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Transition and Problem of Probe Data Research in the Field of Road Transportation in Japan

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Abstract: In the field of road transportation, probe data has been actively utilized, and various studies have been reported. In this research, we overview the existing research from the viewpoint of the transition of the probe data research so far and the type of utilization data. By arranging the issues obtained in that, we aim to contribute to research and practical utilization of future probe data. In this research, paying attention to the types of probe data used in practice and research, we organized research contents by age. As a result, the probe data research was classified into five themes, and the transition of research contents and utilization data addressed in each period was arranged. In order to improve the number of data acquisitions, as for joint use with different probe data and other data, examination of its effectiveness is arranged as future task.

Keywords: Probe car data, Road traffic, Road conditions and behavior, Transition of research

1. INTRODUCTION

Grasping various traffic conditions and traffic action of people is an extremely important factor for transportation planning and infrastructure maintenance. In conventional grasp of traffic conditions, their contents are often expressed based on findings obtained by observation and findings for which periods and scopes are limited have been used. In contrast, in the field of road traffic, as a method to collect and analyze information on traffic actions or flow data effectively with expanded periods and scopes, utilization of probe data (information on vehicles' paths and speeds) has been advancing. In recent years, probe data are utilized in road administration variously and further utilization and advancement are expected in future.

Investigation and observation methods to collect traffic actions and flow data continuously have been reported by various studies. For these process, Kusakabe (2015) have categorized data studies that have been performed in the field of traffic into three types; Needs -leading type (top priority given to acquisition of observation value needed for the study model), Seeds-leading type (acquisition of detailed data and development of methods that allows continuous and long term observation) and Data-leading type (study development on the premise that continuous data already exist). Utilization of storage data such as traffic control data and action data obtained by Probe Person survey has been sought for the studies

categorized into Data-leading type among them since around 2000. For probe data, GPS has been deployed for the purpose of service management of logistics operators, and taxi and bus companies, and an attempt to utilize such data has been made experimentally. In addition, database compilation of the data obtained from commercial vehicles equipped with digital tachograph has been advancing. One of the characteristics is that the above-mentioned data including data collected for the purpose of charging such as ETC data and traffic IC card data, or probe data obtained for the purpose of service management and navigation are collected continuously and automatically as far as there are original purposes such as business operations.

On the other hand, studies have been actively performed for its utilization in business practice accompanied with data accumulation and evolution of data acquisition technology and information processing technique. Chenet *et al.* (2016) have pointed out that studies on big data are directly related to investment in traffic infrastructures, which are important for the society and judgment for urban environment policy, based on the knowledge obtained by conventional studies with specific samples (framework of the studies and concept of hypothesis).

The above suggests that the role of accumulated data in transportation planning and infrastructure maintenance has been expanded in recent years. Therefore, this study surveys existing studies from the viewpoint of transition of probe data and types of data utilized in the field of road traffic. The authors aim at marshaling transition of probe data that have been utilized in the field of study and business and problems that have been clarified so far, so as to contribute to the development of future studies and business for which probe data are utilized.

The data for this study are the probe data that enable to grasp not information on passage at fixed points such as ETC data or traffic IC card but continuous travel information on vehicles or various behaviors on roads among various traffic data. Based on the above, we focus on type of data used in studies conducted after 2000, when utilization of accumulated data began to be sought, and divide the period to (1) early stage (2000 - 2005), (2) middle stage (2006 - 2011) and (3) later stage (after 2012).

Chapter 2 summarizes properties of each datum according to acquisition information for major probe data utilized mainly in the fields of study and business. Chapter 3 summarizes characteristics of data acquisition amount and data acquisition methods of (1) early stage, (2) middle stage and (3) later stage, and then study contents of each stage. Chapter 4 summarizes characteristics and problems of probe data by GPS such as cellular phones which are particularly utilized, ITS spots that started their service in 2011 (the function were expanded from 2014 and operated as ETC2.0 probe data) and utilization of private probe data for studies conducted in (3) later stage outlined in Chapter 3. Chapter 5 describes conclusion of this study and future tasks.

2. PROPERTY OF PROBE DATA

Characteristics of probe data include routing information, travel time (speed) and behavior history by position information. While there are some differences in contents depending on data acquisition device and acquisition methods, various traffic analyses have been attempted based on utilization of the above-mentioned data.

Routing information can be acquired from ETC2.0 probe data, commercial car probe, congestion statistics , smart phone applications and so on and position information is acquired for every vehicle with GPS. The acquisition interval for probe data is 100m - 200m for ETC2.0 and one second for private probes and commercial car probes, and they can be

utilized for capturing detailed routing information. In contrast, the data acquisition interval for congestion statistics is as rough as 5 minutes shortest, and therefore it is applied to broad-based route analyses.

Travel time (speed) may be acquired from probe data by utilizing position information from GPS, and moreover average travel time per unit time (15mins / 1hr) is totalized from ETC2.0 probe data and private probe data for every DRM links and survey sections of a road traffic survey. In addition, average travel time per 15 minutes in DRM links is totalized also in commercial car probe.

Vehicle behavior history can also be acquired from ETC2.0 probe, private probe and commercial car probe data. Occurrence of heavy braking is recorded from change in front and back acceleration in the data, and moreover in ETC2.0, abrupt steering and vibration to the vehicle are recorded from change in right and left acceleration and yaw angle speed.

Although various probe data have been utilized in studies so far, no great difference is seen in type of data to be treated. However, looking at the contents of data in detail, there is different in data acquisition frequency or attributes of the data to be acquired. Therefore, care must be taken for the use of data.

3. CLASSIFICATION OF PROBE DATA RESEARCH BY PERIOD

3.1 Characteristic of Probe Data in Each Period

Figure 1 shows change in data acquisition methods and image of the change in acquisition amount in each period. In the early stage, data obtained by specific devices such as test vehicle or bus probe were mainly used. It was the period when various studies were conducted and methods for utilizing probe data were sought while versatility of the acquisition devices was low and available data were limited.

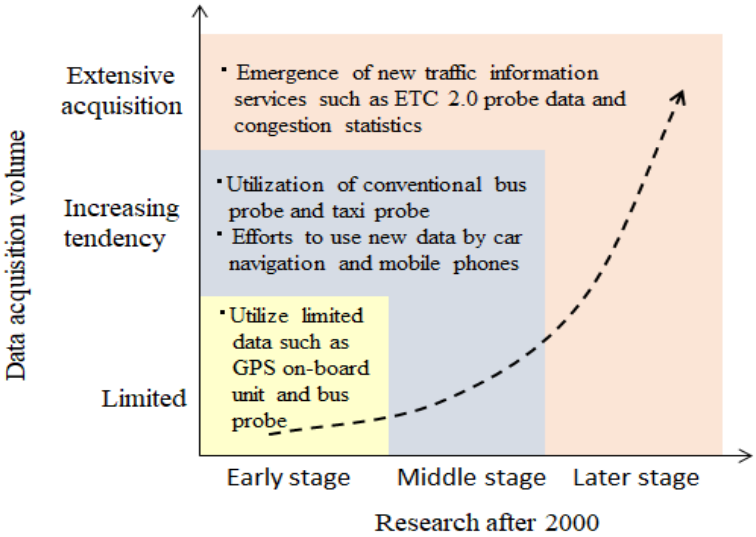

Figure 1. Change in data acquisition methods and image of the change in data acquisition amount

In the middle stage, specific probe data which has been conventionally used were used while an attempt was made for utilization of new data including ETC2.0 probe data and private probe data. Therefore, it was the period when probe data spread in both acquisition and utilization.

In the later stage, data acquisition amount was drastically increased by the spread of car navigation system and smart phones. In this stage, conventional probe data such as bus probes were applied in studies while on the other hand the percentage of studies that used newly appeared probe data was high. One of the factors for the above is that data acquisition amount was largely improved compared with conventional probe data temporally and spatially by evolution of information and communication technology. It is presumed that efforts to work on problems of road traffic based on these data were activated due to increase in data acquisition amount of general traffic.

3.2 Early Stage (2000-2005)

In the early stage, communication equipment such as car navigation had not spread sufficiently to general vehicles and probe information of bus probe, taxi probe and in-vehicle GPS was mainly used. Therefore, a number of fundamental studies were conducted for practical use of probe data.

As a basic study of probe data utilization, Tanaka *et al*. (2002) proposed the map matching method and a method to create velocity data for between intersections and between major points as data conversion to provide vehicle information in real time from information obtained from a probe car. Studies on probe data collection include a study on sample extraction ratio required for road traveling speed survey with a probe car by Ishida *et al*. (2001) and a report on accuracy validation of estimated traffic information by probe data collection frequency and data collection interval required for realizing the accuracy equal to VICS by Yamane *et al*. (2005). Studies on possibility and usability of probe data utilization include a study that confirmed that the use of mobile telephone systems is technically possible for a traffic behavior survey based on the position identifying function of PHS (Asakura *et al*.,2000) and a study that compared probe data analysis results and field study analysis results for through traffic in minor streets and showed possibility and usability of their utilization(Kitamura *et al*.,2003).

In addition, attempts to grasp traffic conditions based on probe and taxi data obtained from route buses include validation of transportation improvement (Ariyoshi *et al*.,2004) and a report on verification of road safety measure effects (Hashiji *et al*.,2003).

Studies on construction of traffic volume estimation models based on probe data and validation of travel time include estimation of dynamic OD movements and path traffic flow (Mitani and Hato, 2004 ; Kurokawa *et al*.,2005), link cost functions and OD travel time estimation (Okada *et al*.,2005 ; Mitani and Hato, 2005) and model analysis for route selection (Miwa and Morikawa, 2004). Taxi probe and probe person data are used for them.

As a study on simulation for which probe data are assumed, (Uesugi *et al*.,2003) verified difference between estimated results of dispersion and expected values of travel time for the whole section using probe trajectories that completely and partially passes the object section. Furthermore, Horiba *et al*. (2005) formulated a method to estimate path traffic volume based on probe car data and data from a vehicle detector, and moreover proposed an error calibration method for accuracy improvement of traffic volume.

In this stage, studies with limited probe data obtained from vehicles, buses and taxis experimentally equipped with GPS were conducted for practical use of the probe technology. Traffic behaviors in data obtained from business operations service such as bus or taxi are unique, and bias that may occur in route information is a concern. Need for probe information of general drivers and collection of more probe data for accuracy improvement is pointed out as a future task (Kurokawa *et al*.,2005).

3.3 Middle Stage (2006-2011)

In the middle stage, studies on taxi probe, bus probe and the probe person data were reported following the early stage.

In this stage, as a study on taxi probe, Miwa *et al*. (2008 ; 2009) attempted to estimate OD movements using observation travel speed considering dispersion of the sample size of each link obtained from a taxi probe in Nagoya area, while they modeled passage frequency in each road link and required sample size and discussed about optimum allocation of a probe car with the maximum information-gathering probability. In addition, Kinuta *et al*. (2008) indicated that objective traffic conditions obtained from probe data are useful for construction plan by a contractor road construction as a model case. They state that drivers' behaviors are more likely to be changed by showing that passage time information of construction point is useful for drivers and it is an important action for the future as one of the traffic congestion measures.

Studies on bus probe include a proposal of a method to estimate general vehicle traveling speed in consideration of bus stop behaviors (Matsunaka *et al*.,2006) and that of a method to estimate travel trajectories of general cars for the purpose of interpolation of general auto probe information for bus routes (Saisyo *et al*.,2011). In addition, validation of time reliability for which bus probe data were used was reported (Uno *et al*.,2006).

Studies that utilized probe person include a study that constructed and verified a dynamic routing model focusing on route choice models of each day (Saitou *et al*.,2010), and a study that examined construction of a fusion type control system for expressways and general roads for which information on time required in real time was reflected (Takiguchi *et al*.,2011).

Conventionally, methods to grasp and estimate traffic conditions have been examined based on behavior data obtained from traveling behaviors of vehicles for specific types of operation such as buses and taxis or from specific monitors. For these methods, bias of samples is a concern as described above and it has also been pointed out that it is necessary to secure sufficient number of samples (Kurokawa *et al*.,2005).

On the other hand, studies using data acquired with communication equipment that was different from conventional one such as cellular phones were conducted with improvement of mobile communication technology and cost reduction as a background in this stage. Specifically, they include studies on route analysis for which GPS of cellular phones was utilized, those on ETC2.0, which is spreading now, and those on utilization of private probe data.

Tanaka *et al*. (2011) focuses on the point that a large quantity of behavior data can be acquired by using GPS functions of cellular phones easily and continuously, and Yokota *et al*. (2011) about described collection of high-frequency probe information by GPS of ta cellular phone and off-line process.

As studies on ETC2.0, Hatanaka *et al*. (2007 ; 2008) performed an experiment for collection of car behavior data under various conditions by road-vehicle-communication with a DSRC road side device and a car navigation system, so as to detect near misses. Furthermore, they performed a data collection experiment for collection for intra- and inter-urban expressways and general arterial roads aiming at practical use of the system and showed that the accumulation distance of car behavior data greatly varied depending on road types. In this stage, studies on road-vehicle-communication based on DSRC mainly were experimental studies aiming at its practical use, and basic studies have lead to utilization of ETC2.0, which is currently spreading.

Studies that utilized probe data provided by car manufacturers include a study that

compared and evaluated running safety before and after the enforcement of road safety measures based on sudden deceleration data (Utsumi *et al*.,2010) and a study that analyzed relationships between traffic accidents and near misses and discussed the possibility of utilizing near miss data for road traffic safety (Nakamura *et al*.,2011).

In the middle period, while the amount of obtainable data is still limited, studies on route selection with GPS data of cellular phones or taxi probe in urban areas were actively conducted, and problems on accuracy of the route choice model based on probe data difference in route selection properties for population were pointed out (Miwa *et al*.,2008 ; Takiguchi *et al*.,2011). In addition, in this stage, among the new data for which the possibility of its utilization was focused, a number of studies particularly on DSRC and private probe data were conducted for grasping car behaviors. Above all, need for discussing the setting of threshold values and indices to detect near misses was pointed out (Hatanaka *et al*.,2007 ; Nakamura *et al*.,2011).

3.4 Later Stage (after 2012)

In the later stage, the number of studies on probe data drastically increased (Figure 2). Moreover, types of probe data to be used, in addition to conventional data, are diversified such as ETC2.0 probe data, private probe data and congestion statistics.

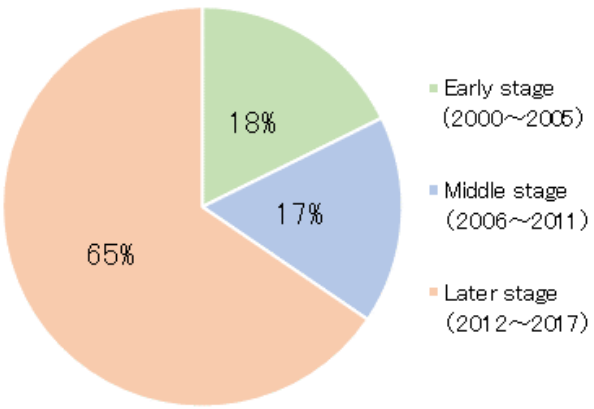

Figure 2. Ratio of researches on probe data in each period (Japan Society of Civil Engineering and Japan Society of Traffic Engineering collections)

From the early stage, studies that utilized taxi probe and bus probe that had been often utilized had also been continuously conducted. Kiyota *et al*. (2014) analyzed the gridlock phenomenon that occurred in Tokyo at the time of the Great East Japan Earthquake Using taxi probe data. In addition, there is a study that extracted travel history of daily service roads from taxi probe data and clarified influence of street properties and roadside properties on traveling speed (Shimizu *et al*.,2012), and a study on interpolation of traffic states of the entire network using a statistical model constructed from probe car data accumulated in the past and partial observation data obtained in real time (Hara *et al*.,2016).

Studies that utilized bus probe data include acquisition of high-definition and highly precise travel trajectory (Zaitsu *et al*.,2013) and analysis of occurrence situation of sudden deceleration (Zaitsu *et al*.,2014). Furthermore, one of the cases that used data from digital tachograph together with bus probe is estimation of travel trajectory of general vehicles and traffic conditions by Sakamoto et al.(2014 ; 2017) and Akabane *et al*.(2016).

In this stage, studies on traffic estimation methods mainly based on experiments by simulation were often seen with the spread of probe functions to general vehicles as a

background. Seo et al. established a traffic state estimation method based on movable body observation by vehicular gap measurement technique and probe cars (Seo *et al*.,2013) and proposed a method to estimate fundamental diagram based on data collected by movable body observation (Seo *et al*.,2016). In addition, studies on grasp of traffic states include proposal of an incident detection method by probe car (Kusakabe *et al*.,2015) and construction of traffic monitoring procedure in consideration of influence of inflow and outflow in sections (For example Kawasaki *et al*.,2016).

In this stage, different plural probe data became able to be utilized and it was pointed out that highly accurate traffic condition analysis based on integration and consolidation with conventional data source such as taxi probe was important (Shimizu *et al*.,2012). About this point, similar problems were pointed out for studies on data obtained by GPS of cellular phones (smart phone) which became able to be utilized after the middle stage and ETC2.0 probe data (Noguchi *et al*.,2014 ; Miyoshi *et al*.,2017).

In recent years, data from GPS such as cellular phones, ETC2.0 and private probe which have been actively utilized in business and research fields enable to acquire larger amount of general vehicle data than conventional data, and are utilized to verify effects of road construction and to grasp bottleneck points. However, they are utilized to grasp traffic conditions to the last, and it is difficult to identify related factors from such data. It must be noted that it is necessary to confirm situations in actual sites to grasp factors for traffic environment improvement and traffic congestion.

In the later stage, studies that use above-mentioned probe data are drastically increasing. These data are heavily used in the field of road traffic service and therefore contents of the studies are summarized according to data type in the following chapter.

4. PROBE DATA OFTEN USED IN RECENT YEARS

4.1 Probe Data by GPS of Cellular Phone

In recent years, utilization of GPS data obtained from hand-held units is expanding accompanied with the rapid spread of smart phones. Here, the contents of the studies for which data (position information) obtained from GPS locator-equipped terminals such as cellular phone are used are summarized by categorizing them mainly into "Basic study on data utilization" and "Study on traffic state and traffic behavior".

Basic studies on data utilization include a study on accuracy of map matching data by GPS positioning data of up to five minutes interval (For example Hara and Kuwahara,2013). In addition, utilization of information obtained from a smart phone for probe person surveys such as person trip survey is also expected, and methods to distinguish transportation from GPS and acceleration sensors have also been studied (Matsushima *et al*.,2015 ; Nakamura *et al*.,2015). In addition, as a study on travel time and speed, there is a study on accuracy of position and seed information obtained from smart phones and grasp of traffic congestion (Watanabe *et al*.,2013).

As a study on traffic behavior, Kii *et al*. (2015) analyzed influence of spatial accuracy and observation period on visiting frequency distribution parameter using probe data acquired by GPS for years, and discussed measures required for a modal shift plan suggested by the traffic behavior model and visiting frequency distribution. In addition, Sasaki *et al*. (2015) built up the Metropolitan expressway usage judgment logic for the purpose of grasping usage status of the Metropolitan expressway way. They verified the logic through data extract from the data obtained from a traveling status survey while the verified validity of the extraction

volume by comparing transitions according to time zones for the estimated number of vehicles that used the Metropolitan expressway and spot traffic volume obtained by vehicle detectors based on the logic. Based on the verification result, they pointed out sophistication in grasping usage trend such improvement of statistical accuracy by expansion of population by referring to various probe data such as ETC2.0 or private probe, as a future development for grasping the usage trend of the Metropolitan expressway express way.

In addition, Noguchi *et al*. (2014) attempted to establish a method to extract car OD based on "congestion statistics", and verified the method in a local region where the influence of vehicle sharing rate is small (Hama-dori district, Fukushima pref.) and an urban area for which the influence of vehicle sharing rate was considered (Hiroshima urban area) as a case study. The verification in Hama-dori district, Fukushima prefecture revealed that the trip number by the proposed method was smaller than that by the existing OD, and that OD lists similar to the existing OD can be estimated by using scaling factors according to distance zones. In addition, the verification in the Hiroshima urban area showed that both the trip number and spot traffic volume were highly correlated with the existing OD and the proposed method. On the other hand, for their application to traffic volume estimation, either verification pointed out influence by convenience of public transport, indicating problems on methods to extract car OD only by probe data.

From the above, based on the fact that utilization of probe data obtained from GPS of cellular phone terminals is planned for both business and research fields, further effective utilization of probe data can be expected by sophistication of technique for transportation judgment and integration of probe data by plural smart phone applications.

4.2 ETC2.0 Probe Data

ETC2.0 service has been offered with road side devices for ETC2.0 (ITS spot) at approximately 1,600 spots mainly on an express highway since 2011, and traveling histories such as routing information or speed information of vehicles equipped with ETC2.0 are collected together with provision of the above service. They have been effectively utilized for grasping road traffic conditions and developing various measures for road traffic. Makino *et al*. (2017) described their properties and utilization plan in detail.

For road side devices that perform road-vehicle-communication with vehicles running on the road, Kanazawa and Tanaka (2013) described effective ITS spots according to the need of road administrators from the viewpoint of probe data utilization in a traveling speed survey. At existing ITS spots, the maximum cover range that enables to acquire probe data is calculated, the range that satisfies data sample size required in a travel speed survey is identified, and a cover rate is calculated. In addition, a cover range in which required probe data are obtained is set for general roads, with an assumption that ITS spots are installed in the center (government office) of the city, ward, town and village. Based on requirements by road administrators, the above review schematically shows additional arrangement of ITS spots that enable to grasp traveling speed in arterial roads more than the roads for the road traffic census, in addition to expressways. Moreover, Suzuki *et al*. (2014) calculated the present conditions and grasp level of traffic path at the time of additional arrangement of road side devices using the index "path-acquirable road ratio " based on special vehicle passage permission data for the purpose of grasping traffic path of special vehicles. As a result, they revealed that the present path grasp level is insufficient, and that the grasp level of the traffic path does not greatly improve for arrangement at over 900 spots in the event that road side devices are additionally located on a national highway.

ETC2.0 probe data have a characteristic that routing information is acquired by vehicle

traveling trajectories, and there are plural studies that focus on route information. For example, for methods to collate estimated traveling paths created by probe data collected from ITS spots and specified traveling paths created by permit data by a special vehicle passage system, Suzuki *et al*. (2015) compared and verified plural methods using probe data of an experimental vehicle, and calculated "violating travel motion extraction ratio" for extraction of vehicles violating permit requirements and "accurate judgment rate" that indicates accuracy of violation judgment. Hirai *et al*. (2017) studied methods to construct database of trip behaviors including break behaviors of individual vehicles using traveling history information of ETC2.0 probe data. They grasped properties of traveling history information and quantitative break behaviors when extracting break behaviors while they summarized findings of points for the use of ETC2.0 probe data such as bias of car configuration (bias to passenger car), non-production of trip for plural days and so on through a basic analysis. Further, Miyoshi *et al*. (2017) analyzed time of stay at parking area in expressways for break behaviors for which ETC2.0 probe data were utilized.

Studies on the use of ETC2.0 probe data other than routing information include verification of road construction effect, factor analysis of speed deterioration, grasp of traffic congestion passing time and so on. For example, Narushima *et al*. (2017) and Kasai *et al*. (2017) analyzed velocity turbulence conditions and factors for two provisional lane sections using rate data obtained from ETC2.0 and traffic volume obtained from a traffic counter, while they examined transportation service using the indices of tracking hour rate and following vehicle density for two provisional lane sections on Joban Expressway.

For utilization of ETC2.0 probe data, compatible instruments are spreading and the possibility of bias occurring in car models and component percentages according to time zones has been pointed out (Kasai *et al*.,2017), and improvement of diffusion rate of compatible instruments is expected as a future task. In addition, one of the factors is that a number of studies target traffic in expressways, and road-vehicle-communication service on expressways as ITS spots was preceded, we presume.

In recent years, maintenance of road side devices to acquire travel motion data is advancing on national highways, and it is expected that studies on for general roads increase. In particular, since route selections are more various on general roads than on expressway s and traveling paths are complicated by intersections on general roads, the route selection behaviors in general roads can be one of the new study fields.

Moreover, for ETC2.0 probe data, traffic behaviors analyzed by combination with other probe data for the purpose of interpolating car models and time zones have not been reported so far , and therefore they need to be considered in the future, we presume. In addition, as a fundamental problem on utilization of ETC2.0 probe data, road traffic information collection, physical distribution vehicle support, consideration of road side device spots conformed to the service and of effective additional device spots (Kanazawa *et al*.,2013), judgment of traveling route information, handling of trip of plural days and data cleansing (Hirai *et al*.,2017) were pointed out.

4.3 Private Probe Data

One of the characteristics of private probe data is that travel time (speed) and rapid deceleration behavior data are obtainable. Studies on travel time (speed), temporal reliability and traffic safety are conducted by utilizing these data mainly through case studies in practical fields.

Suzuki *et al*. (2013) examined simplified predictive formulas for travel speed according to time zones based on private probe data and traffic data of road traffic census while they

calculated travel speed according to time zones and construction effects through case studies. The calculation result shows that the applicability to road construction impact analysis by the simplified predictive formulas is high.

As a study on intersection with traffic congestion, Jinno *et al*. (2013) proposed a demanded traffic volume estimation method based on travel rate data and traffic data and set evaluation sections for the cases of single bottleneck measures and continuous bottleneck measures. Moreover, Hashimoto *et al*. (2014) proposed a method to identify a bottleneck intersection as an origin of traffic congestion and its impact range using relations of traffic congestion and non-traffic congestion between highway sections. Results of verification of the proposed method for the major traffic congestion spots that were selected in practice revealed that bottleneck intersections and area influenced by them were grasped by the method.

As a study on temporal reliability, Sekiya *et al*. (2014) created sample data set with the assumption that probe data were not acquired virtually, using probe data that were actually observed, and analyzed differences between sampled values and true values for travel time reliability index calculated from them. For the analysis, among the OD sections comprised of plural DRM sections, two sections whose dispersion of travel time was small and great were analyzed, and the number of days of acquiring probe data required to calculate a travel time reliability index with constant reliability was compared. Their results revealed that the number of days for acquiring required data was large for the section with great travel time dispersion and that the required number of days for data acquisition increases with an increase in length of the data-missing section. Moreover, it was found that the ratio of the required number of days for data acquisition (number of days for data acquisition / for number of days for evaluation) almost decreases with an increase in the number of days for evaluation.

Studies using data of sudden deceleration behaviors include the cases that they are used as an index for grasp of the current status of traffic safety and for effect measurement in road construction service. For example, Kikuchi *et al*. (2012) proposed the number of times of sudden deceleration behavior occurred and speed and deceleration at the time of sudden deceleration occurred as an index that enables collection of a large quantity of data in the short term and instantaneous effect measurement compared with the conventional evaluation based on casualty accident rate, and presented expression of effects of the measures with road safety measures service as an example.

Moreover, Oyanagi *et al*. (2014) analyzed risks at local intersections using traffic accident data and data of sudden deceleration behaviors. They compared analysis results according to formation processes of the intersections, and showed that the number of accident occurrence and the number of times of sudden deceleration are large at intersections formed by daily service roads divided by formation of arterial roads and their widening, indicating that process of the intersection formation influenced the risk of the accident occurrence.

The above findings suggest that most of the studies that utilized private probe data were not of estimation of OD and traffic states based on taxi probes, but were of practical approaches such as effect measurements accompanied with road construction or grasp of traffic congestion conditions and accident risks.

5. CONCLUSION

Among a number of studies on probe data, this report targeted studies published in journal, and classified them by generation according to the type of probe data that have become the base of various studies, and reviewed their contents. As a result, the studies that utilized probe data are further categorized into the following themes.

1) Theme 1: Basic study on probe data utilization ... Studies on placement of road side devices
2) Theme 2: Study on travel time (speed) ... Evaluations of temporal reliability
3) Theme 3: Study on traffic state and traffic behavior ... Grasp of traffic flow rate and density, estimation of OD and so on
4) Theme 4: Study on route analysis ... Grasp of through traffic in minor street
5) Theme 5: Study on road safety ... Effect verification of road safety measures by grasp of sudden deceleration behavior

Figure -3 shows summarizes type and utilization theme of probe data utilized during each period. In the early stage of probe data studies, fundamental studies for probe data utilization using specific probe data such as taxi probe, bus probe, in-vehicle GPS and so on (Theme 1), travel time (speed) (Theme 2), and traffic state and traffic behaviors (Theme 3) were mainly conducted. In this stage, problems due to bias of data attribute and need of collection of information on general drivers were pointed out. These problems were greatly improved by improvement of functions smart phones or car navigation systems after the later stage and spread of them.

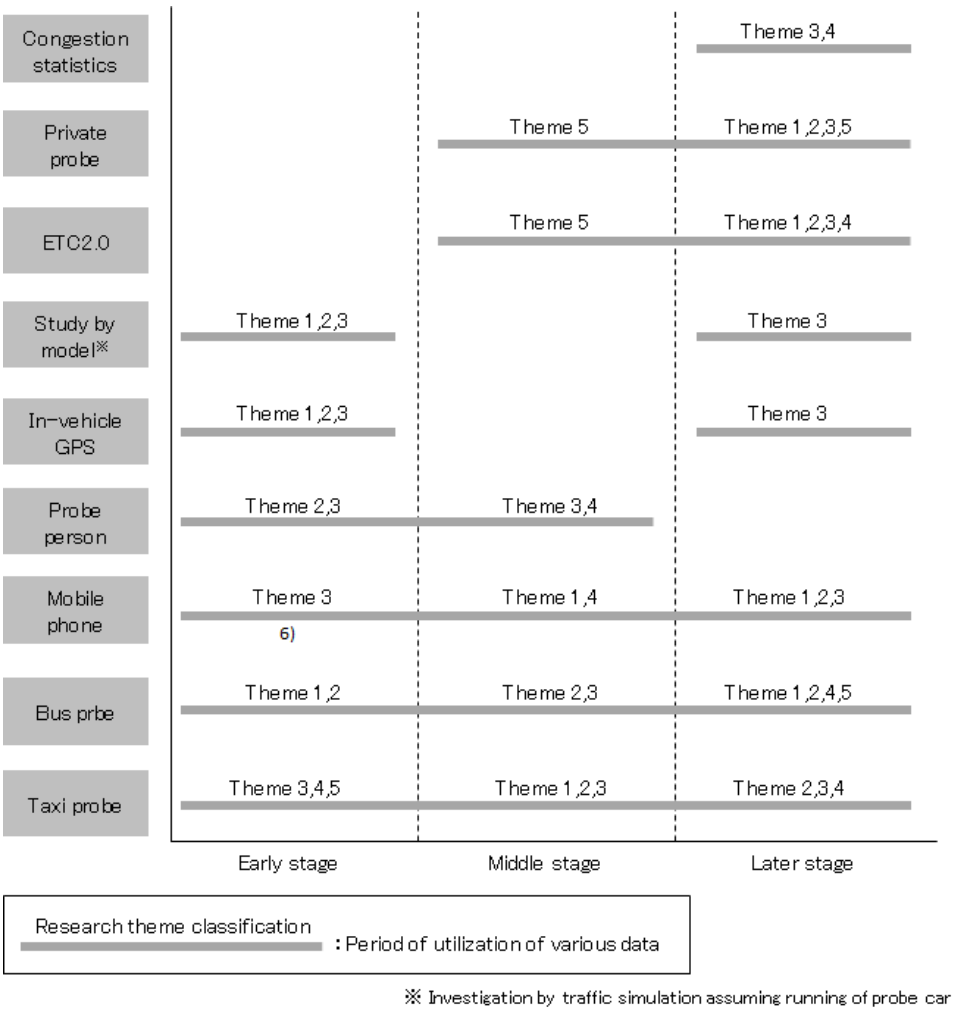

Figure 3. Type and utilization theme of probe data utilized during each period

In the middle stage, studies mainly on Theme 3 utilizing taxi probe and a bus probe were actively conducted following the early stage. Moreover, studies with ETC2.0 probe data

and private probe data were conducted as a new study in this stage. The possibility of utilization of these probe data is continuously studied even now while utilization of new probe data with smart phones has also been studied.

From the middle to the later stages, studies on route analysis and road safety (Themes 4 and 5) utilizing ETC2.0 probe data and private probe data that are spreading for the purpose of grasping actual situations of road traffic were reported. Moreover, studies on GPS information obtained from hand-held units such as smart phones whose users suddenly increased were also conducted. Bias of probe data attributes and problems due to limitation of the number of the data pointed out in the early and middle stages were possibly improved by the above researches.

On the other hand, for utilization of probe data such as GPS with mobile terminal, ETC2.0 and private probe, which are currently spreading, need of improvement in statistical accuracy by information interpolation among probe data was pointed out (Noguchi *et al*.,2014 ; Miyoshi *et al*.,2017 ; Sasaki *et al*.,2015). Since data volume to be acquired is limited in rural areas in particular compared with urban areas, improvement in the number of data acquisition in rural areas is one of the important tasks for planning development of probe data utilization.

In recent years, construction of a real-time transportation forecasting model has been attempted by data acquired by plural media and those acquired by a loop detector for the purpose of improving accuracy and reducing vagueness of data (Nantes,A., *et al*.,2016). However, there have been only few studies on combination of different probe data. For discussing grasp of realistic road traffic conditions and route selection in general roads, it will be necessary to examine validity of analysis of traffic behavior by combination of different probe data and data from a vehicle detector.

The important role of probe data studies is to realize labor saving in practice through effective grasp of traffic conditions and expansion of acquisition amount for it. Therefore, it is needed to deepen studies on utilization of probe data continuously for grasp of traffic conditions, as well as to simplify analyses of collected data. Moreover, for expansion of acquisition amount, since acquisition of probe data is originally passive, it would be difficult to acquire data actively from the viewpoint of privacy. On the other hand, effective plans for utilization of acquisition data have been presented in various recent studies, and therefore we will consider to aim at active utilization of these data for grasping high resolution traffic conditions.

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