Measuring Area-Wide Road Travel Speeds in Urban Areas in Developing Countries - A Case Study in the Colombo Metropolitan Area

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Abstract: Many urban areas in developing countries are experiencing serious traffic congestion. There are several obstacles to overcome in order to implement a travel speed survey (TSS) in these areas such as budget and time, lack of information on road segments, flexible operation of traffic control and relatively high deviation of travel speeds. Taking these obstacles into consideration, the methodology of an affordable and precise TSS with simple procedure can be developed. The methodology is tested with the field observation of the eight month TSS in the Colombo Metropolitan Area. Based on this, guidelines on the sample size of TSS as well as an appropriate method are proposed and discussed. It is understood that the development in methodology and findings can contribute to the practice of transportation planning in urban areas in developing countries.

Keywords: Travel Speed Survey, GPS, Developing Countries, Sample Size Determinations

1. INTRODUCTION

In urban areas in developing countries, especially in those countries and regions experiencing rapid economic growth, called emerging economies, deteriorating traffic congestion due to rapid motorization is a common issue. Travel time and speed are simple and clear indexes of traffic congestion which is easily understood by a variety of stakeholders. Therefore, a travel speed survey (TSS) is essential for transportation planning purposes. Apart from the developed world, there are several characteristics to be considered for implementing a TSS in developing countries.

Traffic congestion is often more serious and wide-spread in emerging countries mainly due to rapid motorization and the gradual development of transport infrastructures. In addition, there are a number of times and locations where specific traffic problems occur, such as traffic congestion in front of schools and religious facilities in some countries. Daily fluctuation is also obvious due to road work, demonstrations, traffic accidents and the closure of roads for very important persons. Thus, a continuous survey to grasp these variations is required.

Many governments in developing countries are facing financial deficit. On the other hand, they have to deal with rapid motorization of which no developed countries have experienced. In this sense, it is highly required to prepare affordable and accurate travel speed surveys.
data in a limited time. Thus, city-wide year-round TSS is an effective tool for transport planners to identify traffic issues in urban areas.

There are some attempts of surveying metropolitan-wide traffic congestion information in developing countries such as the case in the Jakarta Metropolitan Area (Yagi et al., 2008). Mauricio et al. (2003) surveyed travel speeds by GPS in the arterial roads in the Manila Metropolitan Area. Several issues of measuring travel speeds were identified by those pioneering studies such as black spots of GPS, identification of road segment from the GPS survey results. However, these issues which are unique to developing countries were not highlighted by the previous studies. Therefore, the objectives of this study are;

1) to develop a methodology for measuring travel speeds accurately in urban areas in developing countries at an affordable cost, and,
2) to test that methodology in the field taking the Colombo Metropolitan Area as an example.

2. METHOD OF ESTIMATING TRAVEL SPEEDS IN URBAN AREAS

2.1 Estimation of Travel Speed

2.1.1 How to Average Travel Speeds?

There are several methods of estimating “average travel speed” such as the arithmetical mean of spot travel speeds, geometric mean of travel speeds and harmonic mean of travel speeds which is equal to the distance of a road segment divided by the arithmetical mean of travel time. In the field of transportation planning, mean travel time is one of the most important aspects as it is directly related with the loss of opportunity due to traffic congestion (Turner, 1998). There are two major methods to estimate average travel speed using GPS (Cheu et al., 2002).

[1] Space Mean Speed by Segment Entry and Exit Time

This is a conventional method of estimating travel time recommended in many references (Turner et al. 1998; Cheu et al., 2002; May, 1995; Robertson, 1994). By surveying the entry time and exit time of a road segment, travel time for passing the segment of each survey vehicle can be estimated. By dividing the distance by the arithmetic mean of travel time, the harmonic mean of travel speed of the segment can be estimated.

[2] Mean GPS Spot Speed

GPS devices usually can record instantaneous travel speed by a specific interval such as 30 seconds. Though the method of estimating instantaneous travel speed is different by GPS device, the accuracy of instantaneous travel speed can reach approximately 0.8 km/h using the Doppler effect of the signal from satellites(D’Este et al., 1999; Nagatsuma et al., 2002).

However, the spot travel speed is not considered as representative as it does not cover the entire road segment to be surveyed (May, 1995). It is also mentioned that there is a tendency for overestimation of the travel speed.

On the other hand, some recent researchers have argued that the mean GPS Spot Speed method can also be utilized for the travel speed analysis with some adjustment. Zito et al. compared GPS spot speeds and Travel Time Data Acquisition System (TTDAS), and, concluded that the average error of the two methods were 0.60 km/h in downtown areas.
provided that the GPS signal condition can be received (Zito et al., 1995). Zhao et al. proposed truck GPS Spot Speed data as a performance indicator of freight policy (Zhao et al., 2011). The GPS spot travel speeds of trucks were compared with a loop detector, and, it was verified that the difference in mean travel speeds were less than 6 percent.

In theory, the estimation of travel speed of a road segment by two methods can be closer ignoring measurement errors unique to each method on the condition that the number of the sample size is significantly huge, and the sampling is random. However, [2] Mean GPS Spot Speed Method has a loss of information during the record interval of a GPS device for surveying the travel speed of an entire road segment. This implies that [2] Mean GPS Spot Speed Method might need a relatively larger number of samples in case the fluctuation of travel speed is significant. Therefore, the accuracy in measuring travel speed by these two methods needs to be examined with the observation in the field in the context of developing countries.

2.1.2 Errors and Biases in Measuring Travel Speeds

There are several biases and loss of information in measuring travel speed by GPS devices as described below:

1) Bias due to vehicle type
2) Loss of information during the recording intervals of GPS devices (this is unique to [2] Mean GPS Spot Speed Method)
3) Biases caused by the differences in GPS programs of estimating instantaneous speed (this is unique to [2] Mean GPS Spot Speed Method)
4) Error of data where the GPS signal is weak
5) Errors of the global positioning system itself such as signal arrival time measurement, atmospheric effects, ephemeris and clock errors
6) Loss of data due to GPS device settings such as an option of removing the record in the case that the travel speed is less than a certain level

For the estimation of travel speeds, the effects of biases should be considered. The method of minimizing these biases will be discussed in Section 4. ‘Discussions on Two Methods of Averaging Travel Speed’.

2.1.3 Sample Size Determination

According to the central limit theory, the distribution of errors of sample mean, in other words the difference between the sample mean and population mean, is a normal distribution with variance $\sigma^2/n$, regardless of the distribution of the parent population where $\sigma$ is standard deviation of the parent population and $n$ is a sample size. Thus, the formula to determine the sample size for the mean including travel speed and travel time is shown below (Cheu et al., 2002; Nezamuddin et al., 2008; Meyer and Miller 2001). Normal distribution is assumed in the formula below. While there is an argument that travel speed is not normally distributed during a congested situation, the following formula is widely utilized expecting to give a reliable sample size (Quiroga and Bullock, 1998). In case the number of the sample is large enough, such as more than 30, a z-statistic can be utilized instead of a t-statistic.

$$n \geq \left( \frac{t_{1-\alpha/2,n-1} \sigma}{\varepsilon_a} \right)^2$$

where

$n$ : sample size
\( \varepsilon \): tolerable margin of error of mean value
\( \sigma \): standard deviation of population distribution
\( \alpha \): fraction of area under normal curve representing events not within confidence level
\( t_{1-\alpha/2, n-1} \): t-distribution statistics for \( 1 - \alpha \) confidence interval with degree of freedom \( n - 1 \).

From the practical point of view such as congestion analysis and provision of travel speed information to drivers, a 5km/hour tolerance margin and confidential level of 95 percent was often used in the previous studies (Cheu et al. 2002; Nezamuddin et al., 2008). Thus, the standard deviation of travel speed is a key variable to determine a sample size according to the equation (1).

For the [1] Space Mean Speed by Segment Entry and Exit Time, there are several studies on the required sample size. Cheu et al. (2002) examined the recommended sample size for the link travel speed based on the microscopic simulation using the road network of Singapore. It is recommended that at least ten samples are required to achieve an absolute error of 5km/h at least 95% of the time. Nezamuddin et al. (2008) further examined the required sample size by the traffic volume by lane by travel speed and traffic volume survey results in the United States. A sample size of seven was proposed for the road segments with traffic volume ranging from 300 to 1,100 vehicles per hour per lane, and, 13 – 14 were proposed for other traffic volume ranges of arterial roads. However, studies in urban areas in developing countries are scarce. Therefore, the observed standard deviation in the field of developing countries is examined in sub-section 4.1 ‘Key Statistics of Two Methods’.

2.2 Identification of a Road Segment

By overlaying the GPS survey results and the digital road map based on the geographic information system (GIS), identifying a road segment where the survey vehicle passed is a key obstacle to be overcome for estimating the average travel speed. Especially in urban areas in developing countries, detail digital road map data with a variety of attributes such as one direction road, turning movement restriction at an intersection, and road polygon data are rarely available. Therefore, the method of identifying a road segment with relatively simple GIS data such as polyline road data was developed. The procedure of identifying a road segment of GPS survey points with a polyline road map are mentioned below.

2.2.1 Preparation of Digital Road Map and Segmentation of Roads

A polyline-based digital road map is the base for the travel speed analysis. While a road segment of the polyline-based digital road map is sometimes too short or too long for the analysis of travel speed, these polylines should be combined or divided for the travel speed analysis considering how to utilize data.

2.2.2 Setting Road Segment Buffer Polygon and Intersection Buffer Circle

Once road segments for travel speed analysis are fixed, “road segment buffer polygon” as well as “intersection buffer circle” is prepared. As the GPS survey results contains various biases due to signal arrival time measurements, atmospheric effects, clock data etc.; a certain margin is required for the road segment identification. In addition, road width information is not accurate in some countries. In the case of the Colombo Metropolitan Area, 30m from the center line of the road is defined as a standard buffer for the analysis of travel speed of arterial
roads or in other words, the road segment buffer polygon. In the case where the information on accurate road width or exact right of way is available, it is recommended to utilize these data with a certain margin.

In addition to the road segment buffer polygon, an intersection buffer circle is defined for confirming the entry and exit to a road section. An intersection buffer circle was defined by a circle with a radius of 60m from the center of the intersection or start/end point of a segment taking the size of the intersection into consideration. The image of a road segment buffer polygon and intersection buffer circle is illustrated in Figure 1.

2.2.3 Confirmation of Entry and Exit of a Road Section
Geographic coordinates of a survey vehicle stopping at the intersection due to a traffic signal or congestion slightly fluctuates due to the various biases of the GPS. Thus, the intersection buffer circle was utilized for the confirmation of the entry and exit of the road section. The entry and exit are confirmed when the survey vehicle track intersected with the hypothetical intersection area as shown in Figure 1. By setting the intersection buffer circle, the screening of candidate GPS points which might pass a road segment can be easily and accurately conducted before the following procedure of removing errors which requires time for data processing.

![Figure 1. Image of road segment buffer polygon and intersection buffer circle](image)

2.2.4 Removal of Inappropriate Data for Travel Speed Analysis

For the purpose of minimizing survey costs, it is practical to utilize the existing vehicles with GPS devices such as taxis and commercial vehicles as many taxi or logistics companies require GPS data for managing their vehicles. GPS data of these vehicles contains the data which is not suitable for travel speed analysis such as parking on the street for loading and unloading and a vehicle entering/exiting to a roadside facility in the middle of a road section. These GPS survey points should not be utilized for travel speed analyses.

In order to remove unnecessary data for the travel speed analysis and to avoid the GPS biases, the method of screening the valid data for travel speed analysis was developed as below.

After the confirmation of an entry and exit of a road segment, all the GPS survey points are verified whether each one is in the road segment buffer polygon. In case there is a survey point which is out of the road segment buffer polygon, the series of data is excluded for the travel speed analysis.

Even if a part of the data is missing due to various reasons, such as a road which goes under a flyover and roads at GPS black spots, they can be utilized as long as the intersection data is valid. However, the data which contains a blank of data for more than five minutes and a survey vehicle stays the section for more than one hour are screened out assuming that these survey vehicle reached their destination.
2.2.5 Estimation of Entry and Exit Time

While the entry and exit of a road section is identified by the intersection buffer circle, the entry and exit time is, in general, estimated by the entry/exit of the road segment buffer polygon.

To avoid duplication and missing time in counting travel time, travel time at the start/end of a road segment, or in other words the “boundary time”, is estimated as shown in Figure 2. The boundary line is defined as a set of points keeping equal distance from the edge line of both segments at the intersection. The boundary time is the time it takes to pass the boundary line. The boundary time is estimated by interpolating the time of survey points just before the boundary line and just after the boundary line assuming constant travel speed between the two points.

![Figure 2. Image of Estimation of Entry and Exit Time](image)

In many congested intersections in urban areas of developing countries, survey vehicles become stranded at intersections. As the coordinates from the GPS device normally contains certain errors, the coordinates fluctuate at the intersection even though the vehicle is stopped. Thus, the above clear definition in entry and exit time is useful for travel time estimation.

However, it should be noted that this method cannot be applied to two close parallel roads and the road segments where entire sections are underneath elevated roads.

2.3 Characteristics of Urban Areas in Developing Countries

As mentioned in section 1. ‘Introduction’, the city-wide year-round travel speed survey (TSS) is an effective tool for transport planning as it can observe local traffic problems, corridor-wide traffic congestion and even daily events. However, there are several obstacles in implementing TSS which are unique to urban areas in developing countries.

Compared with the developed world, the number of vehicles with GPS devices is limited. Car navigation systems are not prevalent compared with developed countries. Thus, various types of GPS devices need to be utilized to increase the number of survey vehicles. As a result, the settings of the GPS devices are various such as observation intervals and the estimation method of travel speeds. This makes the TSS complicated.

The basic information on GPS black spots, locations of underpasses, flyovers and tall buildings which affects the GPS observation is not commonly known.

Serious traffic congestion is also an issue for the TSS. If the survey vehicle stops for a long time, it is not easy to identify whether the vehicle reached its destination or got stuck in a
traffic jam. At the intersection, the survey coordinates fluctuate at the boundary of the road section, and this can confuse identifying the entry and exit of the road section.

Traffic rules are often “flexible” in these countries. Some drivers constantly ignore traffic rules such as one-way rules, lane markings, U-turn prohibition and turning movement prohibition. Even government authorities suddenly change their rules and traffic operation such as the revision of one-way rules without proper prior notice. Thus, the TSS method should be flexible enough.

For the development of the TSS method in developing countries, the above points should be taken into account.

3. TRAVEL SPEED SURVEY IN COLOMBO METROPOLITAN AREA (CMA)

3.1 Colombo Metropolitan Area

The Western Province is the largest province in terms of population in Sri Lanka. The Western Province includes the Colombo Municipal Council (CMC) and the national capital of Sri Jayawardenapura Kotte. The population of the area was approximately 5.8 million in 2010 and the gross regional products per capita was 489,000 Sri Lankan Rupees in 2011 (approximately 4,300 USD with exchange rate of 1 United States Dollar, USD = 113.90 Sri Lankan Rupees, LKR at year end of 2011) (Central Bank of Sri Lanka, 2014). The number of households who can afford to buy private vehicles are drastically increasing. Thus, the surge in the number of cars is salient. The average annual growth ratio (AAGR) of the number of motor vehicle for the last decade reached 8.0%.

The Colombo Metropolitan Area (CMA) is the defined area by the study called CoMTrans which is mentioned in the following paragraph. The CMA consists of the CMC, and surrounding urbanized local authorities. The CMA has a population of 3.68 million in an area of 996 square kilometers (JICA and MoT, 2014).

3.2 CoMTrans Project (JICA and MoT, 2014; Kawaguchi et al., 2015)

As the traffic congestion is becoming serious, the Ministry of Transport initiated the “Urban Transport System Development Project for the Colombo Metropolitan Region and Suburbs (CoMTrans)” with assistance from the Japan International Cooperation Agency in 2012.

The objectives of the CoMTrans projects include the preparation of an urban transport database including comprehensive transport surveys, the formulation of an urban transport master plan and a feasibility study on the monorail system. The travel speed survey (TSS) is a part of the comprehensive transport survey. A city-wide continuous eight month TSS was conducted.

This paper selected CMA for a case study as it is one of the typical growing urban areas in developing countries. In terms of GPS condition, CMA is ideal for the first trial as there is no GPS black spots and few tall buildings, and the number of flyovers and underpasses are limited compared with other urban areas.

3.3 Summary of the TSS in CMA

With 198 vehicles, an eight month travel speed survey (TSS) was conducted in the CMA from January to August 2013. All the arterial roads in the CMA were surveyed. A total of approximately 43,000 vehicle-hours were surveyed. The survey area and survey roads are shown in Figure 3. A total of 572 km of roads were divided into 551 road segments for the
TSS analysis. The average length of a road segment is about 1 km. The length of segments is shorter in urbanized areas. The survey vehicle type includes 61 passenger cars and taxis, 59 lorries and bowsers, 40 vans, 25 commercial vehicles and others. While a variety of GPS devices were utilized, the average interval of recording geographic coordinates by GPS device was roughly 16 seconds.

Figure 3. Travel Speed Survey Area and Roads
3.4 Survey Results

The survey results were summarized with [1] Space Mean Speed by Segment Entry and Exit Time Method. A part of the survey results were verified with the manual travel time count with the GPS survey results. It is observed that the survey results were consistent with the manual observation. Figure 4 shows average travel speeds from 5PM to 6PM in the Colombo Municipal Council (CMC). It is evident that the travel speeds of arterial roads in the city center are less than 10km/h. It is noteworthy that most of the roads are congested in both directions during evening peak hours while the congestion is salient for roads going to the city center during the morning peak hour. This can be explained that some commuters stop by shops or their children’s school on their way home.

Figure 4. Travel Speed of CMC during Evening Peak Hour

The survey results were summarized as travel time and the travel time between the city center of Colombo and the suburban city center were estimated. The Figure 5 shows the hourly average travel time between Colombo and the suburban city of Battaramulla. During the peak
hour, the travel time is almost three times that of the non-peak hours. Other examples of the application of the TSS results are described in the section 5. ‘Application for Transport Planning Process’.

![Figure 5. Hourly Average Travel Time between Fort Lake House (City Center) and Battaramulla (Suburban area)](image)

4. DISCUSSIONS ON TWO METHODS OF AVERAGING TRAVEL SPEED

4.1 Key Statistics of Two Methods

With the TSS results, two methods of estimating the mean travel speed, [1] Space Mean Speed by Section Entry and Exit Time and [2] Mean GPS Spot Speed were compared to verify the validity of the methods. While the TSS results contain huge travel speed data of various road segments in the CMA, eighteen typical road segments with more than 100 survey vehicles which passed in one hour time with hourly traffic count survey results were selected for the comparison of the two methods of averaging travel speeds, taking the distance of the road segments, urbanization and road type into consideration. A total of 166 road segment-hours where 24,155 survey vehicles passed with GPS spot data of 230,788 points were analyzed. As the traffic count survey was conducted for only one day per location throughout the survey period, the date and time of the traffic count survey and the travel speed survey are different. Only business days during the eight month survey period were analyzed. While the composition of the survey vehicle type does not represent the share of the vehicle type of a survey location, the survey results were weighted by vehicle type. The weighted average and the weighted standard deviation by vehicle composition of the road segments were utilized in the analysis below.

4.1.1 Mean Travel Speed by Two Methods

Travel speeds were estimated by two methods as shown in Figure 6. The [2] Mean GPS Spot Speeds are, on average, 10% higher than [1] Space Mean Speed for 166 road segment-hours. Thus, several analyses were conducted to identify what is affecting these differences. As it is assumed that [2] Mean GPS Spot Speeds potentially have a loss of information during an observation interval of GPS spot speed, the difference of the two methods are compared
(Figure 7). It was also considered that the land use along the road segment can affect the fluctuation of travel speed of road segments as the traffic is often disturbed by vehicles from/to shops along the road. Figure 7 clearly illustrates the impact of the average GPS observation interval and land use along the road segment. The differences of road segments with commercial land use are almost double of those with residential land use. It is also noteworthy that the difference of the two methods is almost 1km/h in the case that the GPS observation interval is less than 14 seconds. Thus, it is recommended that the observation interval of GPS devices should be shorter for [2] Mean GPS Spot Speed.

The difference of the two methods is analyzed from another perspective. Figure 8 shows the difference by hourly link traffic volume per lane by share of large vehicles. The large vehicles include large trucks, truck trailers and buses. It is obvious that the difference decreases as the hourly number of vehicles in the lane increases. This might be explained by the increase of GPS observation points due to slow travel speed caused by high traffic volume while further investigation with the detail attribute data is awaited. Although it is still not evident as the traffic volume, the difference decreases with the increase of the share of large vehicles.
4.1.2 Standard Deviations and Sample Size of Space Mean Speed

To analyze required sample size for the travel speed survey, standard deviations were cross-tabulated with various variables. Hourly traffic volume per lane (Figure 9) as well as land use along the road segment (Figure 10) showed salient features. Passenger Car Unit (PCU) factors used for the analyses are passenger car, 1.0; small bus, 1.6; bus 1.8; medium truck 1.7; heavy truck 2.8; motorcycle 0.5; and three wheeler 0.8 respectively. Mean, median, 80th percentile value and 90th percentile values are shown in the graphs. While fluctuations are observed, standard deviations of traffic volume from 750 – 1,500 PCU/hour are smaller than other ranges. They are in line with findings of previous studies (Nezamuddin, 2008). Standard deviations of suburban residential land use are smaller.

Note: Numbers in the figure are of the 90th percentile (upper one) and the mean (lower one).

Figure 9. Standard Deviations of [1] Space Mean Speed by Hourly Traffic Volume per Lane
With these standard deviations, sample sizes were estimated with four levels of accuracy requirements. In developing countries, constraints in conducting a travel speed survey should be taken into account such as budget and time. Taking the standard deviations in Figure 9 and Figure 10, error margins and confidential level, a sample size was estimated with equation (1). The sample size is slightly larger than previous studies of 10 (Cheu et al., 2002) in case the required accuracy level is similar. This implies the relatively complicated and deviated feature of travel speeds in developing countries. Under a minimum accuracy requirement condition, even 4-5 samples give meaningful information to planners bearing in mind that the error margin is high and confidence level is low.

### Table 1. Proposed Sample Size for Space Mean Speed

<table>
<thead>
<tr>
<th>Accuracy Requirement</th>
<th>Assumed Standard Deviation</th>
<th>Error Margin</th>
<th>Confidence Level</th>
<th>Sample Size*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>11-13 km/h</td>
<td>5 km/h</td>
<td>95%</td>
<td>21-29</td>
</tr>
<tr>
<td>High</td>
<td>9-10 km/h</td>
<td>5 km/h</td>
<td>95%</td>
<td>15-18</td>
</tr>
<tr>
<td>Standard</td>
<td>7-8 km/h</td>
<td>5 km/h</td>
<td>95%</td>
<td>10-13</td>
</tr>
<tr>
<td>Minimum</td>
<td>7-8 km/h</td>
<td>7.5 km/h</td>
<td>90%</td>
<td>4-5</td>
</tr>
</tbody>
</table>

Sample size is counted based on the number of survey probe vehicles which passed the road segment.

### 4.1.3 Standard Deviations and Sample Size of Mean GPS Spot Speed

Similar to [1] Space Mean Speed, the standard deviations of [2] Mean GPS Spot Speed were crossed with the hourly traffic volume per lane and land use along road segments. The values of standard deviations are significantly higher than [1] Space Mean Speed. The general trend by categories are in line with [1] Space Mean Speed. However, the trend does not always follow it, such as a traffic volume of less than 500 PCU/hour/lane. This might be due to a lack in the number of samples for this category.
Note: Numbers in the figure are of the 90th percentile (upper one) and the mean (lower one).

Figure 11. Standard Deviations of [2] Mean GPS Spot Speed by Hourly Traffic Volume per Lane

Figure 12. Standard Deviations of [2] Mean GPS Spot Speed by Land Use along Road Segment

With standard deviations in the previous graphs, sample sizes were estimated by four levels of accuracy requirement. The number of samples is not based on the number of survey vehicles passed the road section, but on the number of GPS spot speed observations of the road section.

<table>
<thead>
<tr>
<th>Accuracy Requirement</th>
<th>Assumed Standard Deviation</th>
<th>Error Margin</th>
<th>Confidence Level</th>
<th>Sample Size*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>19-21 km/h</td>
<td>5km/h</td>
<td>95%</td>
<td>56-68</td>
</tr>
<tr>
<td>High</td>
<td>15-18 km/h</td>
<td>5km/h</td>
<td>95%</td>
<td>35-50</td>
</tr>
<tr>
<td>Standard</td>
<td>12-13 km/h</td>
<td>5km/h</td>
<td>95%</td>
<td>25-29</td>
</tr>
<tr>
<td>Minimum</td>
<td>12-13 km/h</td>
<td>7.5km/h</td>
<td>90%</td>
<td>9-10</td>
</tr>
</tbody>
</table>

*Sample size is counted based on the number of observations of GPS spot speed.
4.1.4 Discussions and Implication on Sample Size

The analysis on the difference of the two methods of travel speed depicted that the differences of the two methods can be minimized to roughly 1km/h with shorter GPS observation intervals. On the other hand, analysis on the standard deviations and sample size presented guidelines on the required number of sample sizes. As the unit of sample size is different by both methods, the number of survey vehicles passed the road segments and the number of GPS spot speed observations; simple comparative analysis is conducted here. To collect very accurate travel speed data from [1] Space Mean Speed, 29 samples which passed the road segment should be collected. On the other hand, [2] Mean GPS Spot Speed requires 68 GPS spot observations which needs to be collected with shorter observation intervals. If the GPS observation interval is ten seconds, the average travel speed is 10km/h, and, the segment length is 1km, a survey vehicle can pass the road segment in six minutes. Thus, 36 GPS spot speed observations can be collected from only one survey vehicle. This means that just two survey vehicles can collect the required number of observations for the sample, 68. However, attention should be paid on the biases caused by a driver and vehicle type. In case the number of vehicles which pass the road section is limited, the results can be largely biased even though the number of collected GPS speed observations is high enough. Considering the required number of survey vehicles for [1] Space Mean Speed with standard accuracy requirement, at least 10 – 13 vehicles are recommended to be collected for reliable analysis. However, even a small number of GPS spot speed observations such as ten observations can be meaningful bearing in mind that the results potentially contain certain errors and biases. These are helpful in developing countries to roughly understand travel speed trends in the region.

4.2 Comparison of Two Methods of Averaging Travel Speed

With findings on the potential errors and sample size of the two methods discussed in the previous sections, the strength, limitations and potential area of application are discussed from the practical point of view in urban areas in developing countries.

4.2.1 Space Mean Speed by Section Entry and Exit Time

Strengths and limitations of the [1] Space Mean Speed by Segment Entry and Exit Time Method is summarized in Table 3. While this method is accurate, the estimation method is complicated and it requires time. Therefore, this method is appropriate for the TSS of transportation planning process which does not require real-time or instant travel time information. It is also should be noted that data with missing parts in the middle of the road section can be utilized for analysis. For instance, even if an intermediate part of the road section is under a flyover, travel speed can be accurately observed as long as the entry point and the exit point data are valid. This is advantageous in urban areas in emerging economies where a number of flyovers and skyscrapers cause GPS black spots.
Table 3. Strength and Limitations of Space Mean by Section Entry and Exit Time

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>· Speeds can be accurately estimated without overestimation characteristics of spot speed.</td>
<td>· Complicated estimation requires longer computation time.</td>
</tr>
<tr>
<td>· Data with missing sections in the middle of road segment can be utilized. (Ex. road segment with underpass section)</td>
<td>· In case of real-time TSS, samples with partial data cannot be utilized.</td>
</tr>
</tbody>
</table>

4.2.2 Mean GPS Spot Speed

This method requires less time for travel speed estimation. In addition, the samples with only a part of the section can be utilized. This is advantageous especially for real-time TSS. For instance, although the closure of roads due to traffic accidents cannot be illustrated until the road opens for the method [1] Space Mean Speed Method, this method can show the decrease of travel time due to it.

While there is a trend of overestimation of travel speeds compared with [1] Space Mean Speed, the results can be accurate enough for roughly understanding congestion trends. The differences also can be minimized by reducing the speed observation intervals. Thus, this method can be applicable for quick travel speed analysis for transport planning as well considering constraints in developing countries.

Table 4. Strength and Limitations of [2] Mean GPS Spot Speed

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>· Speeds can be calculated with less computation time.</td>
<td>· Speeds can be overestimated compared with Space Mean Speed.</td>
</tr>
<tr>
<td>· Samples with only a part of the section can be utilized for analysis. This is advantageous for real-time TSS.</td>
<td>· Sample with a part of the section might cause biases in analysis. Ex. data of roads in CBD with skyscrapers can be excluded from the analysis.</td>
</tr>
<tr>
<td>· Accuracy can be tolerable for trend analysis.</td>
<td>· Biases due to a driver and a vehicle type can be salient in case the number of survey vehicle is limited.</td>
</tr>
<tr>
<td>· Sample size in terms of the number of vehicles passing the road section can be smaller.</td>
<td></td>
</tr>
</tbody>
</table>

6. CONCLUSIONS

There are several obstacles to be overcome in order to implement a travel speed survey in urban areas in developing countries while it is a fundamental source of information for transportation planners and for drivers and riders. These include constraints in budget and time, lack of information on road segments, flexible operation of traffic control and relatively
high deviation of travel speeds. Taking these obstacles into consideration, the methodology of an affordable and precise travel speed survey (TSS) in urban areas in developing countries with simple procedures can be developed. The method of identifying road sections can be done with simple road segment data. The developed procedure is tested with the field observation of the eight month TSS in the Colombo Metropolitan Area. For the method of averaging travel speeds, two methods are presented and tested with a huge data source from the TSS results. Based on this, guidelines on the sample size by two methods of averaging travel speed were proposed and discussed. The strengths, limitations and implications on how to use the two methods were discussed. Finally, two examples of applications of the TSS results in the transportation planning process were presented. It is understood that the above development in methodology and findings in the TSS can contribute to the practice of transportation planning in urban areas in developing countries.

Further detail quantitative examinations are required on the root causes of the differences between the two methods of averaging travel speed; [1] Space Mean Speed by Entry and Exit Time and [2] Mean GPS Spot Speed. While these two results were compared with the same source of information in this paper, these should be tested with other speed observations such as video number plate surveys, loop traffic counters and microscopic traffic simulations.

There are other obstacles in urban areas in developing countries which were not tested in this paper. Survey methods of large GPS black spots in urban areas caused by roads under flyovers and skyscrapers need to be studied further. Identifying two roads located parallel and close each other or physically separated lanes of a road segment are other areas to be studied. As this paper utilized the survey results in the Colombo Metropolitan Area (CMA), further empirical studies are required in other urban areas taking the driver’s behavior, vehicle types, traffic rules and the road networks into consideration. However, the methodology for estimating travel speeds might be applicable to other urban areas due to CMA’s typical characteristics of rapidly growing urban areas in developing countries.

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REFERENCES

Japan International Cooperation Agency (JICA) and the Ministry of Transport (MoT), Democratic Socialist Republic of Sri Lanka (2014) Urban Transport Master Plan,


