Analysis of Day-to-Day Variations of Travel Time Using GPS and GIS

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Abstract

This paper presents an analysis of day-to-day variations of travel time on road network using Global Positioning System (GPS) and Geographic Information System (GIS). Data collection system was developed using GPS connected with notebook PC, which can capture vehicle movement of multiple days. One-week vehicle travel surveys using the system were conducted for commuting drivers in local cities. Methods for handling GPS data on GIS platform were summarized, and day-to-day variations of travel time and speed were analyzed in the study area. Although positional data are very promising, usefulness in travel time studies depends on the process of data handling and the quality of GIS database.

Introduction

In urban transportation planning, it is the most basic and important element to understand people's travel behavior. The existence of day-to-day variations of travel behavior and road network performance has been recognized. In order to evaluate the effects of transportation demand management (TDM) measures and intelligent transport system (ITS) technologies on travel behavior, more detailed and accurate travel data have to be collected considering day-to-day variations. Although travel surveys of multiple days are needed to capture these variations, it is difficult to conduct that kind of survey by traditional survey techniques.

There is strong possibility for advanced positioning technologies, like Global Positioning System (GPS) and Personal Handyphone System (PHS), greatly contributing to travel data collection. Data on position and speed collected at one-second intervals by GPS would give effective information, when analyzing the

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changes of travel behavior (start time, route and travel time, etc.) and performance measures (link's travel time, link's travel speed, stopped time, etc.) after introduction of TDM and ITS. More detailed evaluations would be possible for investigating vehicle emissions such as CO_2 and NO_x. PHS location tracking systems have been available since 1998 in Japan. Although positional accuracy is lower and the minimum logging intervals are longer than GPS, PHS is portable for people in their pocket or bag, and it can also collect positional data in the buildings and subway stations where PHS service is available. Recently an innovative device combined PHS with acceleration sensor was developed in order to estimate travel mode (for example, car, bus, bike or walk) from acceleration data (Okamoto et al., 2000).

Many empirical studies have been reported in recent years, which examined the applicability of GPS, PHS and GIS as a tool for travel behavior surveys and the possibility of traffic monitoring techniques. Zito et al. (1995) examined basic characteristics of vehicle position and speed data using GPS and demonstrated its usefulness for collecting travel data. Murakami and Wagner (1999) compared computer-assisted self-interviewing using GPS with retrospective trip reporting using telephone interviews. They showed the differences of travel distances and travel times comparing both data, and gave examples of breakdown of travel and speed by roadway functional class. Quiroga and Bullock (1998) developed the integrated system analyzing travel time using GPS and GIS, and analyzed appropriate road segment length to detect traffic conditions and sampling period for GPS data collection. Schütte et al. (1999) analyzed travel time using "probe vehicles" equipped with GPS and aerial photograph in München ring road. The characteristics of PHS data and its applicability to travel behavior surveys have been studied. Asakura et al. (2000) developed algorithms dividing PHS tracking data on time-space path of a whole day into travels and activities, and proposed the method for estimating travel route using the data. Asakura and Hato (2001) analyzed the differences of the number of trips and travel time between PHS data and self-reported diary data. Ohmori et al. (2000) compared PHS data and self-reported diary data for the elderly and non-elderly people. These studies have shown the usefulness of positioning technologies for travel data collection and monitoring traffic conditions.

This paper focuses on development of GPS data collection system, its application to one-week travel surveys of drivers commuting the same work place and analysis of day-to-day variations of travel time and speed on GIS platform.

Development of GPS Data Collection System

Data collection system was developed using low-priced GPS connected with notebook PC, which can collect GPS data on vehicle movement of multiple days by easy operation. We also paid attention to the cost of the devices, the way of power supply, capacity of data logger and the ease of transferability from vehicle to vehicle (Ohmori, et al., 2000). The equipment is set in a vehicle, so that GPS antenna/receiver is on the dashboard and a power cord is connected to a vehicle cigarette lighter for supplying power to both GPS and PC. A driver starts traveling by starting the engine and pushing a switch button of PC. After PC working, the batch file programmed by “WinBatchEh” starts automatically and “HyperTerminal” for both communications to GPS and data logging begins to run in about 30 seconds (depending on the performance of PC). A-data file of which the name is travel start time, for example “03150805.txt” for start time of 8:05 on March 15, is created. The driver arrives at a destination and immediately pushes two buttons of PC, so that the batch program restarts and save the GPS data file. Lastly, s/he just turns off the engine.

This system was applied to collect data for commuting drivers in two local cities (Ohmori, et al., 2000). After these surveys, the system was enhanced to display vehicle’s current position and travel tracks on a digital map like a car navigation system using “ProAtlas” software (Figure 1). The enhanced system was applied to touring behavior surveys in mountain areas and has successfully collected GPS data, where drivers were much interested in real-time view in their traveling (Fujiwara, et al., 2001). Since May 1, 2000, when United States had stopped Selective Availability (SA) that degrades GPS accuracy deliberately, GPS accuracy has dramatically improved. Now, positional accuracy is several meters not using differential GPS (D-GPS) (Assistant Secretary of Defense, 2001). The usefulness of the low cost system developed in this study has increased.

One-Week Travel Data Collection Surveys

One-week vehicle travel surveys for commuting drivers were conducted in two local cities, Tochigi City (about 80,000 population) and Toyota City (about 340,000 population), using this system (Ohmori, et al., 2000). These surveys were conducted in January and March in 1999. When SA had been working, the positional accuracy of standard positioning system (SPS) was tens of meters. Participants were asked to equip their vehicle, which is used in daily commuting, with the GPS data collection system, and to record other information about trips (travel purposes, the name of destination site, etc.) on a questionnaire sheet. All participants in two surveys

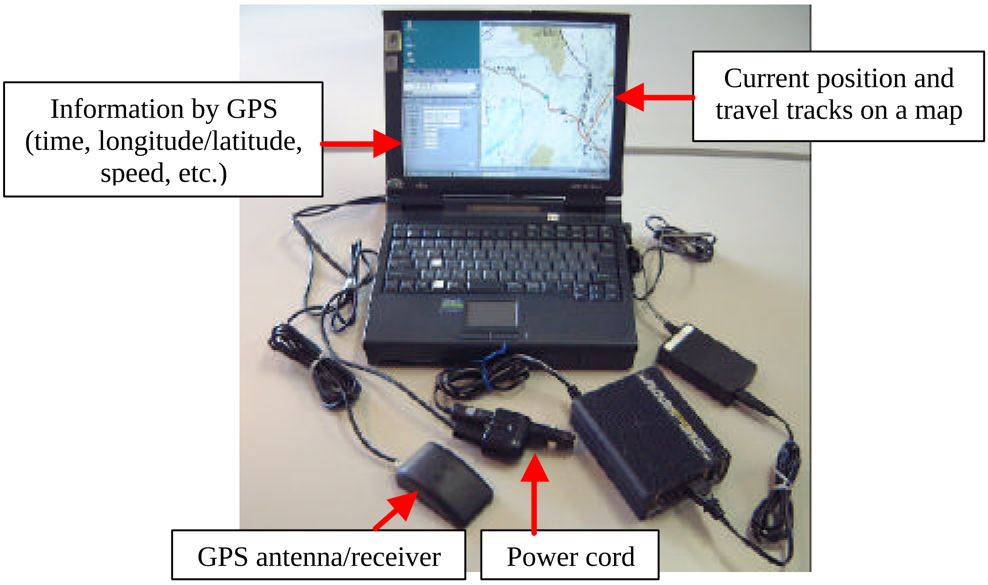

Figure 1. GPS data collection system

commuted to the same working places located at the center of the city; especially all participants in Toyota City living in the same direction (southwest) from the working place. The number of participants is 15 in Tochigi and 28 in Toyota. PCs were rented from a rental office. The PC sets were available at low price. The Garmin GPS 35 was used as low-priced GPS receiver.

Obtained Information According to Data Available in Analyses

Accurate and detailed travel data for an individual travel, such as travel start/end time, start/end location, travel time, travel distance and travel route are very useful to understand travel behavior and to develop more detailed travel behavioral models.

Another usage of GPS data is traffic monitoring of road network, "probe vehicles". Quiroga (2000) and Taylor et al. (2000) summarized performance measures and congestion indices captured by GPS. Obtained information differs according to additional data as shown in table 1 that summarizes what kinds of information are obtained according to data available in analyses. Only GPS data on time and position can provide trip start/end times and start/end positions, and then total travel time and travel distance can be also calculated. Duration of stopped time and the number of stops are calculated using data on speed of each position. Total vehicle emissions such as CO_2 and NO_x could be also estimated more accurately by considering acceleration calculated by speed profiles. Road network data are needed for providing information on travel movement (e.g. travel route) in urban spatial environment. Travel time and travel speed at each road segment can be also calculated by combination of GPS data and GIS road network data. If data on various attributes of road segments are available, performance measures are calculated by road characteristics (functional class, width, the number of lane, etc.). Land/property data enable us to specify buildings and parking places where trip starts and ends. Monitoring data on traffic conditions at fixed points and video recorded data with the vehicle contribute to understand the events during travel. Although more information can be collected if probe vehicles are equipped with positioning devices and also other instruments (e.g. engine management system), only GPS provides useful information about travel and road performance measures.

Table 1. Obtained information according to data available in analyses

Data	Obtained Information
GPS data	trip start/end time, start/end position, total travel time, travel distance, the number of stops, stopped time, vehicle emissions
+ road network data	trip start/end location, travel route, link travel time, link travel speed, (calculated by road characteristics)
+ land/property data	buildings and parking places where trip starts and ends
+ monitoring/video recorded data	information about travel environment (vehicle volume, events, etc.)

Data Handling Process for Selecting Congestion Points in Road Network

GPS data on vehicle travel need to be converted into link information for analyzing road network performance. First step is to filter GPS data for excluding extraordinary points and transforming them into GIS format data. Then, each GPS point should be matched with GIS road link, because we cannot know which link each GPS point was collected at. This procedure is actually very difficult but several methods have been proposed (Asakura and Hato, 2001). Although the simplest matching method is that each GPS point is considered to be on the closest link, this method often doesn't specify a reasonable travel route. For that reason, it is better to estimate a travel route before each point is matched to a road link. In this study, each travel route was specified manually and GPS data were matched with each link of the specified route. When matching GPS data with GIS road links, distance between each GPS position and links, and topological angles between successive positions and links were considered.

Recently, a car navigation system is available, which can record data on vehicle movement. This car navigation system can collect more accurate positional data and be used in urban canyon and tunnel, since it uses GPS but also gyrocompass, pulse code and real-time map matching technologies. Yet, this system is much expensive and is not so easy to install to vehicle in comparison with the system developed in this study. Experiments of probe vehicles (taxis and trucks with the car navigation system) have been conducted at Tokyo Metropolitan Area by Ministry of Land, Infrastructure and Transport in Japan (Makimura et al., 2002).

After each GPS point is matched with road network links, it would be better to estimate driving mode because low speed do not necessarily mean the unique travel condition, for example congestion. It is difficult to distinguish congestions from stopping at red signal by only one point speed data. Travel mode estimation models or algorithms should be developed to specify congestions. The best way would be using video recording methods on vehicles but expensive. Finally, congestion points can be selected through a series of processes.

Digital Road Map (DRM), which is the most standard road network data in Japan, is used as GIS road network data in the study. MapInfo is used for GIS platform and a series of data handling programs are written in MapBasic and C.

Analysis of Day-to-Day Variations of Travel Time and Speed

As mentioned in previous sections, GPS data provide information about trip start/end times, start/end positions and total travel times. Figure 2 shows the variations of commuting travel times traveled on weekdays during the survey period in two local cities. The analysis uses data on trips which drivers traveled using almost the same route and their start times are also the same (within 10 minutes). Travel times of each individual range from 3 to 11 minutes (average of the range is 6.1 min.) in the Tochigi survey and from 2 to 21 minutes (average is 6.3 min.) in the Toyota survey.

After each GPS point is labeled link code, average link travel speed as one of road performance measures can be calculated as:

$$u_i^k = \frac{\sum_{j=1}^{m_i^k} u_{ij}^k}{m_i^k} \qquad (1)$$

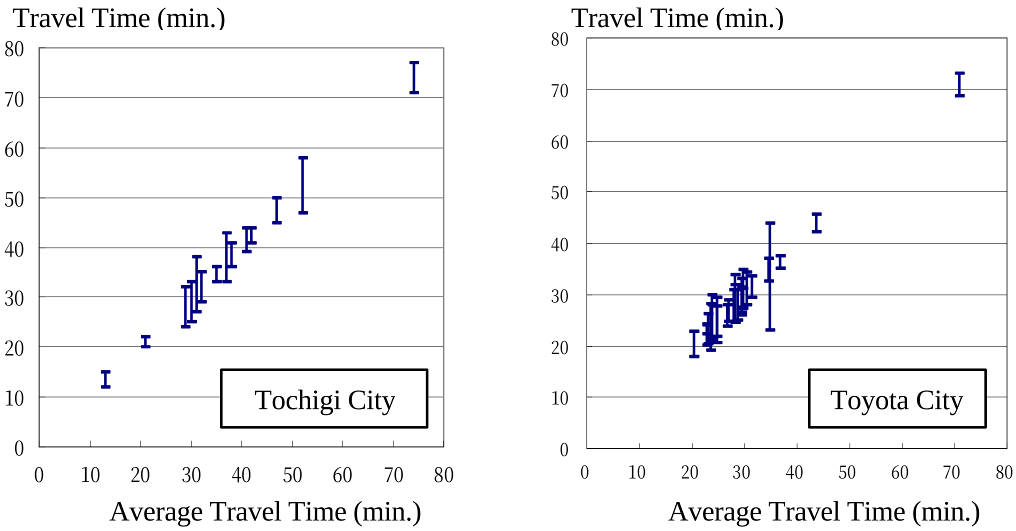

Figure 2. Variations of travel time of commuting trips

u_i^k : the average link travel speed of link *i* on date *k*

u_{ij}^k : *j* th speed record associated with link *i* on date *k*

m_i^k : the number of records of link *i* on date *k* (the number of participants' vehicles traveled through link *i* on date *k*)

Figures 3 and 4 show the examples of analyses of day-to-day variations of travel speed using GPS data on 117 commuting travel (from home to the working place) of 28 participants in the Toyota survey. All trips were traveled from 7:00 to 9:00 and these figures showed road network conditions at morning peak period on weekdays. The number of total links is 1,058 and total length of all links is 176,528 meters. Figure 3 shows low speed links considering its variation. "Max [u_i^k] < 20 km/h" in the figure means that the maximum average link speed is under 20 km/h, so it took longer time to run through these links on weekdays during the survey period. Total length of these links is 15,342 m. "Min [u_i^k] < 20 km/h" means the minimum average link speed is under 20 km/h and the maximum speed is over 20

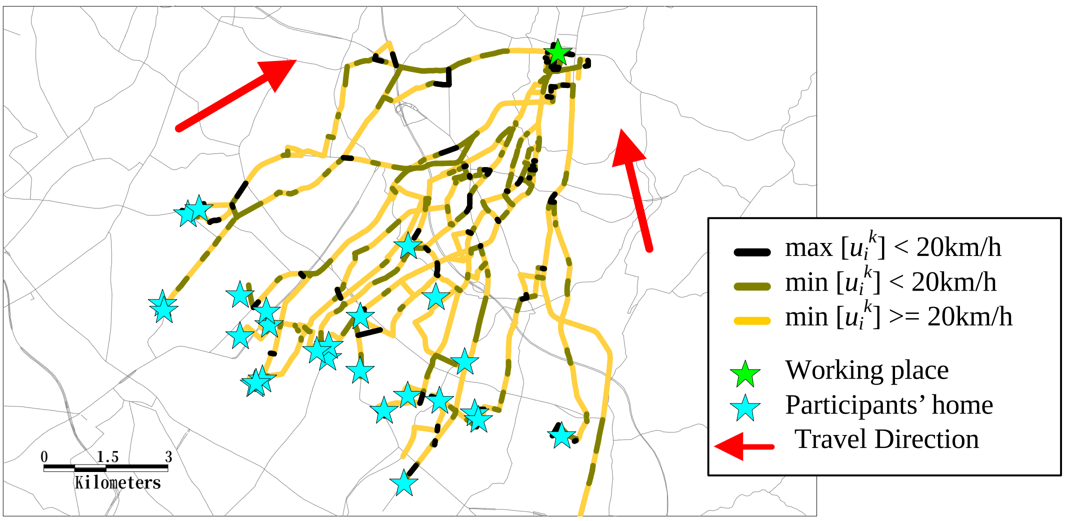

Figure 3. Low speed links at morning peak periods on weekdays

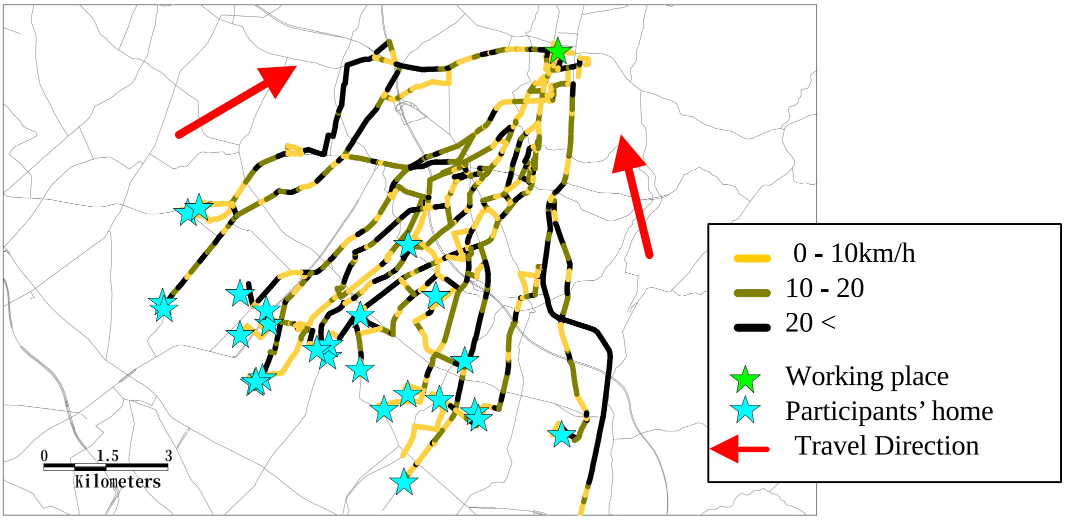

Figure 4. The range of link travel speeds at morning peak periods on weekdays

km/h. Total length of these links is 43,121 m. "Min [u_i^k] = 20 km/h" means the minimum average link speed is over 20 km/h. Figure 4 shows the range of link speeds (max [u_i^k] – min [u_i^k]). The analyses in the study do not distinguish congestion and stopping at signals or intersections, but suggest the existence of day-to-day variations of traffic conditions in road network. Effects of a policy measures to road network performance should be evaluated by travel times and speeds of multiple days, considering day-to-day variations.

Travel time between every two nodes can be also calculated using information about each link travel time calculated by link speed and link length. In this calculation, much attention should be paid to vehicle turning movement at intersections, because travel time crossing intersections differ between going straight and turning left and right.

Conclusions

This paper presented development of GPS data collection system, its application to one-week travel surveys and analysis of day-to-day variations of travel time and speed on GIS platform. Variations of travel times of commuting drivers who started traveling at a regular time were identified using GPS data collected in the one-week travel surveys. Low speed links at morning peak period and its day-to-day variations were analyzed using GPS data and GIS road network data.

Positional data are very promising for tracking vehicle movements. However, usefulness in travel time studies depends on the process of data handling and the quality of background GIS database. Further research concerns the followings:

- More appropriate algorithms should be developed for matching positional data with GIS road network.
- Methods for estimating driving mode should be developed for distinguishing congestion from other conditions.
- Sample sizes required for statistically significant results should be examined for

analysis of network performance measures in the study area.

- Detailed GIS road network data with various attributes should be prepared and updated periodically, because some road links are not included in the DRM database especially in local cities. In this study, we added road links of which total length is about 7,000 meters. Since not all road links have useful attributes (width, the number of lane, etc.), analyses by road characteristics are limited to major roads.
- Comparative analysis of drivers' commuting travel routes would be interesting.

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