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THE FACTORS DETERMINING RELIABILITY OF TRAVEL SPEED ESTIMATION BASED ON LBS

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Abstract: The objective of this research is to develop techniques for travel speed estimation of main roads using GPS and Mobile (mobile phone) data collected from probe vehicles. To this end, a methodology for travel speed estimation need to be developed first and the reliability of the estimated travel speed in terms of accuracy need to be evaluated.
The coordinate of a mobile location means the location of the base station and not that of the actual probe vehicle. Therefore, erroneous coordinates of the mobile location may result in inaccuracies in the estimation of travel speed based on LBS.
The factors determining the reliability of travel speed using LBS are the number of base station, the distance between nearby base stations, the coverage of base station, and the data collection time interval. To estimate a stable travel speed, the base station network should be dense, that is, the base stations should be close together and its coverage should be dense. It needs to collect data for the estimation speed through detailed data collection time and at reasonably long data update time interval.

Key Words: LBS(Location Based Service), Travel speed, Reliability, Base station, Polling time

1. INTRODUCTION

1.1 Background And Purpose

Traditionally, beacons and detectors were used for creating transportation information and measurement of travel speed for ITS. But these methods have weak points in that it is difficult to enlarge the application scope, and the cost to build and maintain the total system is expensive. Therefore in this study, a method of using mobile phone base station location information and mobile information as an alternative to the traditional transportation information system is proposed.

Especially, since there are 3.5 million mobile phone subscribers in Korea, there is sufficient infrastructure to use mobile information such as GPS location and that of base station for creating transportation information such as travel time and travel speed.

The main objective of this research is to analyze the factors determining the reliability of travel speed in order to construct a methodology for the estimation of travel speed based on LBS, and consequently to enhance the estimation process to be more economical and accurate.

1.2 Scope And Methodology

In this paper, we present a methodology for travel speed estimation based on LBS. The travel speed estimation method that utilizes mobile phone base station location information and GPS location information assumes travel speed using GPS as the true value and the travel speed using mobile base station information as observed value. In connection therewith, we validated statistically the significance of travel speed based on mobile base information.

The travel speed verification result applies field data based on the factor analysis that determine travel speed reliability. As the reliability of the travel speed describes the error ratio of the travel speed, it is essential that the reliability of the travel speed estimation be validated through the factor analysis and relation analysis between error and travel speed. Therefore, first, we reviewed the existing methodology of travel speed estimation and the results of the existing study on GPS and mobile base station location information.

In this research, we used probe vehicles for data collection, model development and model validation, collected field data matching on GIS map (map-matching), and derived the minimum distance on the shortest path by applying Dijkstra algorithm. With this travel distance and travel time obtained through the above methods, we calculated the travel speed of each link of the 6 main arterial corridors of Cheongju city and validated statistical the stability and reliability through tests.

1.3 Organization Of This Paper

This remainder of this paper is organized as follows. Chapter 2 provides a review of the results of the existing study on GPS and mobile base station location information and methodology and analyzes the issue. Chapter 3 describes the methodology on travel speed estimation based on LBS and provides a theoretical model equation for travel speed, data

collection and GIS DB construction. Chapter 4 describes the model development results and validation results. Chapter 5 analyzes the factors determining the reliability of the travel speed. Lastly, Chapter 6 presents the conclusions, discusses about the factors determining reliability of the travel speed estimation and future prospects of this research and presents related topics for future research.

2. LITERATURE REVIEW

2.1 Current Status On The Technical Development Using GPS Information

Quiroga and Bullock (1998, 1999) presented a method for estimating travel time and travel speed using GPS information data and carried out related field experiments. The results showed trade offs between sampling ratio and the reliability of the section speed and expressed the change in the travel speed in time-space diagram through a mono vehicle trajectory.

Lee Na Kyung (2002), through the research performed in Japan Hukui city on the applicability of the traffic survey where handy GPS receiver was used, showed that the traffic survey data were very accurate and that it can be sufficiently applied in practice.

Meaker and Horner (2004) used a probe vehicle that was attached to GPS equipments and showed similarities between the GPS speed data and that obtained from loop detectors.

2.2 Current Status On The Technical Development Using Mobile Information

Yim and Cayford (2002) conducted studies on the methodology for collecting transportation information using GPS/Mobile information. After matching the location information on the GIS map, the routes were determined and the travel speed for each road section was calculated. They demonstrated that the location information must be accurate for the transportation information system to operate efficiently and further reported that although mobile phone tracking can be expected to be of valuable use, more extensive researches will need to be done to achieve high quality travel time data creation.

Lee Chang Jin (2002) used mobile base station data to calculate the travel speed for the urban highway area and compared this result with the result obtained through GPS. Upon examining the data which were collected after every 5 minutes, they found that the average speed data for a period of about 15 minutes showed true value of above 80%.

Cayford and Johnson(2003) analyzed all factors that are known to affect the accuracy of the creation of transportation information using mobile phone. They reported that the most important factor is the accuracy of the location, measurement interval, the number of the survey spot, etc.

Based on the researches above, the technical development on the creation of transportation information using GPS and mobile information is still in the initial stages. Many researches on the practicality and scope of application of the technology are currently in progress.

With respect to creating transportation information using mobile phones, GPS data were used to compare and verify research results. However, a majority of the cases, data which were collected separately by the researchers for their research purpose were used and only a few researches had been conducted using travel information that are general in scope. Especially, as there have only been a few research performed on the calculation of travel time on city networks using mobile information, the main focus of this study is to find successfully estimate travel speed using GPS/Mobile information data. As the ultimate objective is to be able to estimate the travel speed based on mobile information data, we analyzed and presented herein the various factors needed to accurately estimate travel speed.

3. METHODOLOGY OF THE TRAVEL SPEED ESTIMATION

3.1 Travel Speed Estimation

The methodology for travel speed estimation based on LBS is illustrated in Figure 1 below.

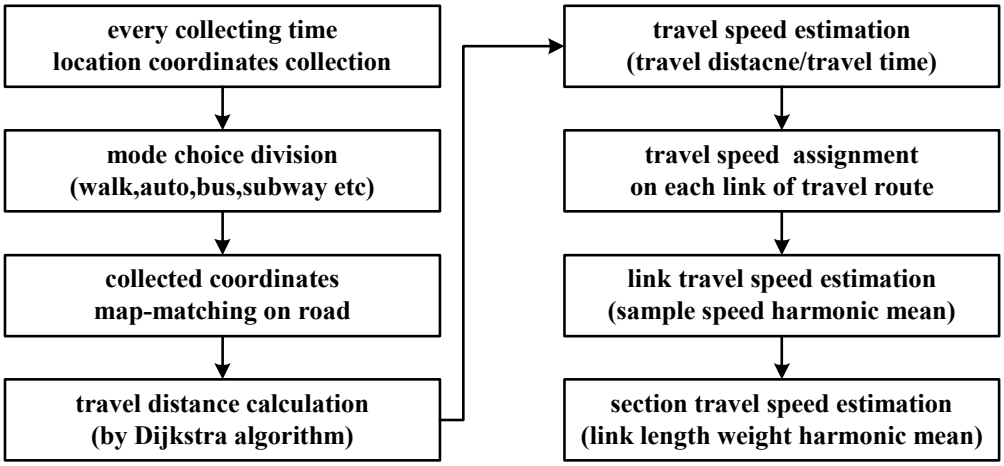

Figure 1. The Methodology of The Travel Speed Estimation

First, field data is collected using GPS/Mobile location coordinates data at each collecting time. The collected data are the classified according to the choice mode by applying the rule-based algorithm. Then, map-matching is performed using the collected coordinates on a road map. After map-matching, travel distance is calculated by applying travel route to Dijksta algorithm. The travel distance and travel time obtained above can then be used to estimate travel speed. Estimated speed is assigned to each link on the travel route. We can find the link travel speed which is the harmonic mean of the sample speed. With this link speed, we can calculate section travel speed by link length weighted harmonic mean.

From the methodology of the travel speed estimation, it is expected that two steps - map-matching of the location coordinates, and the shortest path searching and finding stage - affect the accuracy of the travel speed estimation.

Map-matching is a process of correcting any discrepancy between the GPS or base station location coordinates and the actual road. As GPS normally shows discrepancies of not more than 10 meters or even greater depending on the width of the road, a map-matching is

essential to correct such errors. However, in the case of mobile phone base stations, the base station is not located on the road but on building roofs or mountains. Because of this, map-matching is used to link the base station location to the corresponding road on the map in order to estimate the speed of the vehicle. Therefore, utilizing an appropriate map-matching shall be the key to correct the coordinate for travel speed estimation.

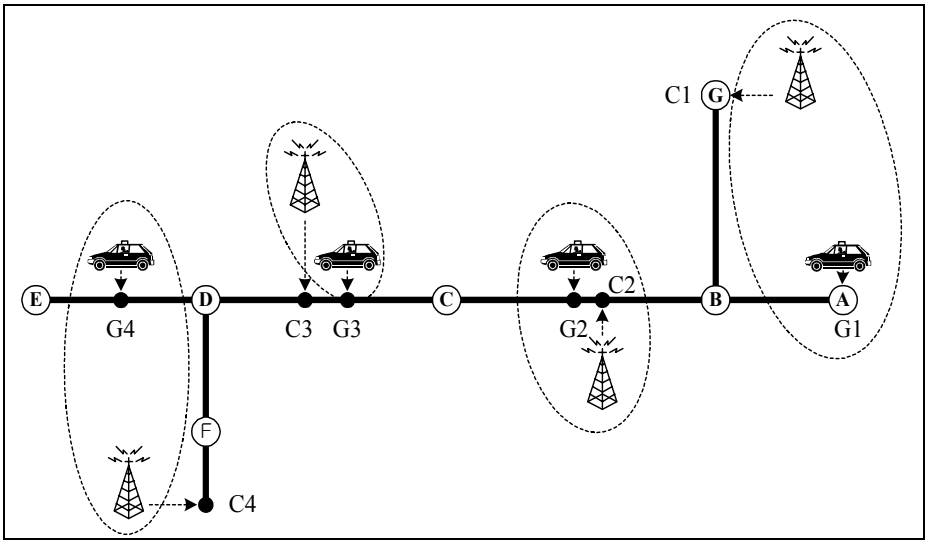

Figure 2. Map Matching on GPS Location and Mobile Base Station Location

From Figure 2, the location of the actual GPS probe vehicle is from G1 heading towards G4, but the mobile phone base station location of that probe vehicle is matched from C1 to C4 through map-matching. From the map-matching results, the mobile path can be seen to be from C1 - B - C2 - C3 - D- C4. The travel speed estimation based on mobile base station information takes into account some degree of error.

With respect to finding the shortest path between two points, there are various algorithms that can be used for tracking location coordinates travel path. After finding the shortest path between two points, it can be divided by the time interval to obtain the average travel speed between the two points. This travel speed is assigned to the moving path between the two points.

The harmonic mean of speed at each link can be used to calculate the space average speed of each link.

The equation of the link travel speed can be expressed as follows:

$$\overline{u}_i = \frac{1}{\frac{1}{n}\sum_{j=1}^{n}\frac{1}{u_{ij}}} \tag{1}$$

where u_{ij} : the j th vehicle speed on the i th link

$\overline{u}_i$: the representative speed of i th link

For the estimation of link travel time, the link travel time and the link travel distance need to be calculated. For the data collecting time, the vehicle shows the origin and destination. This information is used to estimate the passed route using the Dijkstra algorithm. First, it shows travel time. Second, the total link distance can be calculated by summing total link showing on GIS map. This time and distance can be used to calculate the travel speed. It is assumed that this travel speed is assigned to all the links that have the estimated same routes. This each link travel speed used to calculate the representative link travel speed.

Route guidance or travel speed (travel time) guidance should provide specific origin-destination route information rather than a single link information. In this case, when it produces the representative speed of the each link from link speed, we can calculate main O/D section travel speed by link length weighted harmonic mean.

The equation of the O/D section travel speed is as follows:

$$\bar{u}_L = \frac{L_T}{\sum_{i=1}^{n} \bar{t}_i} = \frac{L_T}{\sum_{i=1}^{n} \left[\frac{L_i}{\bar{u}_i} \right]} = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} \left[\frac{L_i}{\bar{u}_i} \right]} \tag{2}$$

where $\bar{u}_L$: the representative speed of the total section
L_T : the length of the total section
L_i : the length of i th link
$\bar{t}_i$: the travel time of i th link
$\bar{u}_i$: the representative speed of i th link

3.2 Field Data Collection

This ultimate objective of this study is to create transportation information such as travel speed and travel time by using mobile phone information only. So, we used taxies, which is installed with both GPS and mobile phone, as a probe vehicle for data collection, model verification and model validation. Normally, data is collected after every 2 min., but in the case where the taxi has passengers are on board, data is collected after every 5 min.

The used data were collected for one month period from January 13th, 2004 until February 12th, 2004. They are the location information of the Daejeon metropolitan area that includes Cheongju city, Cheongwon county, and Daejeon city. The data contained coordinates pair of total 306,548 things (GPS coordinate and mobile phone base station coordinate), among which the coordinates data corresponded to Cheongju city were 67,564 pairs. The Cheongju data were reflected in this research.

3.3 Construction Of GIS DB

To create transportation information, a digital map (GIS map) that shows road characteristics such as node, link, turn penalty, etc, is essential. Cheongju city digital map is the transportation map that provided KTDB(Korea Transportation Data Base) .

GPS location coordinates can be expressed on the KTDB transportation map through the ArcGIS as follows. It can be seen that the GPS location coordinates are distributed according to the road link as shown below.

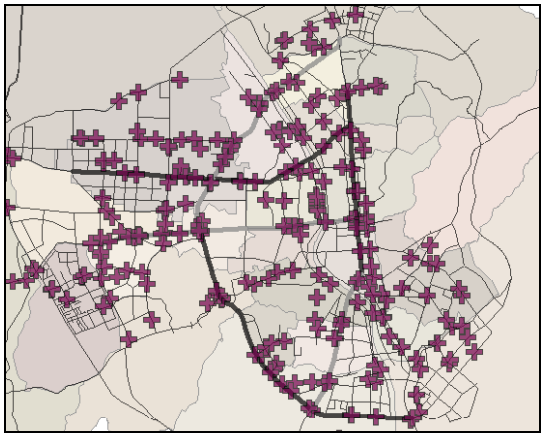

Figure 3. Distribution of the GPS Location Coordinates

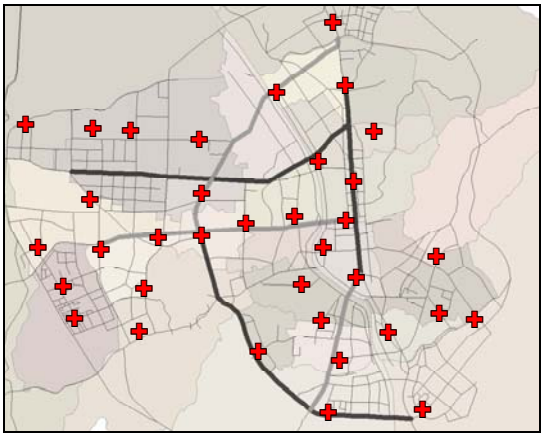

Figure 4. Distribution of the Mobile Base Station Location Coordinates

The distribution of the mobile phone base station location is as shown in the figure 4. It is confirmed that there exists a total of 39 mobile base stations in Cheongju city. Mobile data provided by a specific mobile(mobile phone) company .

At this time, the number of coordinates in Figures 3 and 4 are the same, but as only the location of the mobile base station were known, the base station locations are overlapping. This can be a fundamental cause of errors occurring in the calculation of the travel speed using GPS location and mobile location. This is because GPS map-matching as shown in Figure 2 may differ from mobile location map-matching.

Although it is possible to compare and validate the model based on GPS/Mobile data, the use of mobile coordinates information requires care to be taken during the map-matching process because mobile coordinates information do not match with the link on the road, and also, the travel speed estimation result will need to be validated.

4.TRAVEL SPEED ESTIMATION AND VALIDATION

4.1 Subject Road For Travel Speed Estimation

For the travel speed estimation that use real operation LBS data, 6 main arterial corridors were selected: Bukbu uhoi-ro (northern bypass road), Nambu uhoi-ro(southern bypass road), Hungduk-ro, Sajik-ro, Sangdang-ro, and Chungnam-ro.

4.2 Map Matching And Calculation Of Travel Distance

There are various map-matching techniques that can be used to match the GPS/mobile coordinates with the corresponding roads. In this study, we use the nearest link map-matching

that coordinates matched to the nearest link. In the case of the move between the two points continuously over a period of time, the shortest travel distance was calculated by applying Dijkstra algorithm.

4.3 Accuracy Analysis Of GPS/Mobile Base Station Coordinates

The mobile location coordinates represent but the base station location that serve the mobile phone service area, but not the mobile location (probe vehicle location). In case of the mobile, this may cause significant error due to base station coverage area. This error can influence the accuracy of the travel speed estimation depending on the mobile base station location.

Although in the case of GPS, the road center line has numerous meter location error, it can be regarded as a true value as it shows the actual location coordinate. Comparing the difference between GPS location and mobile location of coordinate, we found that the difference of mobiles base station location and GPS location show on average an error of about 300m to 600m in CBD area. In the sub-CDB and suburban area, farther from the city center, the error of degree is higher. It is analyzed that there were the maximum 2000m distances error in the outside area. The average value of the mobile phone coordinate error was found to fall within 500meters. This is the result of a specific mobile phone number 0XX, thus in further studies, we will need conduct whole other mobile phone number service, using the same method.

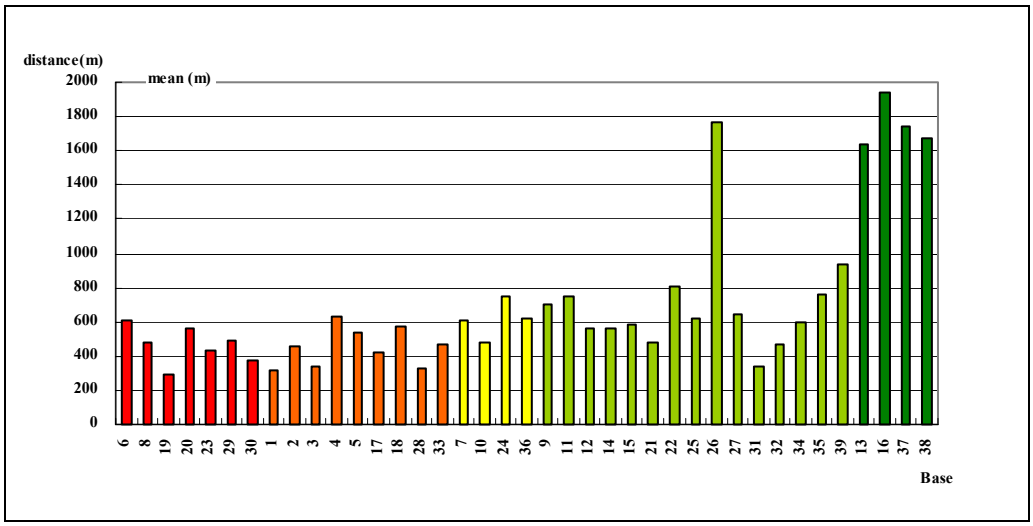

Figure 5. Mean of the Error Mobile Base Station Location Coordinates

4.4 Travel Speed Estimation And Comparison

Using equation 1, we calculated the travel speed per link. In addition, to verify the accuracy of the mobile-based travel speed estimation results, a GPS location based on travel speed was taken as the true value and used for conducting a statistical analysis. The travel speed estimate every time band per each link based on GPS and mobile data.

We used statistical method and compared the GPS based travel speed and the mobile based travel speed by applying the paired t-test and F-test. The mean identity is confirmed from the t-test results, and the variance identity is confirmed from the F-test results.

The statistics results on the comparison of the travel speed estimation are shown in the figure below. The black link means that there is no significant difference between GPS-based travel speed and mobile-based travel speed. That is, the two travel speeds are similar to each other. However there are some different links and missing links due to the lack of the data.

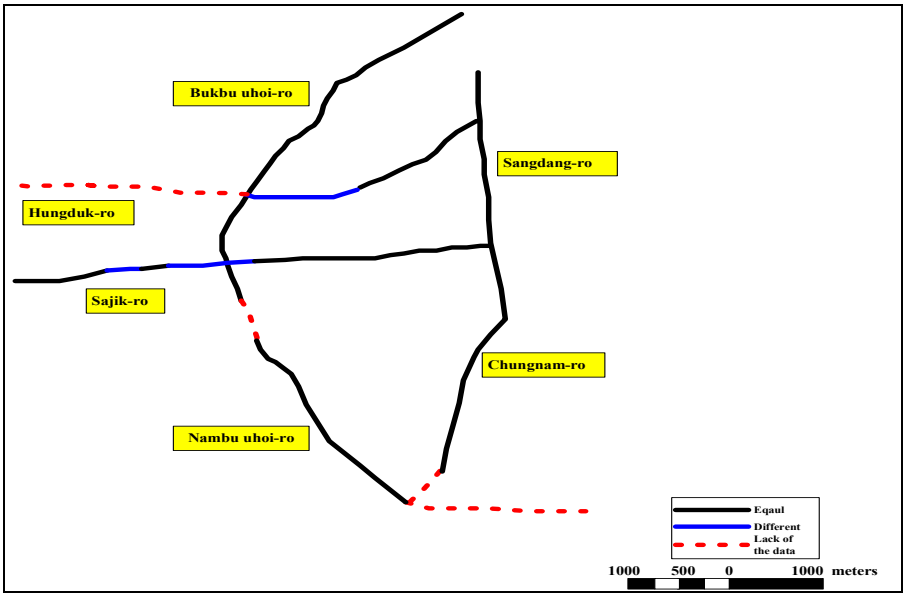

Figure 6. Travel Speed Comparison Result

Each link is composed of 6 corridors. Each corridor is divided in 2 - 3 segments. The section speed calculates the link length weighted harmonic mean. The section speed is shown in the table below. The comparison results of the section travel speeds show that there are no significant differences between the two travel speeds.

Table 1. Travel Speed on 6 Corridors Sections

Corridor	Section	Link	Up bound			Down bound		
			GPS (kph)	Mobile (kph)	MAPE (%)	GPS (kph)	Mobile (kph)	MAPE (%)
Nambu uhoi-ro	1	1~11	23.8	56.3	137.0%	25.5	38.1	49.7%
	2	12~18	33.9	31.2	7.9%	-	37.0	-
Bukbu uhoi-ro	1	1~13	25.0	29.3	16.9%	17.7	26.0	47.0%
	2	14~15	14.5	12.4	14.0%	24.0	16.8	30.1%
Sajik-ro	1	1~10	23.5	24.7	5.1%	20.9	24.6	17.5%
	2	11~15	16.1	31.4	94.7%	20.6	27.1	31.3%
Sangdang-ro	1	1~2	25.4	31.8	25.2%	21.4	27.4	28.2%
	2	3~9	22.4	24.2	7.7%	23.0	30.1	31.2%
	3	10~13	14.3	22.2	55.9%	28.2	31.9	13.2%
Chungnam-ro	1	1~8	18.2	25.3	38.7%	21.0	28.3	35.0%
Hungduk-ro	1	1~8	20.6	32.2	56.7%	19.3	32.7	69.5%
	2	9~18	19.5	-	-	25.4	39.0	53.6%

As a result, it is validated that the results of the new methodology is similar to that of existing speed survey. Therefore, the proposed travel speed estimation methodology can be applied as a speed estimation method. That is, the travel speed estimation is possible based on mobile data on the arterial.

5. ANALYSIS OF FACTORS DETERMINING TRAVEL SPEED RELIABILITY

5.1 Basic Assumption

The fact that there is no significant difference between the travel speed obtained from mobile base station and that obtained from GPS are similar was validated statistically. But, creation transportation information also requires that the travel speed based on LBS is reliable. Reliability of travel speed means that the estimated travel speed should be identical to the true value of the travel speed, and that the error between the GPS based travel speed and the estimated travel speed obtained from mobile. The error of the travel speed should be distributed expectable range. To judge the accuracy of travel speed, the error of LBS-based travel speed need to be calculated, assuming that GPS-based travel speed is a true value. The lower the travel speed error ratio is, the higher the stability of the travel speed is. To reduce speed error, we analyzed the factors affecting speed error, based on which the cause of the error should be eliminated to ensure speed stability.

From the methodology of the travel speed, it is expected that two steps - map-matching of the location coordinates, the shortest path searching and finding stage - affect the accuracy of the travel speed estimation. This is because the travel time and travel distance are normally calculated through map-matching and by searching process. And the accuracy of the mobile location affects the accuracy of travel speed.

The mobile location coordinates determined based on the distribution of the mobile base station and base station service characteristics. The base station coverage shape is not uniform and neither is the coverage distribution. Sometimes the mobile phone company served for the call quality used the near base station. This also suggests that these characteristics of base station location information affect the accuracy the travel speed estimation.

Due to the map-matching techniques, it is different to base station location information. According map-matching method it is decided the accuracy of travel speed estimation. And used digital map is important. The accuracy of the map affects the estimated link length.

However, this study is focused on the factors determining the reliability of travel speed estimation. When this methodology of travel speed estimation applied, the results of the estimated travel speed are analyzed. The analysis of relationship travel speed and error between GPS speed and mobile speed shows that if travel distance is longer, passing base station location data is increased, and travel speed error is smaller.

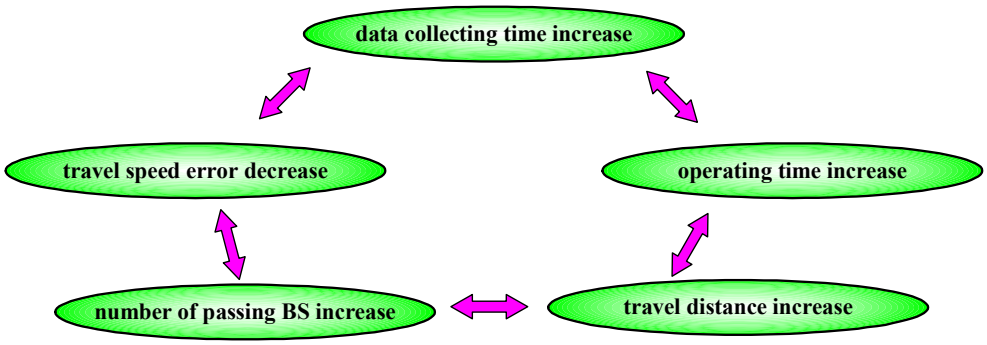

Figure 7. Relationship between Factors Determine Travel Speed Error

5.2 Relationship Between Travel Distance And Travel Speed Error

In this section, we shall attempt to explain the reliability of travel speed in terms of travel speed error. The travel speed error is calculated by setting GPS based speed as the true value and the mobile based speed as the observed value.

The travel speed error is expressed as MAPE(Mean Absolute Percent Error) as follows:

$$\text{error ratio} = \left| \frac{\text{mobile speed} - GPS\ \text{speed}}{GPS\ \text{speed}} \right| \times 100 \tag{3}$$

The relationship between travel distance and travel speed error is shown in the Figure 8 below.

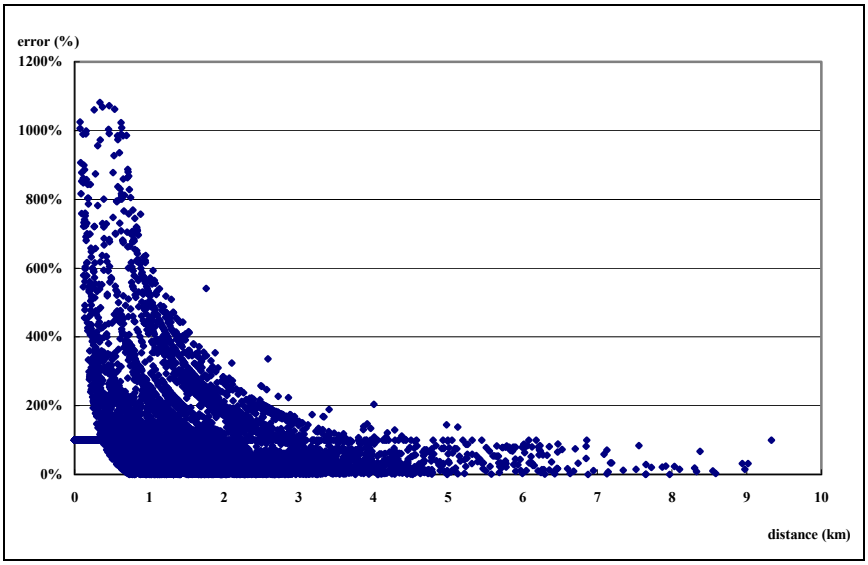

Figure 8. Relationship between Travel Distance and Travel Speed Error

This figure shows that as travel distance increases, travel speed error decreases, which means that travel distance and travel speed error have a reverse (-) relationship with one another. When the error is 100%, the mobile-based speed is 0 and GPS-based speed has some certain value.

5.3 Relationship Between Travel Speed And Travel Speed Error

The relationship between travel speed and the travel speed error is shown in Figure 9 below. This figure shows that as travel speed increases and travel distance increases, travel speed error decreases, which means that travel distance and travel speed error have a reverse (-) relationship with one another. When the error is 100%, the mobile-based speed is 0 and GPS-based speed has some certain value.

Since the relationship between travel distance and travel speed is proportional to one another, Figures 8 and 9 show similar shapes.

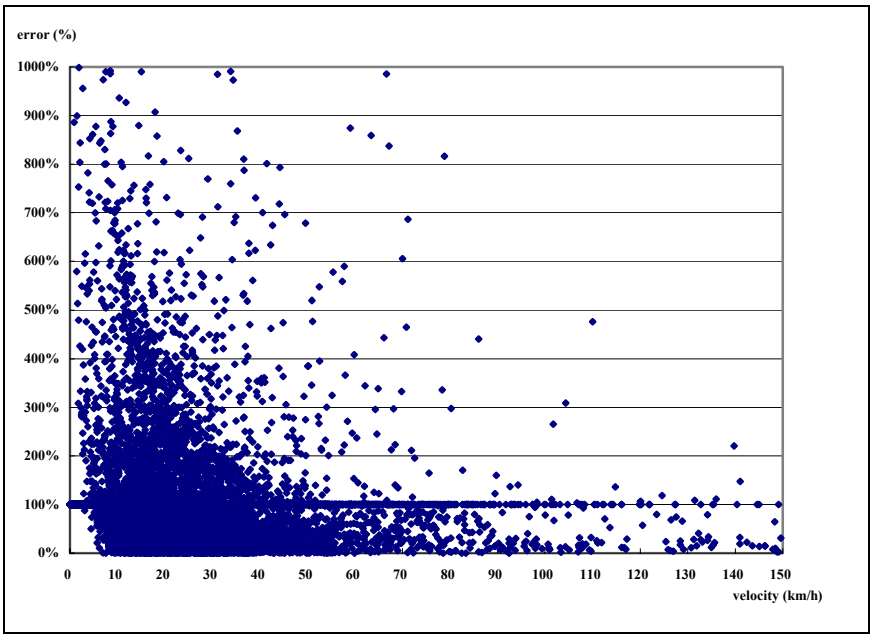

Figure 9. Relationship between Travel Speed and Travel Speed Error

5.4 Relationship Between Operating Time And Travel Speed Error

As operating time increases, operating distance do also increases. If operating distance is longer, travel speed error is smaller.

The analysis of the relationship with respect to O/D operating time and speed error between GPS speed and mobile speed shows that as operating time increases, travel speed error decreases. This in turn suggests that as the data collecting time increases, the reliability of speed also increases. However, it should be noted that if collecting time is long, it becomes difficult to trace passed routes.

Therefore, for the travel speed estimation, it is necessary to set the data collection time. In this study, travel speed estimation time was set as 5 min and was taken after every 5 min. Because of the data collection system, the collecting time interval is fixed as 5 minutes. But it is required that data collecting time interval is detailed. For tracking the passed route, it needs to collect data in details.

From the results of this study, it can be concluded that it is proper to estimate travel distance for 5 mins. This is because in the case of the LBS (mobile location information), the locations of the LBS do not change extensively within such a short period of time.

Travel time error changes according to the change of the travel estimation time. Mobile data was collected every 5 min and the travel speed was calculated at 5 min, 10 min, and 15 min. The figure below shows whether or not travel speed decreases as speed estimation time increases. It should be notes that over a long distance, it tends to be long travel distance and long travel time. The longer the travel distance is, the smaller the travel error is.

For the travel speed estimation, the time interval of the data collection should be detail. But the travel estimation updating time interval should be long.

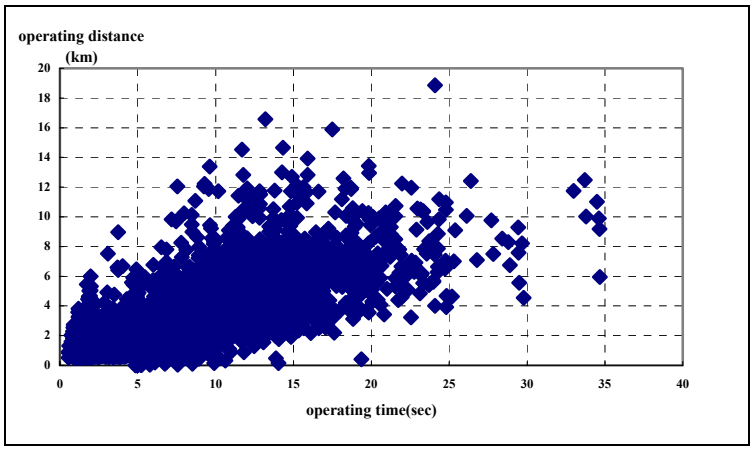

Figure 10. Relationship between Operating Distance and Operating Time

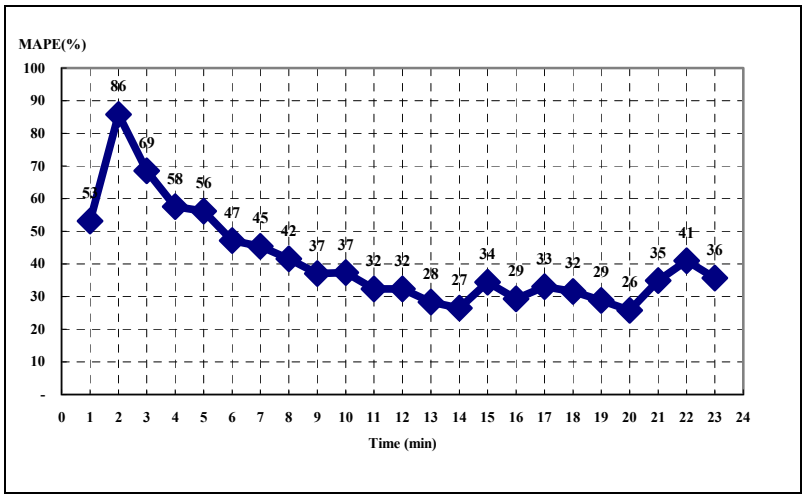

Figure 11. Relationship between Operating Time and Travel Speed Error

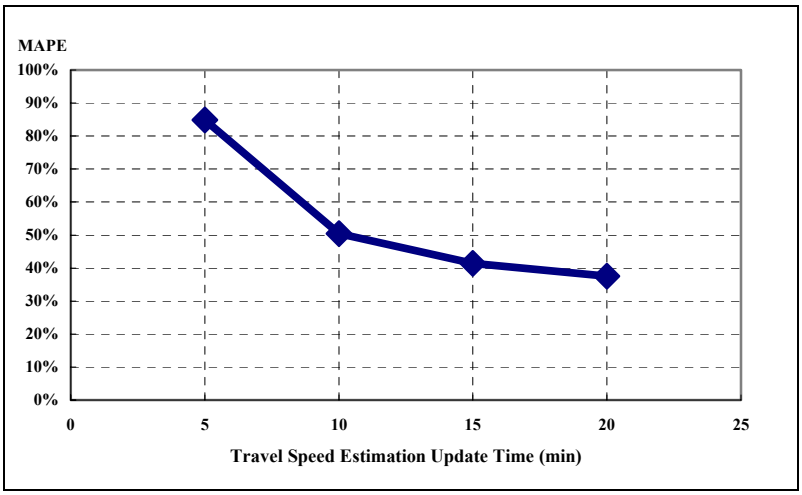

Figure 12. Relationship between Travel Speed Estimation Time and Travel Speed Error

5.5 Calculation Range Of The Travel Distance Per Allowable Error Level

According to real data analysis result, as the travel distance increases, speed error decreases. However, based on the results by allowable error level, we found that as speed error decreased, travel distance range increased. By calculating the distance range by varying the permitted error level between 0~5%, we did not observe any change in the minimum distance range.

When error ratio was 5%, the travel distance range for estimation speed ranged from as short as 700m to as long as 3500m. The former is the minimum distance for passing 2 base stations within 5 min and the latter is the maximum distance which is the longest possible distance that can be traveled within 5 min for data collection.

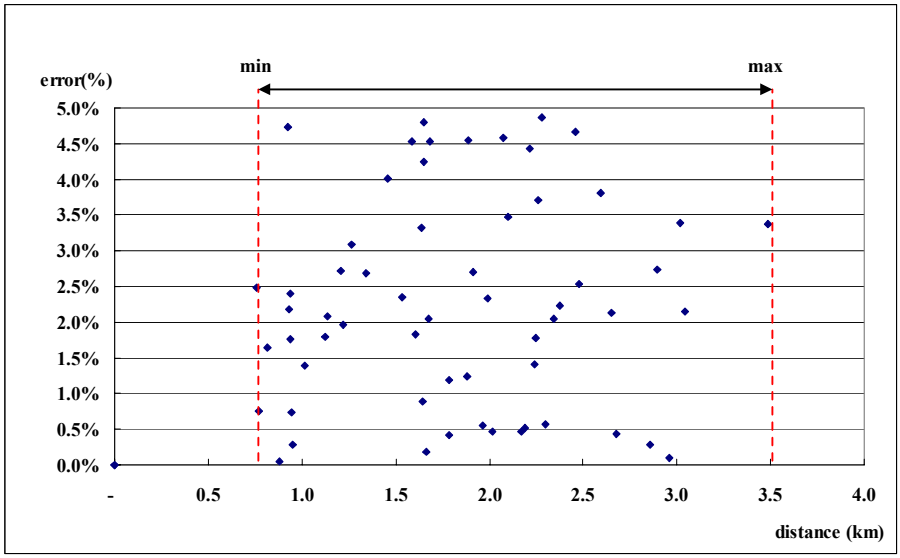

Figure 13. Travel Distance Range per Allowable Error Level

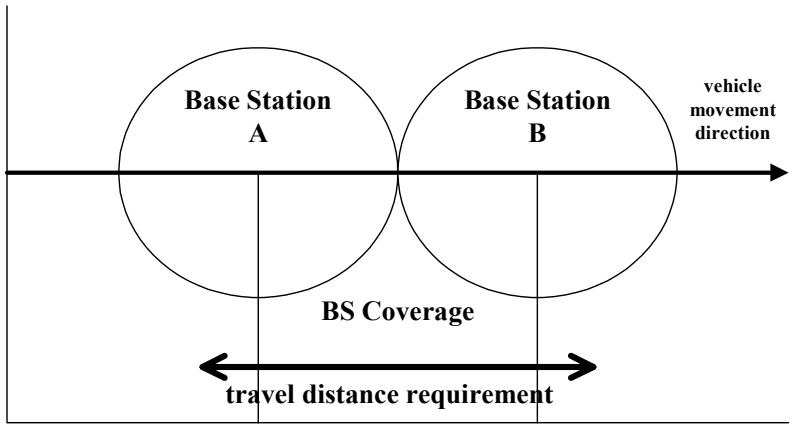

Figure 14. Concept of Minimum Travel Distance

For a stable travel speed estimation, the base station network should be dense, that is, the distance between base stations should be short and base station coverage should be dense.

6. CONCLUSION AND FUTURE PROSPECT

6.1 Conclusion

The objective of this research is to develop techniques for estimating travel speed of main roads using GPS and Mobile (mobile phone) data from probe vehicles. To this end, we developed a methodology for travel speed estimation and evaluated the stability of the estimated travel speed to ascertain its reliability and accuracy.

The GPS/mobile data can be a useful and efficient resource for obtaining reliable travel time data. Map-matching algorithms, which reconcile coordinates of mobile base stations with links, are the basic step for accurate travel speed estimation. The coordinate of mobile location is the base station location and not the location of the actual probe vehicle. Therefore, an error in the mobile location coordinate can greatly affect the accuracy of LBS-based travel speed estimation. LBS set GPS location data as the true value and the error of mobile location coordinate is distributed within a 500m range.

We used a statistical method and compared the GPS-based travel speed and the mobile-based travel speed by applying the paired t-test. The comparison result showed that there is no significant difference between the two travel speeds. As a result, it is validated that existing speed survey result and new methodology result is similar. Therefore, the travel speed estimation methodology can be applied as a speed estimation method.

To judge the accuracy of travel speed, we calculated error of LBS-based travel speed assuming that GPS-based travel speed is a true value.

The lower the travel speed error ratio, the higher the stability of the travel speed. To reduce speed error, we analyzed the factors affecting the speed error, to consequently minimize the cause of error and improve speed stability.

The analysis of relationship travel speed and error between GPS speed and mobile speed showed that if travel distance is longer, the passing base station location data increased, and travel speed error decreased.

According to the real data analysis result, as travel distance increased, speed error decreases. That is, travel distance and travel speed error have a reverse relationship with one another. In addition, as operating time increases, speed error decreases. This means that if the time interval of data collection is longer, the estimated speed is likely to be more stable.

From the level of allowable error, if speed error is smaller, travel distance range is larger. When error ratio is 5%, travel distance range for estimation speed is from min 700m to max 3500m. That means the former is minimum distance it passed 2 base stations, and the latter is maximum distance it passed 5 min for data collection time.

The factors determining reliable travel speed using LBS are the number of base station, distance between near base stations, coverage of base station, data collection time interval. For the stable travel speed estimation, the base station network should be dense, that is, distance between base stations is short and base station coverage is dense.

We need to collect data for the estimation speed through detailed data collection time and suitably long data update time intervals.

Using GPS and mobile data, travel speed estimation techniques are developed and validated. The travel speed estimation using LBS data showed quite reliable results. Thus, it can be said that this method has great possibilities. This research is the first study ever conducted on travel speed estimation using real operating LBS data.

6.2 Prospect

Through this study, we validated the possibility of estimating travel speed estimation based on LBS on arterial roads. However, the reliability of travel speed depends on the accuracy of the mobile base station location information and therefore it is necessary to conduct studies to seek for appropriate map-matching techniques and the shortest path finding algorithms.

For reliable travel speed estimation, the base station network should be dense. Hence, further study about proper base station network composition need to be carried out and further to determine appropriate rational data collection time and travel speed estimation time.

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