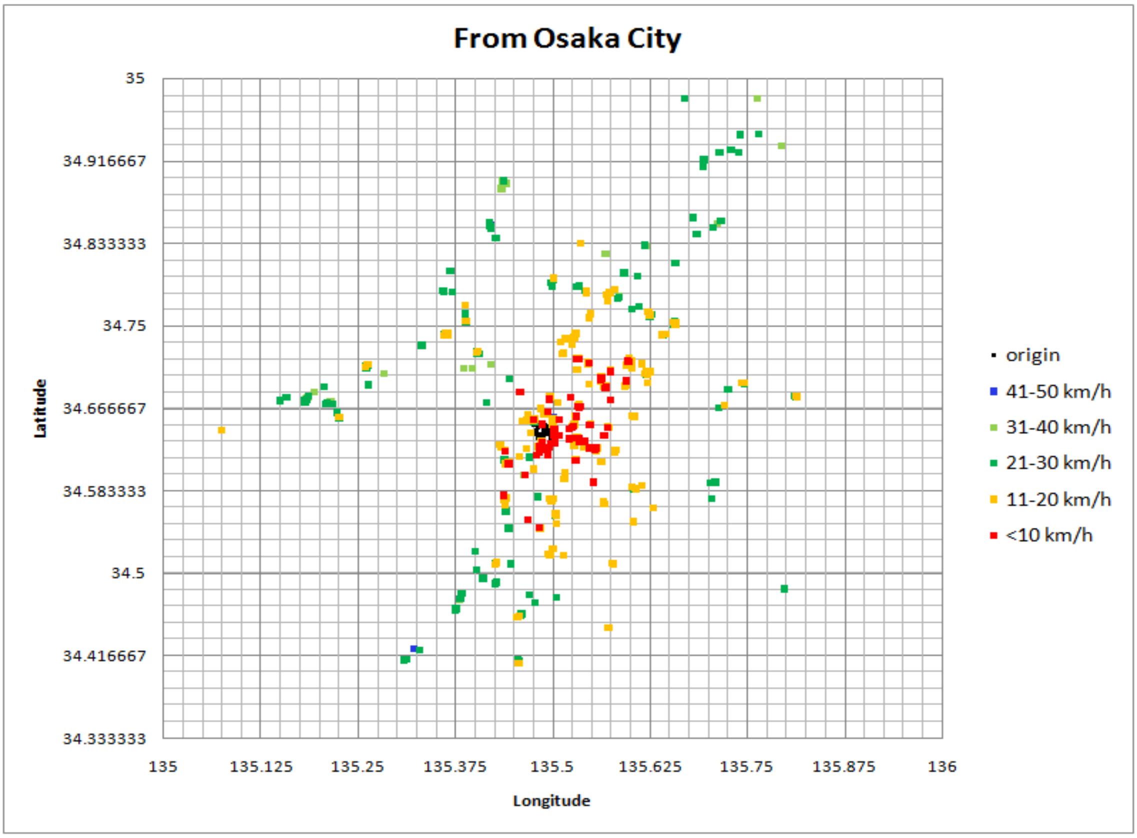


Figure 20 Straight-Line Velocity from Osaka

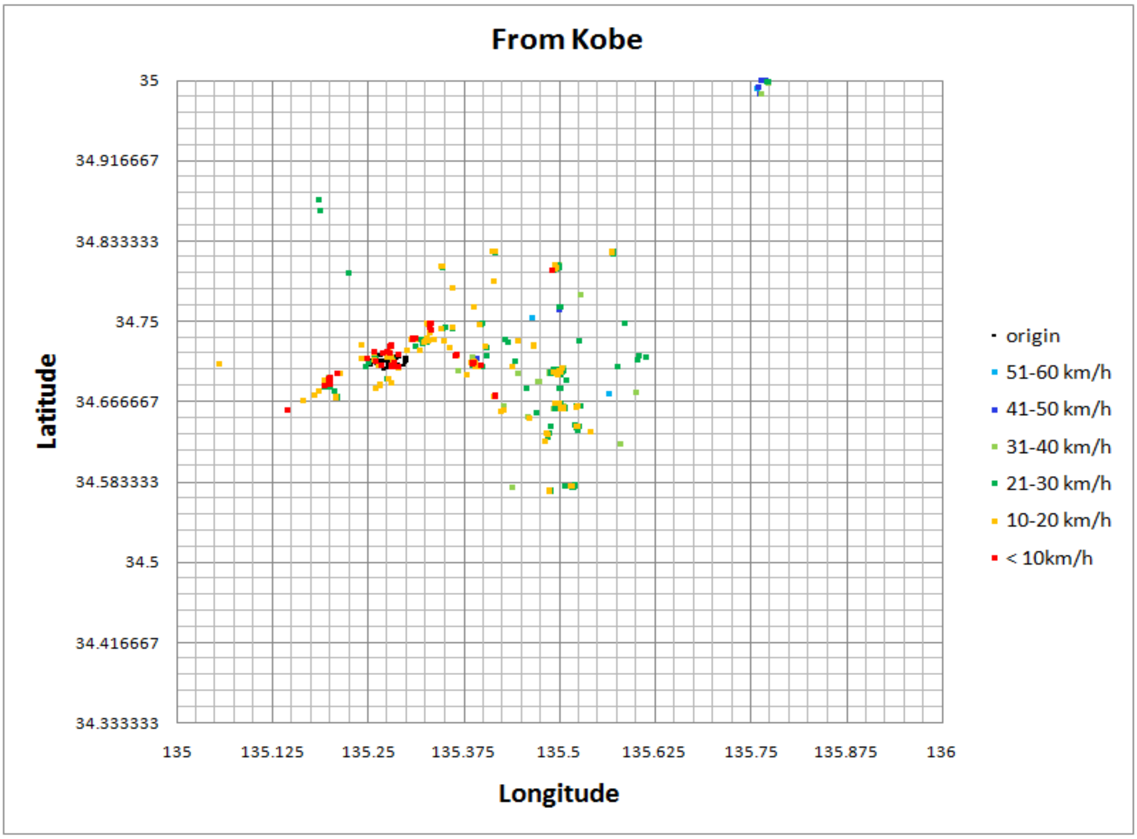


Figure 21 Straight Line Velocity from Kobe city

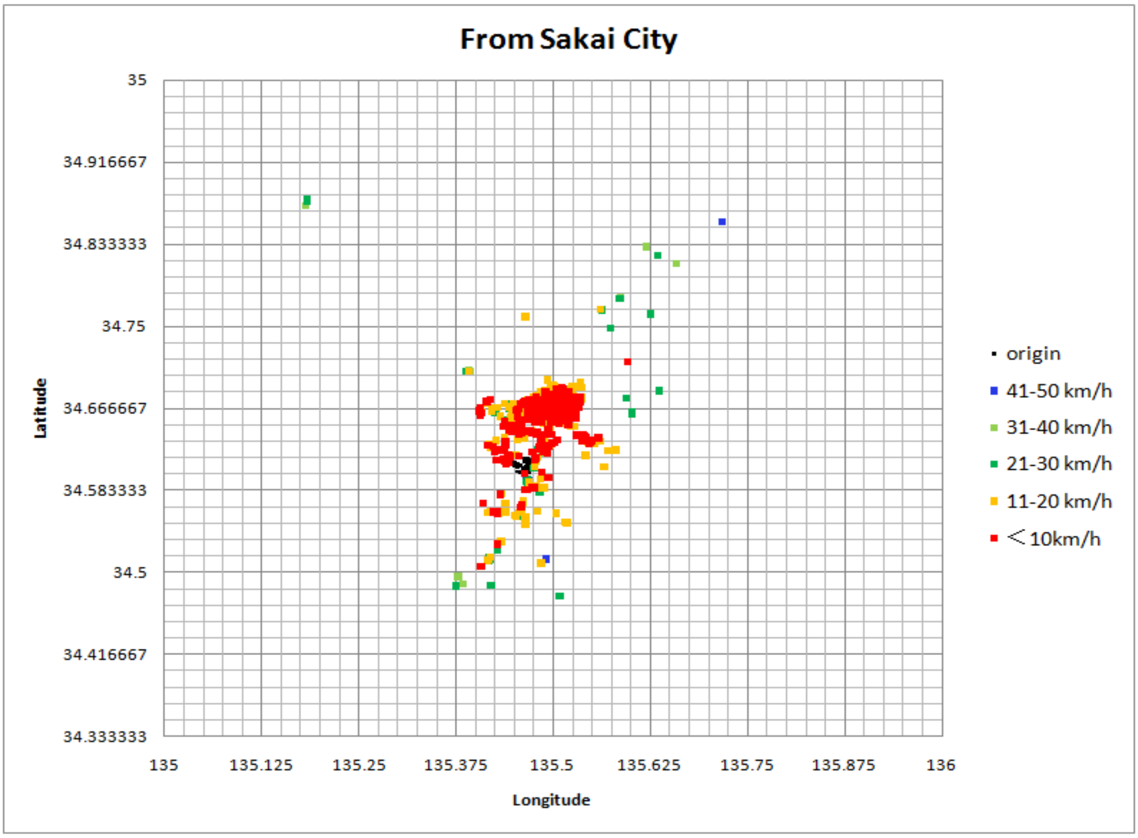


Figure 22 Straight Line Velocity from Sakai city

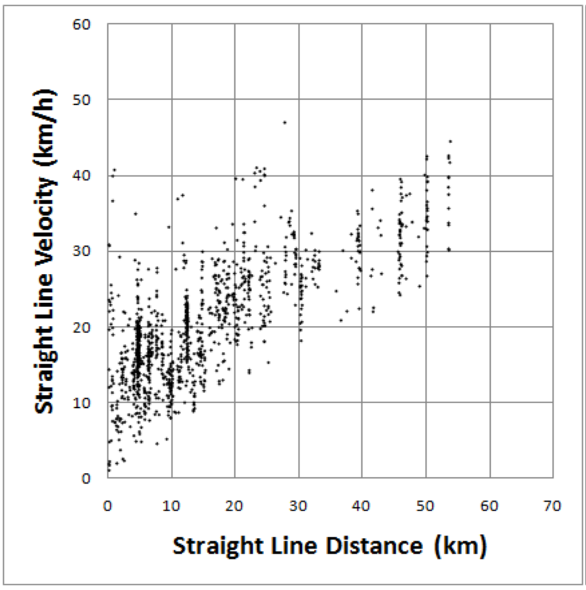


Figure 23 Osaka case

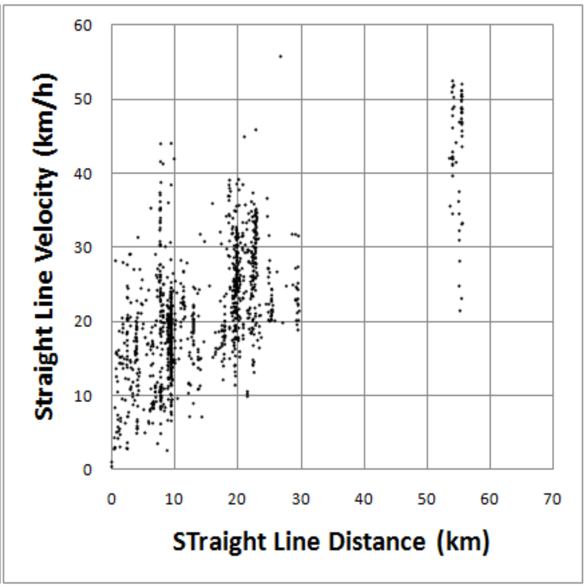


Figure 24 Kobe case

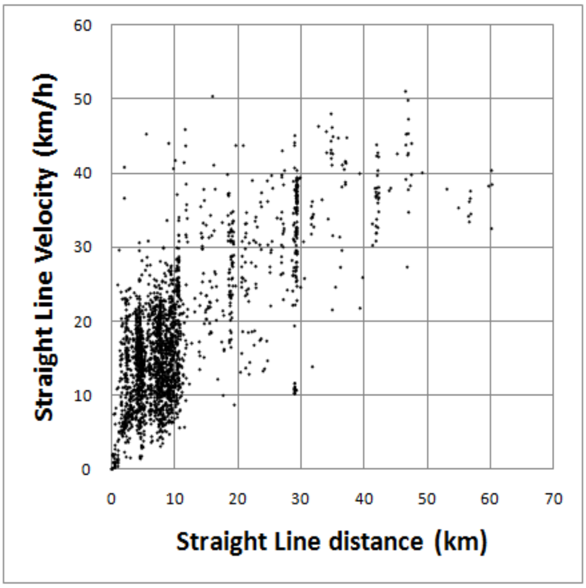


Figure 25 Sakai case

Figures 23,24 and 25 show the scatter plots of straight-line velocity and the straight-line distance for each city. It is clearly shown that "the longer the trip, the faster the velocity" phenomenon exists. In these major cities, the average straight-line velocity is below 20 km/h for vehicles with less than 10 km trips. Improving the efficiency of trips of this category will be very effective economically and environmentally. Because highways cannot contribute much to these short distance trips, promoting electric vehicles for the short trips may be the best way in the future, although it will take some years for this technology to become mature.
Optimizing the schedule of trip chains by taking account of the relationship between the trip distance and the efficiency of the vehicle may be a new research area.

ANALYSIS OF BEHAVIOR OF TRUCKS IN MAJOR ODS

The second objective of our research is:
2) Identify the freight traffic drivers' behavior when they encounter different traffic conditions.

To deal with this, we chose several origin-and-destination (OD) pairs with which we could obtain many probe data and examined travel time distributions. Also, we examined the routes that trucks used. We chose three ODs that had different distances and locations, which are shown in Figure 26.
In each OD, probe data was obtained from a different company. Figure 27 shows the route used in OD1. In this OD, trucks departed from North Osaka and went to South Osaka, and the route was fixed every day. Most of this route was highways. Figure 28 shows the distribution of travel time on weekdays during the survey. Travel time changed largely day by day especially around 10:00 am (from 3,383 to 5,045 sec), so this route (OD) was not very reliable. On the other hand, in considering the fact that the route was fixed, trucks possibly accepted travel time varying substantially and did not change their route when highways were on it.
Figure 29 shows the route used in OD2. In this OD, trucks departed near the port area in Osaka and went to North Osaka. Also in this case, the route was fixed every day and consisted mostly of highways. Figure 30 shows the distribution of travel time on weekdays during the survey. Travel time changed largely day by day also in this case.
Figure 31 shows the route used in OD3. In this OD, trucks departed from Kobe and went to the central district of Osaka. In this case, there were two routes with different departure time, but these routes were fixed day by day. National roads were used in the early morning, and the elevated highways right above the national roads were used at other times. Figure 32 shows the travel time of this OD. Around 8:00 am, travel time changed greatly, but trucks used highways and did not change their route.
Figure 33 shows the standard deviation of travel time of OD1 around 10:00 am and that of OD2 around 6:00 pm. Figure 34 shows the coefficient of variation of travel time shown in Figure 33. As for OD3, we could not obtain a sufficient amount of data, thus we cut these figures. The values of coefficient variation are around 0.1.
In Japan, road traffic information of most highways, such as where is congested, is available via the internet or broadcast, so truck drivers can choose their route by checking the traffic conditions before departing. However, they did not change their route flexibly. Considering these results, we can say that once they decided their route for a delivery and planned to use highways, trucks did not change their routes despite substantial variations in travel time. Therefore, the reliability of travel time on highways must be enhanced for efficient urban freight transport. However, these results are only the case for highways, and the number of sample is very limited. Thus we have to have some questionnaire survey extensively and analyze the relationship between selected routes and the travel time reliability.
In general, we cannot say necessarily that our probe car survey was sufficiently comprehensive compared to traditional data collection method like a questionnaire. However, like the analysis in this section, we can find some characteristics that are barely found by traditional data collection methods. Therefore, when we try to understand some freight transport conditions, including behavior of individual trucks, it is effective to try to find some characteristics at first by conducting a probe car survey and then verifying these characteristics by having a large-scale questionnaire afterward.

Figure 26 Examined ODs

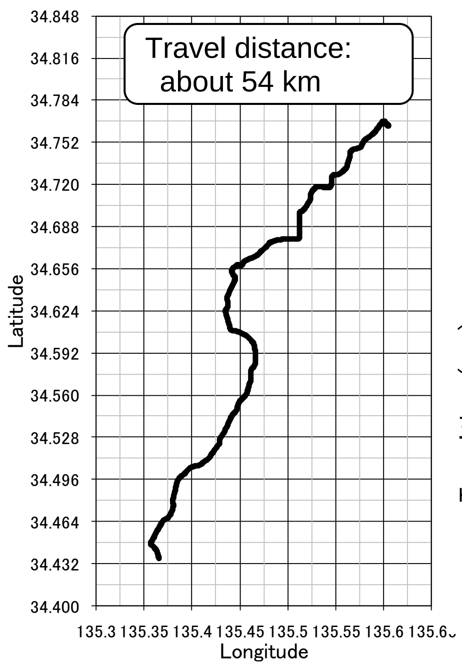


Figure 27 The Route of OD1

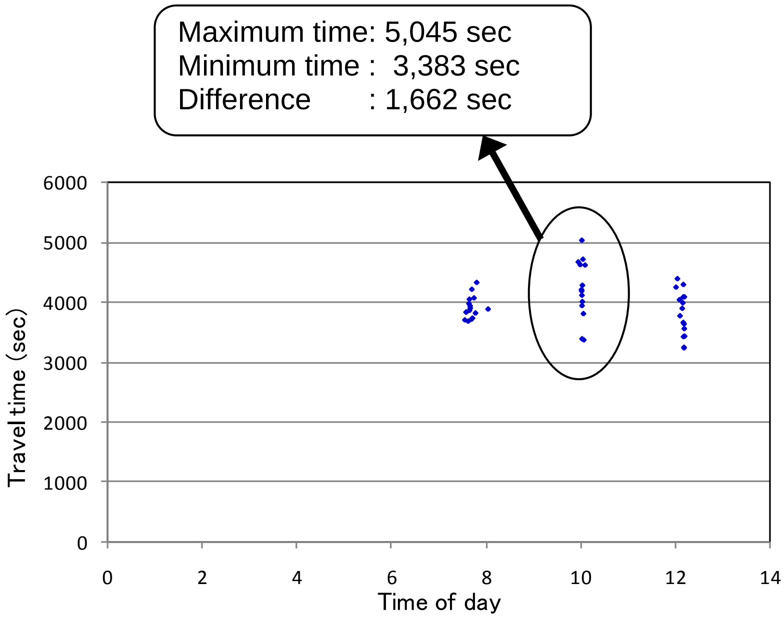


Figure 28 Distribution of Travel Time of OD1

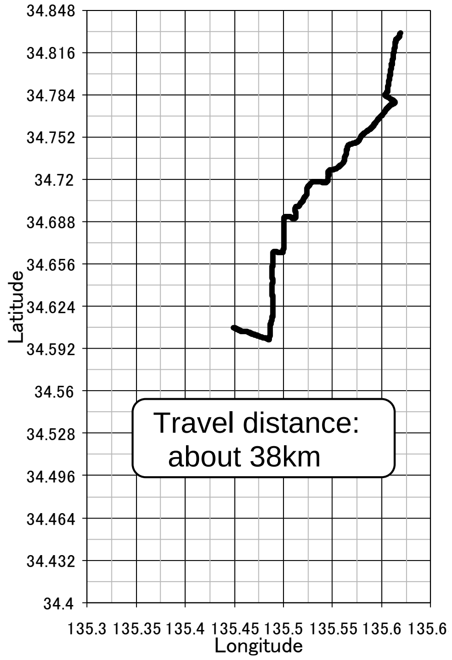


Figure 29 The Route of OD2

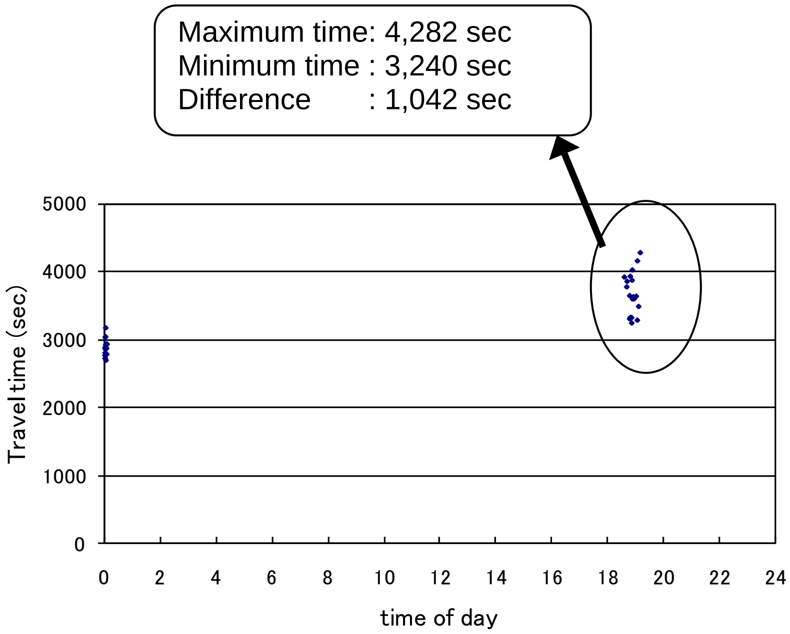


Figure 30 Distribution of Travel Time of OD2

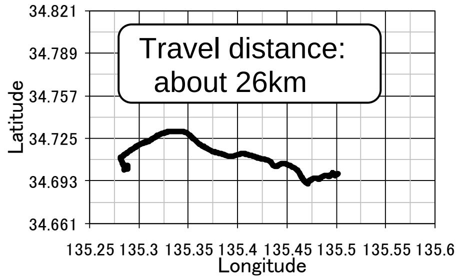


Figure 31 The Route of OD3

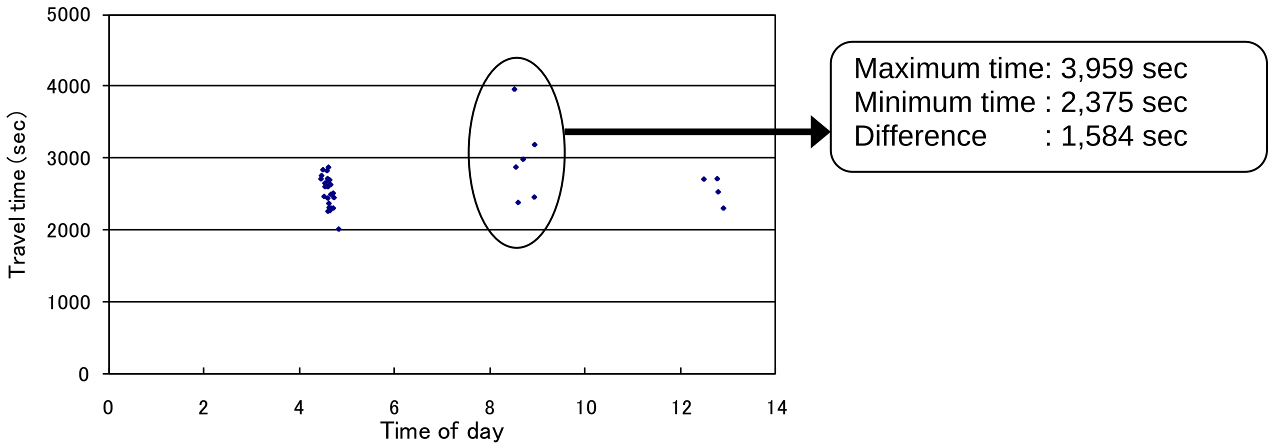


Figure 32 Distribution of Travel Time of OD3

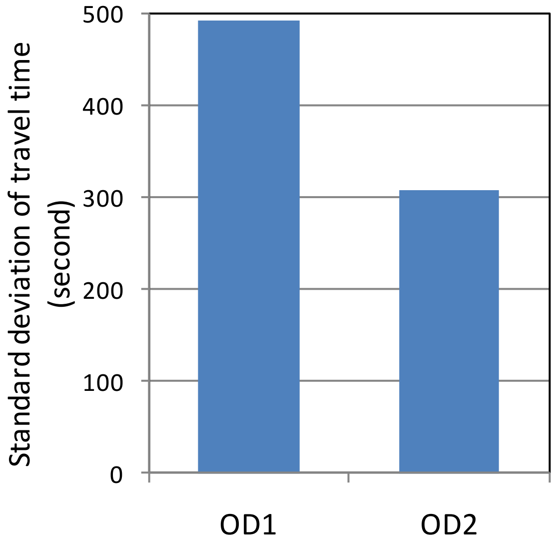


Figure 33 Standard deviation of travel time

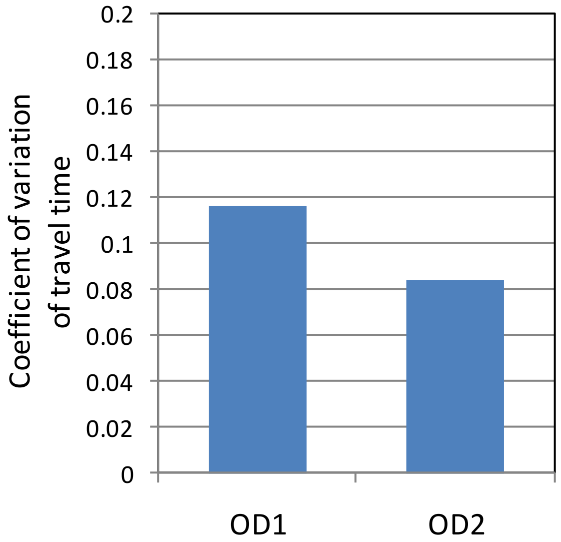


Figure 34 Coefficient of variation of travel time

CONCLUSION

In this study, we found several new, previously unnoticed phenomena.

1) In the Keihanshin area, short trips from major cities like Osaka, Kobe, and Sakai that have less than 10 km straight-line distance have low average straight-line velocity below 20 km/h. Improving the efficiency of trips of this category will be very effective economically and environmentally. Because highways cannot contribute much to these short distance trips, promoting electric vehicles for the short trips may be the best way in the future, although it will take some years for this technology to become mature.
2) Optimizing the schedule of trip chains by taking account of the relationship between the trip distance and the efficiency of the vehicle may be a new research area.
3) Once trucks decided to use highways, they did not change their route even when travel time varied substantially.
4) Therefore, travel time on highways must be made more reliable for the realization of more efficient freight traffic.
5) Probe car survey is effective to find some characteristics of individual vehicles that are barely found by traditional data collection methods like questionnaires. Therefore, when we try to understand some freight transport conditions, including the behavior of individual trucks, it is effective to try to find some characteristics at first by conducting a probe car survey and then verifying the characteristics by having a large-scale questionnaire afterward.

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