Travel Time Estimation by Running Speed and Stopped Delay Method on Urban Road Using Probe Vehicle Data

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Abstract: Travel time is the simplest and vital information in Advanced Traveler Information System (ATIS) and Advanced Traffic Management System (ATMS). It can well represent traffic conditions and is considered as one of the most understood measure for all road users. In this paper, the concept of Running Speed and Stopped Delay (RSSD) method for travel time estimation is proposed. This concept was modified from the average speed method, due to the advantage of moveable sensor, such as probe vehicle, in which the location and speed of tracked vehicle can be automatically detected by moveable sensor. Consequently, the running speed and stopped delay time could be extracted from the total travel time. The field data from urban arterial roadways in Bangkok area were used to verify and investigate the performance of proposed method compared with the average speed method. Results from real traffic data indicate that the accuracy of travel time estimation is significantly improved by RSSD method.

Keywords: Travel Time Estimation, Running Speed, Stopped Delay, Probe Vehicle, Urban Road, Probe Data

1. INTRODUCTION

Travel time is an important quantitative indicator representing traffic condition, it is also considered as the vital information for both road users and traffic operators. In the view point of road users, knowing travel time or traffic condition could help making informed decision in pre-trip planning and/or on road rerouting. For traffic operators, as a key performance for advanced traffic management system, overall travel time is the important marker for evaluating the efficiency of road network and ongoing operational plan.

Travel time can generally be collected by two main techniques (Lin and Zito, 2005); (1) using fixed sensors such as registration plate matching, loop detectors, infrared sensors or radio beacon, etc. to gather data from passage vehicles at selected points, and (2) using moveable sensors or observers such as probe vehicle (PV) method or floating car technique, etc.

The fixed sensors or point detection devices typically measure volume and occupancy of traffic. These kinds of sensors are widely used on freeways and principal arterials, in the past decades, many of research on urban travel time estimation are based on loop detectors information (Sisiopiku, 1994; Lucas et al., 2004; Robinson and Polak, 2005; Guo and Jin, 2006). Although using loop detectors as the traffic data collection device is popular, there are some arguments on using data from loop detector in providing travel time and speed estimation particularly for the signalized urban roads. Firstly, traffic volume and occupancy

are the general form of information measured from loop detectors, many of assumptions are needed to convert these data to travel time or speed, for instance the traffic speed-density-volume relationship, which leads to unavoidable uncertainties and errors in estimation. Secondly, in case of vehicle queues extend over the detector location, the accurate estimation of travel time and speed is hard to perform. Thirdly, loop detector systems need to be installed, operated and managed. Therefore, whole networks or wide area installation of loop detector system could be cost prohibitive. The automatic vehicle identification, the other type of fixed sensors, can give accurate travel time estimate. This type of sensors includes automatic license plate matching, radio frequency identification (RFID). Travel time from these sensors is unarguably accurate as the time of vehicle passage is recorded at sensor locations. However, there are also costly to implement and these sensors generally cannot provide other basic traffic data. RFID-type sensor requires the vehicle units installed on vehicles.

On the other hand, probe vehicle method acts as moveable sensors that travel in the traffic stream and track the real-time location and speed along the travel route, travel time and speed between any two locations directly being measured. Furthermore, this technique does not require any instrumentation or infrastructure to be constructed on the road network. Therefore, based on the promising data from this device, the cost-effective and reliable, application of this technique on the wide area network for travel time estimation could be possible. In recent years, a number of studies on travel time and speed both on freeways and arterial roads were conducted using moveable sensors (Yang, 2005; Poomrittigul *et al.*, 2008;; Herring *et al.*, 2010; Zhao *et al.*, 2011; Puangprakhon and Narupiti, 2012; Zheng and Zuylen, 2013).

Research on travel time and speed estimation by Quiroga and Bullock (1998) has demonstrated the feasibility of performing travel time collection using Global Positioning System (GPS) technology. In their study, a procedure for travel time and travel speed estimation using speed data detected from GPS was proposed. They applied the relationship between average speed and the segment length to estimate segment travel time. Their proposed methodology was verified with the real traffic data from highway network and concluded that the estimation showed good agreement with the real traffic data. Many researchers applied this concept in various purposes, for instance, Zou et al. (2005) applied this technique and developed the new methodology for performing arterial speed study from GPS data, Quiroga (2000) used this concept to measures the performance of congestion management systems, Jiang et al. (2009) analyzed and evaluated the travel time estimation from this concept compare to the direct method.

In this paper, with the advantages of moveable sensors in which they can provide the location and speed of the tracked vehicle, the modified procedure for travel time estimation based on the running and stopped behavior of vehicles is proposed. The field data collected from one-second sampling period GPS on urban arterial road in Bangkok, Thailand were used to confirm the accuracy of proposed method.

The remainder of this paper is organized as follows. Section 2 relates the theoretical background on travel time estimation and the proposed method. The corridor for this study and the data collection method are described in Section 3. Section 4 presents and discusses the results from observed data and the estimated travel time from both average speed method and RSSD method. The concluding remarks are discussed in the final section.

2. THEORETICAL BACKGROUND AND CONSTRUCTION OF TRAVE TIME ESTIMATION METHOD

2.1 Definition of Travel Time

Travel time is defined as the time spent to travel between any two points. In general, the travel time is composed of running time and stopped delay time. Figure 1 depicts the concepts of running time and stopped delay time. As could be seen in Figure 1, the *running time* is time that the vehicle is in motion, while *stopped delay time* can be defined as time when the vehicle is completely stopped or moving considerably slow as to be stopped, typically less than 8 km/hr or 5 mph (Turner et al., 1998).
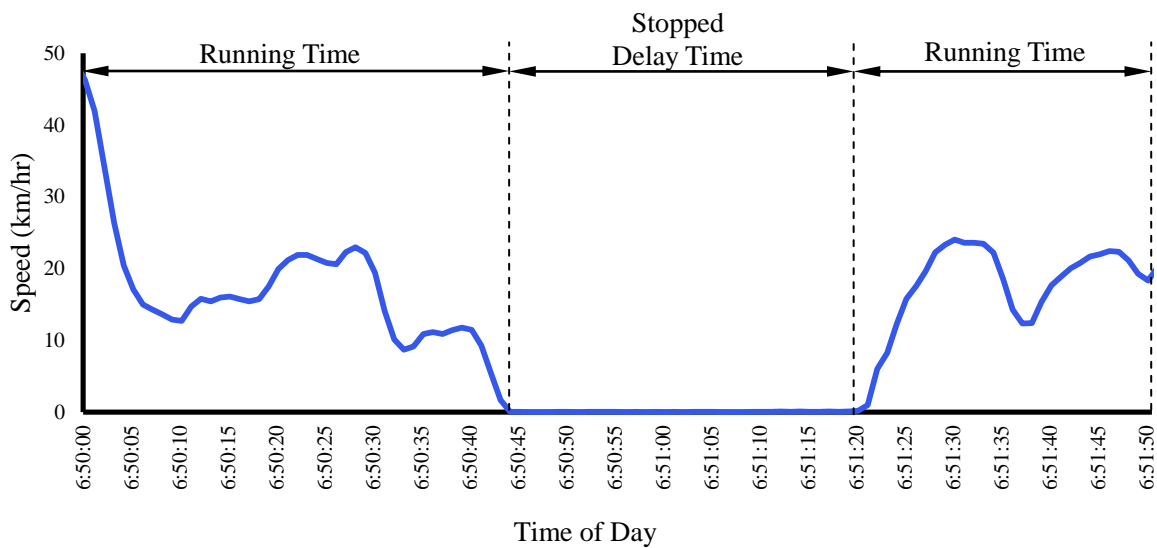

Figure 1. Illustration of running time and stopped delay time

Based on the definition of travel time, segment travel time, T_S or travel time spent for traversing any road segment can be expressed in terms of running and stopped delay time as:

$$T_S = t_R + t_D \tag{1}$$

$$T_S = \frac{L}{v_R} + t_D \tag{2}$$

where T_S denotes the segment travel time, t_R is running time, t_D is stopped delay time, L is distance traveled or length of the roadway segment, and v_R is the average running speed.

2.2 Estimation of Travel Time and Travel Speed from GPS Data: Average Speed Method

GPS recievers is capable to gather coordinates, speeds and time. The speed and the position from GPS recievers are independent due to the speed was calculated from the receivers poll psudorange data (distance between sattelite and GPS reciever) and psudorate data. This allowed to calculate traveling distance from GPS speed and also permitted to calculate the segment speed (Quiroga and Bullock (1998).

Let d be the distance traveled covered by probe vehicle during time t_0 and t_p. From Figure 2, distance traveled can be expressed as:

$$d = \int_{t_0}^{t_p} v\,dt \approx v_0\left(\frac{t_1 - t_0}{2}\right) + \left[\sum_{k=1}^{p-1} v_k\left(\frac{t_{k+1} - t_{k-1}}{2}\right)\right] + v_p\left(\frac{t_p - t_{p-1}}{2}\right) \tag{3}$$

This trapezoidal approximation is reasonable in case of time interval among GPS points is small enough and distance between two adjacent GPS points are much smaller than the segment length or distance traveled.
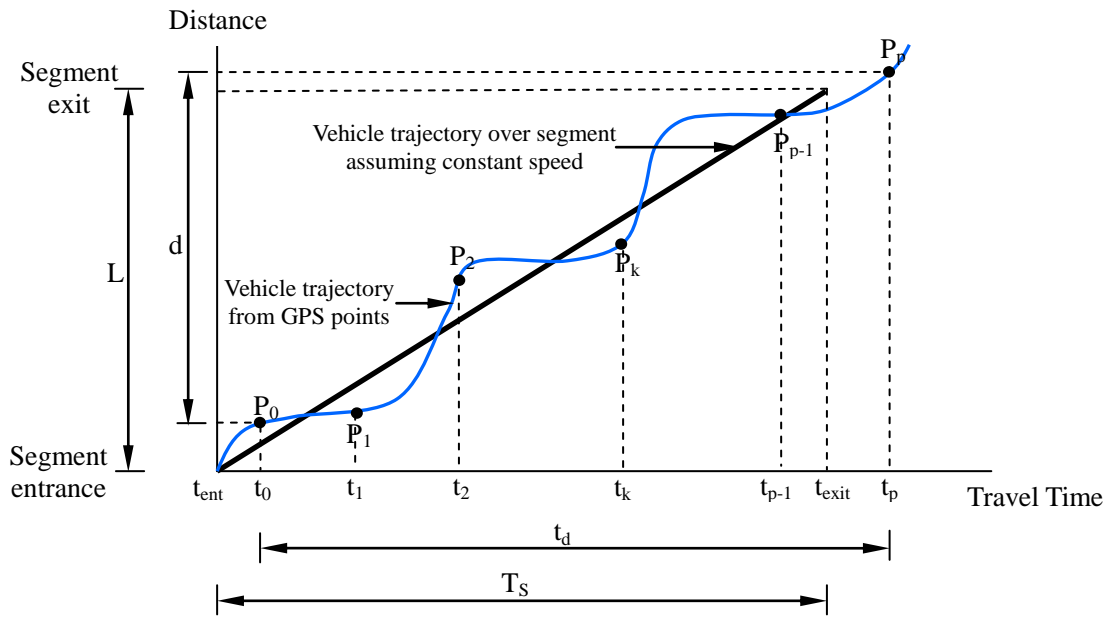

Figure 2. Time-space diagram for GPS points along traveled segment

The average speed u_d associated with distance traveled d can be expressed as:

$$u_d = \frac{d}{t_d} = \frac{d}{t_p - t_0} \tag{4}$$

where t_d denotes travel time spent for traversing through distance d.

In case of the first and last GPS point corresponded to the segment are sufficiently close to the entrance and exit points of segment respectively, the distance traveled d and segment length L should be very similar. As a result, the average segment speed u from u_d can be estimated and equation (4) can be rewritten as:

$$u \approx \frac{1}{t_p - t_0}\left\{v_0\left(\frac{t_1 - t_0}{2}\right) + \left[\sum_{k=1}^{p-1} v_k\left(\frac{t_{k+1} - t_{k-1}}{2}\right)\right] + v_p\left(\frac{t_p - t_{p-1}}{2}\right)\right\} \tag{5}$$

Generally, the segment length L is known, consequently, segment travel time then becomes

$$T_S \approx \frac{L}{u} \tag{6}$$

2.3 Proposed Method for Travel Time Estimation: Running Speed and Stopped Delay Method (RSSD)

As illustrated in Section 2.1, travel time is composed of two parts: the running time and stopped delay time. Recall equation (4), the distance traveled covered by the probe vehicle can be computed by:

$$d = t_d \times u_d \tag{7}$$

As the distance traveled is arisen only from running period, therefore the equation can be rewritten so that the distance traveled is a function of running speed as:

$$d = t_{R,d} \times v_{R,d} \tag{8}$$

where $t_{R,d}$ denotes running time spent for traversing through distance d and $v_{r,d}$ denotes the average running speed associated with distance traveled d.

Equation (5) can then be rewritten in terms of running speed and stopped delay as:

$$v_{r,d} \approx \frac{1}{[(t_p - t_0) - t_{D,d}]} \left\{ v_0 \left(\frac{t_1 - t_0}{2} \right) + \left[\sum_{k=1}^{p-1} v_k \left(\frac{t_{k+1} - t_{k-1}}{2} \right) \right] + v_p \left(\frac{t_p - t_{p-1}}{2} \right) \right\} \tag{9}$$

where $t_{D,d}$ denotes stopped delay time during the vehicle was traversing through distance d.

In all roadway types, it is theoretically recognized that while a vehicle transferring from one road segment to nearby segment, the vehicle speed needs to be more than zero, or in other words it must be in the running state (stopped vehicle cannot move). Furthermore, in case of small GPS sampling period, the vehicle speeds between last GPS point in the former segment and the first GPS point in the latter segment are generally be more than zero (no stopped delay time between two contiguous GPS points which lie on different segment).

For the signalized arterial roads, the road segments are typically spliced at the signalized intersection. The transferring between one segment to another occurs after the vehicle passes the signal (intersection) and occupies the neighboring road section. At this moment, the driver normally needs to maintain the vehicle speed to pass the signal light and move to next section. Let reconsider the concept of travel time estimation in Figure 2, the unknown T_S is estimated through the relationship between known distance traveled d and segment length L (shorten or lengthen the known distance around the edge of segment to the segment length) and the average speed u (which comprises running speed and stopped). However, from the above argument in general, vehicles travel passing the connection point

between two consecutive sections. This means the time changed respect to shorten or lengthen distance is governed only from running speed.

Therefore, it is reasonably to use the running speed instead of average speed in performing travel time estimation. With this manner, the segment travel time can be written in terms of running time and stopped delay time as:

$$T_S \approx \frac{L}{v_{R,d}} + t_{D,d} \tag{10}$$

2.4 Thresholds for Stopped delay Detection

The recorded speeds from GPS receivers are normally included with some discrepancies from real speed of tracked vehicle. Although the amount of this deviation from the new model GPS receivers is not large (most of the new GPS models have the deviation of speed measurement is less than 0.1m/sec) but it is accepted that this sort of error always exists in the recorded data. Figure 3 illustrates speed-time diagram extracted from GPS data. It can be noticed that, even during the stopped delay period, the tracked speeds from GPS are fluctuated and not equal to zero.

Therefore, from the deviation of speed during stopped delay time from GPS reading, the error of measurement in this state can be diminished by setting up the threshold for stopped delay detection. This means that, when the threshold is set, the detected speed valued less than the threshold value will be automatically interpreted as totally stop (0 km/hr). Moreover, in order to perform the travel time estimation from RSSD method, the stopped delay time needs to be detected. In this study, three threshold values for the stopped delay detection (1km/hr, 3 km/hr, and 5km/hr) were used to investigate the appropriate threshold for stopped delay detection on urban arterial roads.
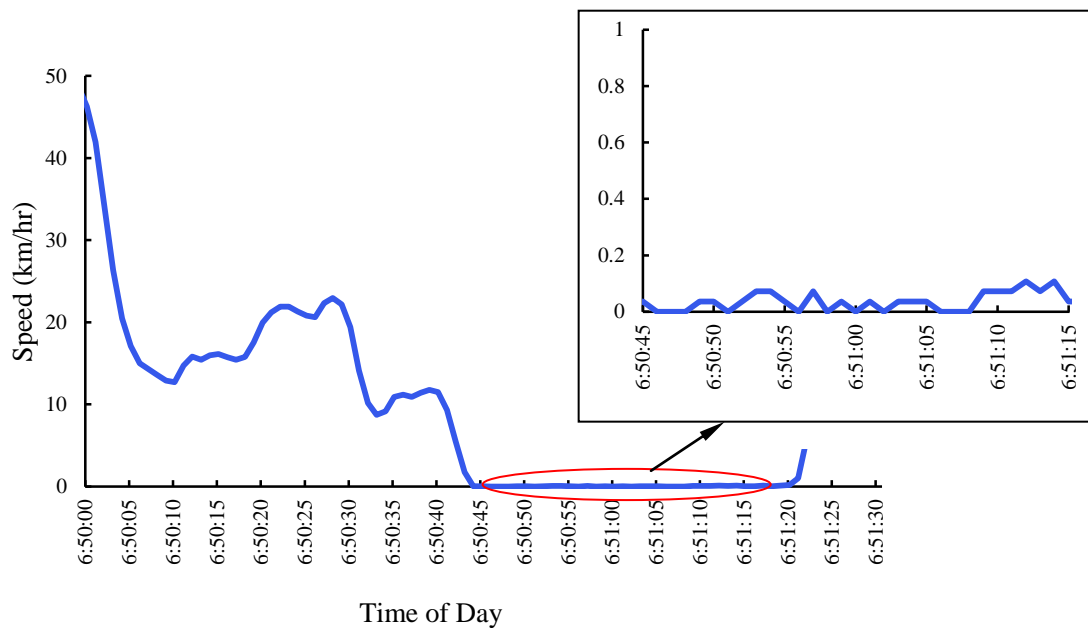

Figure 3. Deviation of recorded speed from GPS during stopped delay time

3. RESEARCH DESIGN AND METHODOLOGY

3.1 Study Location

An urban arterial road in Bangkok, Thailand was selected as the study corridor for traffic data collection using probe vehicle technique. Figure 4 illustrates the location and provides schematics diagram of the study site. The 6.04 km route in-bound direction of Petchaburi road was selected as the study corridor. It composed of 8 road segments, partitioned at signalized intersections, with different lengths ranging from 0.18 to 1.47 km. The number of lanes on road segments also vary, some segments have 3 lanes and others have 4 lanes per direction. Most of the area along both sides of the studied corridor comprised low to medium-rise buildings (most of them are lower than 8 stories). Therefore, in general weather condition, the very high quality of GPS signal could be detected within this corridor (minimal road valley effect).

   The objective of this study is to apply the proposed procedure for travel time estimation on urban arterial road based on probe vehicle data. Therefore, GPS receivers were used to track the movement of probe vehicles in every one second. For each data point, the collect time, location, and speed of the vehicle at regular sampling periods automatically recorded. The field data were collected from 15 probe vehicle runs (5 vehicles, each vehicle run 3 times) throughout the study corridor during 6:00am-16:00pm on August 16, 2012. In addition, two types of GPS receivers were used in this study; the first model has accuracy in position and velocity within 3m and 0.36 km/hr (0.1 m/s) respectively, while the other provides accuracy within 5m and 1 km/hr.
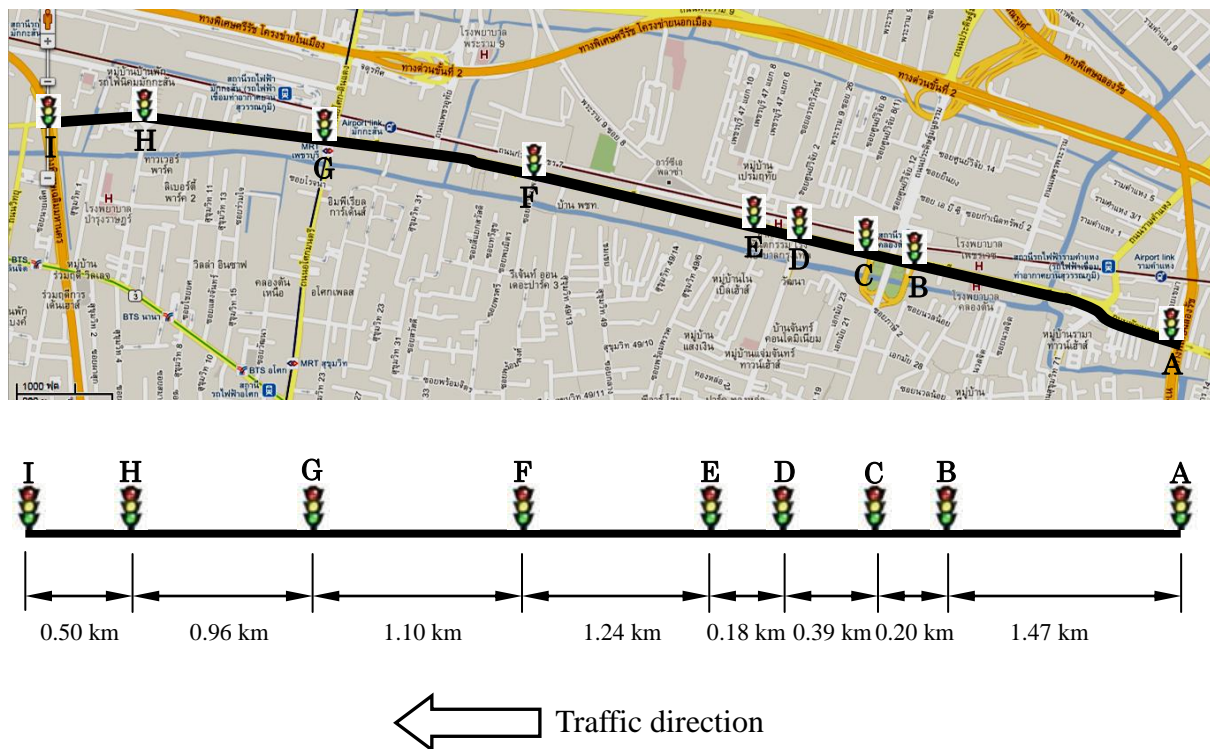

Figure 4. Location and schematic diagram of study corridor

3.2 Evaluation Method

In order to examine the accuracy of the proposed travel time estimation procedure, Mean Absolute Percenage Error (MAPE) and Root Mean Square Error (RMSE) were used to investigate the amount off estimation error compared with the observed travel time since MAPE can express the estimation error in generic percentage terms and is often useful as the accuracy indicator, and RMSE can measure the differences between estimated values and the values actually observed.

$$MAPE = \frac{100}{n} \sum_{i=1}^{n} \left| \frac{tt_{est}(i) - tt_{obs}(i)}{tt_{obs}(i)} \right| \tag{11}$$

$$RMSE = \sqrt{\frac{\sum (tt_{est}(i) - tt_{obs}(i))^2}{n}} \tag{12}$$

where $tt_{est}(i)$ is the estimated travel time of segment i, $tt_{obs}(i)$ denotes the observed travel time of segment i and n is the number of data to be computed.

Percentage of Improvement (PoI) was used to investigate of the performance of proposed method over the average speed method. The PoI of travel time estimation from proposed method related to the average method on segment j can be computed in terms of Root Mean Square Error (RMSE) by:

$$PoI_j = \frac{RMSE_{avg.speed,j} - RMSE_{RSSD,j}}{RMSE_{avg.speed,j}} \tag{13}$$

where $RMSE_{avg.speed,j}$ denotes the RMSE on segment j from the estimation using average speed method, $RMSE_{RSSD,j}$ denotes the RMSE on segment j from the estimation using RSSD method.

4. RESULT AND DISCUSSION

Recorded field data associated with the time-space diagram of all runs throughout the study corridor were shown in Figure 5. The data were collected in both the congested period during the morning peak and the off-peak period in the late morning and afternoon. The first run of probe vehicle was entered the study corridor in the early morning around 7:00 AM while the last run (15th) was exited from the study corridor around 15:45PM. These data were extracted from GPS receivers with one second sampling time. The observed travel time and delay were shown in Table 1. The observed average speed and running speed of all runs were shown in Table 2. These sets of data were used to evaluate the correctness and the performance of the estimation methods

From Figure 5 and Table 1, during the morning peak period (particularly in the 3rd-5th run), higher congestion could be observed through the greater travel time and more frequent stops, compared to those of the off-peak time. Smoother traffic flow and shorter route travel time can be observed from the vehicle trajectory profiles during off-peak hours. The traffic

behaviors were also different from segment to segment. Segment AB, EF and HI were the most congested segments among the all study segments due to their higher ratio between stopped delay time to the travel time (DT/TT) and the non-smooth profile of vehicle trajectories.
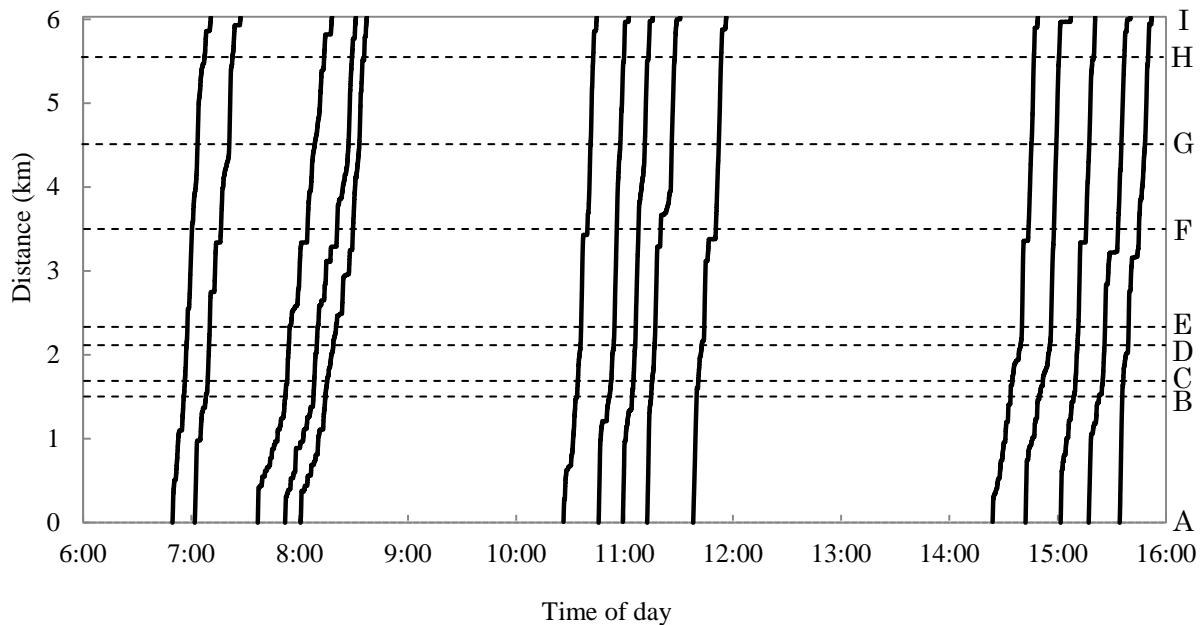

Figure 5. Time-space diagram of 15 probe vehicle runs throughout study corridor

Table 1. Travel time and stopped delay time of all runs

Run	Segment travel time (sec)																Route travel time (sec)	
	AB		BC		CD		DE		EF		FG		GH		HI			
	TT	DT	TT	DT	TT	DT	TT	DT	TT	DT	TT	DT	TT	DT	TT	DT	TT	DT
1	366	131	41	2	50	0	32	0	157	25	192	17	224	46	216	111	1278	332
2	364	182	62	21	44	0	21	0	379	238	283	56	97	8	276	166	1526	671
3	901	644	73	27	49	0	26	0	602	372	276	52	277	66	268	176	2472	1337
4	939	666	31	0	80	26	22	0	656	477	390	186	105	0	136	52	2359	1407
5	818	568	62	9	196	108	75	38	591	423	221	31	152	53	92	24	2207	1254
6	398	150	73	35	80	0	27	0	213	117	118	10	78	0	123	48	1110	360
7	333	146	79	21	79	9	29	0	84	0	127	0	114	3	168	112	1013	291
8	301	129	47	0	50	0	25	0	95	0	219	23	110	26	149	86	996	264
9	124	15	36	0	75	11	28	0	184	85	375	260	95	6	184	108	1101	485
10	112	0	54	29	106	28	91	59	388	268	106	0	72	0	176	109	1105	493
11	593	284	58	32	232	131	85	17	223	140	112	0	67	0	138	71	1508	675
12	411	196	163	101	215	85	50	0	103	0	88	0	79	0	399	326	1508	708
13	429	202	64	28	58	0	27	0	269	168	113	0	141	41	53	0	1154	439
14	338	163	125	90	56	0	18	0	437	286	119	0	90	0	208	138	1391	677
15	85	0	32	8	160	83	17	0	346	217	211	40	95	0	118	58	1068	410
Avg.	434	232	67	27	102	32	38	8	315	188	197	45	120	17	180	106	1453	654
DT/TT	0.53		0.40		0.31		0.20		0.60		0.23		0.14		0.59		0.53	

- TT denotes travel time.
- DT denotes stopped delay time.
- Stopped delay time in this table was considered as the time once traveling speed less than 1km/hr.

The results of travel time estimation were analyzed in several view points; thresholds for stopped delay detection, the evaluation of RSSD method compared with average speed method, the effect of GPS sampling rate, the effect of traffic condition, and the effect of GPS

accuracy on the accuracy of estimated travel time. The thresholds for stopped delay detection analysis depicts on effect of different threshold values on the accuracy of travel time estimation for typical urban arterial roads. The evaluation part gives details and discusses on performance of RSSD method and the average speed method for travel time estimation. The effects from GPS sampling period display the advantage of using high sampling rate, e.g. one second, to estimate travel time. The traffic condition analysis illustrates the effect of congestion level on the correctness of both techniques. The GPS accuracy analysis shows the effect of GPS precision on the accuracy of estimated travel time.

Table 2. Average speed and running speed of all runs

Run	Segment speed (km/hr)															
	AB		BC		CD		DE		EF		FG		GH		HI	
	AS	RS	AS	RS	AS	RS	AS	RS	AS	RS	AS	RS	AS	RS	AS	RS
1	14.5	21.9	17.1	17.1	28.0	28.0	19.5	19.5	28.3	32.1	20.5	21.3	15.6	18.5	8.5	16.9
2	14.6	27.4	10.5	14.5	32.0	32.0	29.1	29.1	11.8	30.6	13.6	14.4	35.9	36.3	6.8	16.7
3	5.9	18.8	9.5	13.5	28.2	28.2	24.4	24.4	7.4	17.7	14.3	16.8	12.5	15.3	6.9	19.9
4	5.0	15.5	20.9	20.9	16.3	23.3	25.9	25.9	6.3	21.0	8.8	13.9	32.2	32.2	13.2	20.8
5	5.9	17.4	10.5	12.1	5.0	10.1	6.5	12.2	6.5	20.9	16.3	18.2	22.6	33.7	19.0	25.0
6	13.3	19.6	9.8	17.2	17.3	17.3	22.3	22.3	21.0	46.0	33.3	33.3	44.4	44.4	15.3	22.5
7	16.2	24.6	8.6	11.0	18.4	19.9	20.3	20.9	52.6	52.6	31.3	31.3	30.4	30.4	11.2	30.2
8	17.5	26.8	16.3	16.3	27.0	27.0	24.9	24.9	46.3	46.3	18.1	18.8	31.8	40.1	12.3	28.7
9	42.3	45.6	16.2	16.2	14.2	15.5	21.3	21.3	23.1	40.6	8.3	18.9	36.7	38.3	9.7	22.2
10	45.9	45.9	13.8	28.7	11.8	14.9	5.4	8.7	10.9	32.6	35.9	35.9	46.9	46.9	10.0	25.6
11	8.9	13.7	12.2	25.2	6.0	10.6	7.2	8.0	19.8	52.6	35.3	35.3	51.0	51.0	13.4	26.3
12	13.0	21.7	4.2	9.4	6.2	7.9	12.5	12.5	42.9	42.9	44.8	44.8	43.6	43.6	4.6	23.6
13	12.0	21.1	10.5	13.6	23.0	23.0	23.7	23.7	16.5	42.2	34.0	34.0	23.9	33.0	33.8	33.8
14	15.1	26.3	4.3	12.8	22.9	22.9	32.2	32.2	9.9	25.8	32.5	32.5	37.0	37.0	8.4	20.5
15	57.4	57.4	25.5	29.1	6.5	10.4	29.5	29.5	11.5	28.5	17.0	19.5	36.1	36.1	14.7	29.5
Avg.	19.5	27.3	12.3	17.2	16.8	18.8	20.4	21.1	20.5	35.7	24.5	26.3	34.6	37.0	12.8	24.7
RS-AS	7.8		4.8		2.0		0.7		15.3		1.7		2.4		11.9	

- AS denotes average speed.
- RS denotes running speed.

4.1 Thresholds for Stopped Delay Detection

The results of travel time estimation from GPS data with and without stopped delay detection threshold are shown in Figure 6, the diagonal plots were used to investigate the under and over estimation of this concept and to illustrate the deviations from observed data when integrated with stopped delay detection thresholes. In this section, travel times were estimated by using the average speed method as described in equation (3) to (6) from GPS data set sampled every one second.

Figure 6 illustrates that travel time estimated by average speed method with and without stopped delay threshold have the same fashion, the estimation without threshold and with 1 km/hr threshold show the approximately equivalent and best fit with observed data. In case of stopped delay threshold were widen to 3 and 5 km/hr the out of fit could be monitored. Although, slightly overestimation could be observed from all cases but in overall, the estimated travel times were well fitted with the observed travel time.

Adding up to the diagonal plots shown in Figure 6, the Mean Absolute Percenage Error (MAPE) and Root Mean Square Error (RMSE) of estimated travel time were analyzed and presented in Table 3.

(a) Without threshold

(b) Threshold = 1km/hr
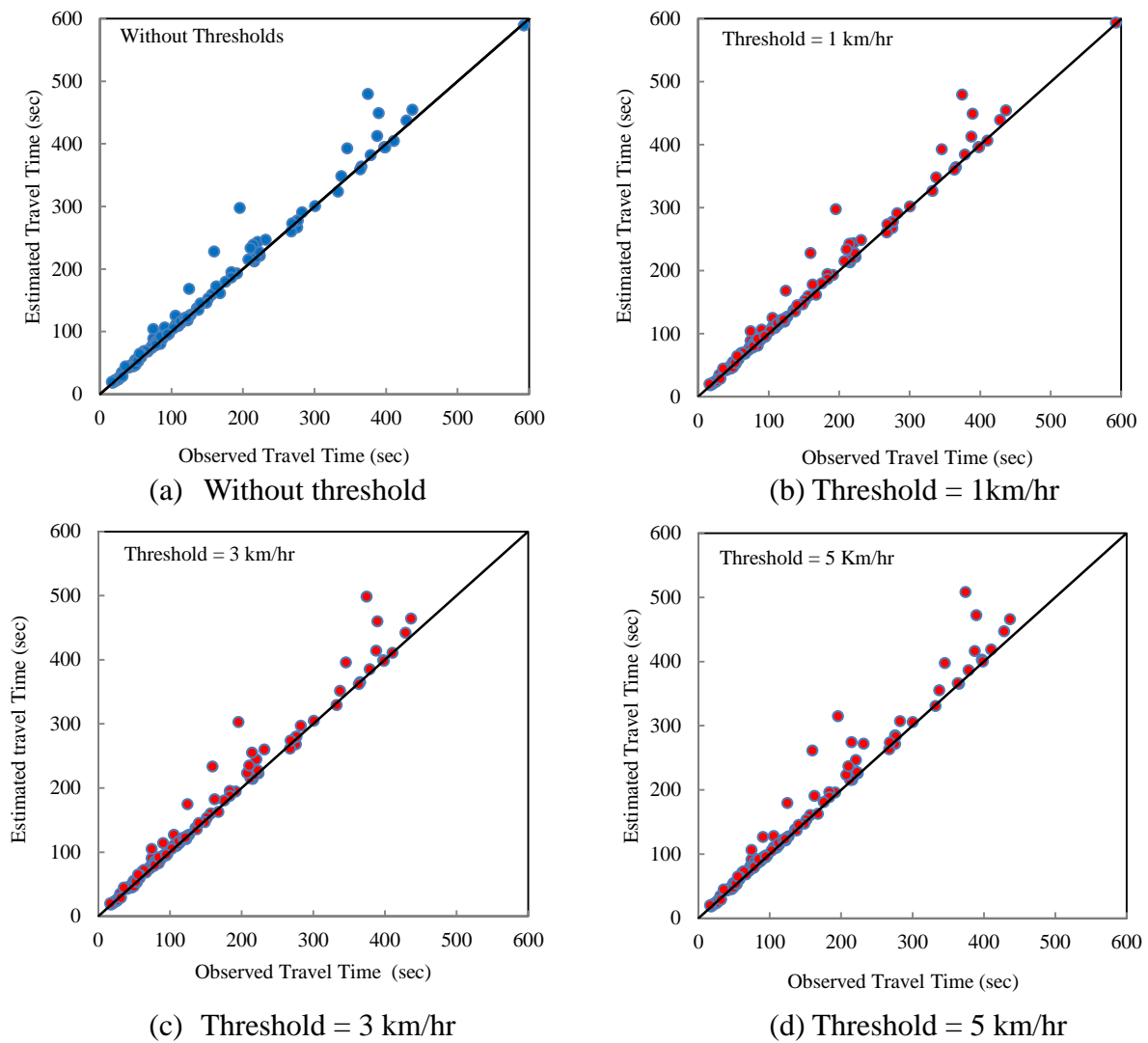
(c) Threshold = 3 km/hr

(d) Threshold = 5 km/hr

Figure 6. Diagonal plots between observed and estimated travel time with different stopped delay detection thresholds

Table 3. MAPE and RMSE of estimated travel time with and without stopped delay detection thresholds from average speed method

Segment	MAPE				RMSE			
	0 km/hr	1 km/hr	3 km/hr	5 km/hr	0 km/hr	1 km/hr	3 km/hr	5 km/hr
AB	2.98	2.78	3.09	3.93	33.29	33.09	37.44	44.64
BC	9.27	9.77	10.88	12.45	12.02	12.43	14.40	16.62
CD	16.22	16.40	17.71	20.58	33.77	34.02	37.09	45.47
DE	8.10	8.07	8.58	9.55	5.72	5.70	7.27	10.20
EF	4.54	4.67	5.16	5.72	33.58	33.69	36.46	40.62
FG	5.20	5.22	6.11	7.14	32.05	32.06	37.72	41.86
GH	1.19	1.20	1.18	1.29	1.76	1.76	1.78	2.28
HI	2.21	1.99	2.15	2.01	4.96	4.41	5.36	5.05
Avg.	6.22	6.26	6.86	8.32	19.64	19.65	22.19	25.84

From the MAPE and RMSE of the each estimation scenario as presented in Table 3, it is found that no significant improvement in the accuracy is noticed when stopped delay detection threshold is applied. Applying 1 km/hr as the stopped delay detection threshold, the better results compared with the original data (without threshold) are observed in segment with high stopped delay time (AB and HI), while in other segments no considerable development could be noticed. Moreover, the accuracy of estimation decreases when stopped

delay detection limit is widen from 1 km/hr to 3 and 5 km/hr, respectively. Therefore, from the aforementioned, the effects of diminishing stopped delay on the accuracy estimation could not be concluded at this stage due to the unremarkable difference in the estimation results. However, the 1 km/hr threshold will be used to detect the stopped delay time in the RSSD estimation approach which will be described later in the next section.

In addition, on the segments comprising large amount data (i.e. AB, EF, FG, GH and HI), the superior results can be noticed through the small MAPE values, on the other hand, in the shorter segments with low sampling the poor results were observed

4.2 Evaluation of Proposed Travel Time Estimation Method

In this section, the accuracy of estimation using the average speed and RSSD methods were investigated and compared. Three testing scenarios with different sampling times, every 1, 3 and 10 seconds, were used to address the correctness and applicability of each estimation technique on various sampling times.

Table 4. MAPE, RMSE and PoI of estimated travel time from average speed method and RSSD method on different sampling time periods

Segment	Average speed Method		RSSD Method		PoI
	MAPE	RMSE	MAPE	RMSE	(%)
Sampling period = 1 sec					
AB	2.98	33.29	1.56	11.28	66.12
BC	9.27	12.02	6.94	5.44	54.71
CD	16.22	33.77	12.44	19.92	41.01
DE	8.10	5.72	7.04	3.78	33.98
EF	4.54	33.58	2.02	11.06	67.06
FG	5.20	32.05	3.64	17.01	46.94
GH	1.19	1.76	1.11	1.56	11.19
HI	2.21	4.96	0.96	1.88	62.10
Average	6.22	19.64	4.46	8.99	47.89
Sampling period = 3 sec					
AB	3.36	34.34	1.82	11.87	65.43
BC	10.36	11.91	7.80	6.18	48.09
CD	17.67	36.00	13.76	21.74	39.62
DE	8.64	7.91	7.20	4.56	42.34
EF	5.14	35.62	2.39	11.66	67.27
FG	6.14	35.70	4.44	18.77	47.41
GH	1.62	2.15	1.51	2.03	5.74
HI	2.63	5.56	1.32	2.33	58.02
Average	6.94	21.15	5.03	9.89	46.74
Sampling period = 10 sec					
AB	5.27	39.04	3.50	15.10	61.32
BC	19.44	12.87	15.51	9.81	23.80
CD	23.62	37.02	18.80	22.91	38.11
DE	19.94	9.77	18.28	6.84	30.00
EF	9.10	51.58	4.67	15.38	70.18
FG	7.42	33.08	5.76	19.21	41.92
GH	4.24	5.80	4.22	5.65	2.67
HI	9.04	24.85	4.62	11.39	54.18
Average	12.26	26.75	9.42	13.28	40.27

Table. 4 shows the estimation results of both techniqhes in the different scenarios. The accuracy of each estimation method can be verified through the MAPE and RMSE values While the development of accuracy, once RSSD approach was employed as the estimation technique compared with average speed technique, can be demonstrated by the Percentage of Improvement (PoI) values.

As shown in Table 4, using RSSD method for travel time estimation provides better agreement with the observed data than average speed approach. It is clearly confirmed by the lower MAPE and RMSE values on every segments in all test scenarios.

In all test scenarios, MAPE values on the shorter segments i.e. BC, CD, and DE (which total travel time were 67, 102 and 38 seconds, respectively) were higher than the longer ones. Therefore, the segment length or the amount of data within segment (shorter segments generally associated with less data than the longer ones) plays important role on the correctness of estimation. The longer segment (higher amount of data), the better estimation results could be expected.

The sampling time affects the accuracy of estimation, the longer sampling periods direct to the lower in accuracy level. As illustrated in Table 4, when the sampling period increases from every 1 second to 3 seconds and 10 seconds, the MAPE values of average method increse from 6.22% to 6.94% and 12.26% (0.74% and 5.32% increasing), while those MAPE of RSSD method increase from 4.66% to 5.03% and 9.42% (0.37% and 4.93% increasing), respectively. It could be noticed that although the MAPE of both methods increase with respect to the increasing of sampling period, the RSSD offers the small rising rate.

In term of improvement, which indicated by the PoI value, the performance of estimation in all test scenarios is significantly boosted by RSSD technique as presented in Table 4. The PoI values of the 1 second, 3 seconds and 10 seconds sampling time are 47.89%, 46.74% and 40.27% , respectively. Moreover, the accuracy of estimation using RSSD technique outstandingly increases on segment AB, EF and HI. These segments are composed of high DT/TT ratio (stopped delay time per total travel time) and the large different between average speed and running speed. Figure 7 illustrates the improvement of accuracy relative to DT/TT ratio when RSSD method is employed as the estimation technique compared to the average speed method. It could be observed that, in all test scenarios, the PoI value increases once the DT/TT ratio increases.
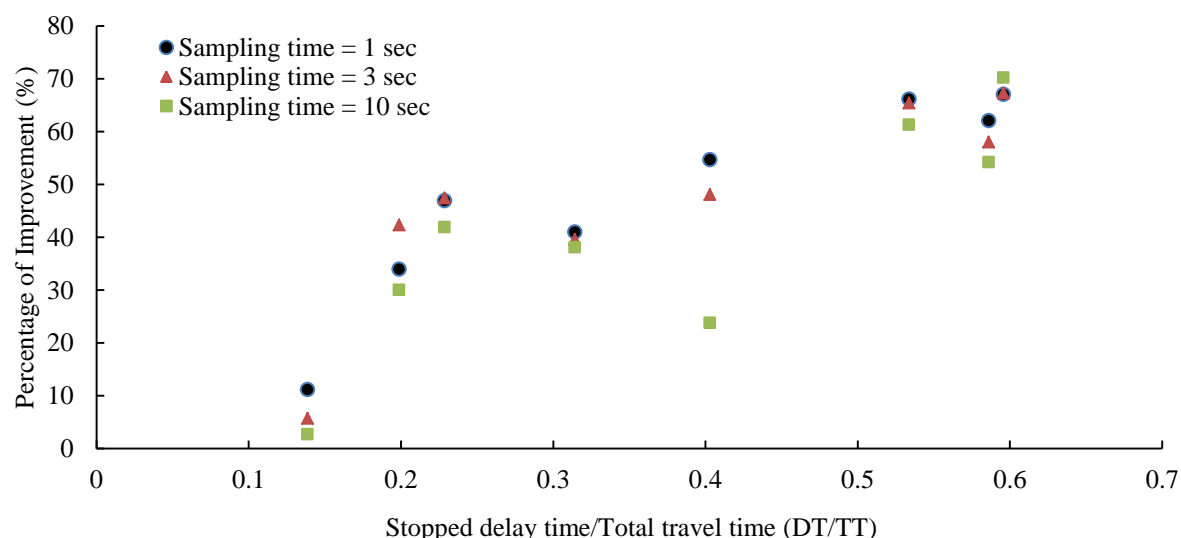

Figure 7. Relationship between PoI and the DT/TT ratio

For more understanding about the effect of traffic condition on the correctness of estimation from both methods, the relationship between MAPE from both techniques and the DT/TT ratio is presented in Figure 8. In case of no stopped delay time within the road segment, both techniques provide the same level of accuracy signified by the equivalent MAPE value. However, once the DT/TT increases (higher congested condition), the RSSD technique provides the better estimation result which could be noticed by the lower value of MAPE, while MAPE value from average speed technique increases which point out the lower level of accuracy. This is attributed from that the RSSD technique uses the running speed in the estimation procedure (the effects of stopped delay are mitigated during the estimation then is added up later). As the result, the accuracy of estimation remarkably increases on the high stopped delay segments. This manner also supports the proposed concept that the running speed should be used to represent the vehicle speed in the connecting zone between two consecutive segments on arterial road. Furthermore, vehicles need to spend more time for traversing through the entire segment in the more congested condition which means the more data points within those segments could be collected. Consequently, the more data points input to the estimation model, the more accuracy the result could be expected.
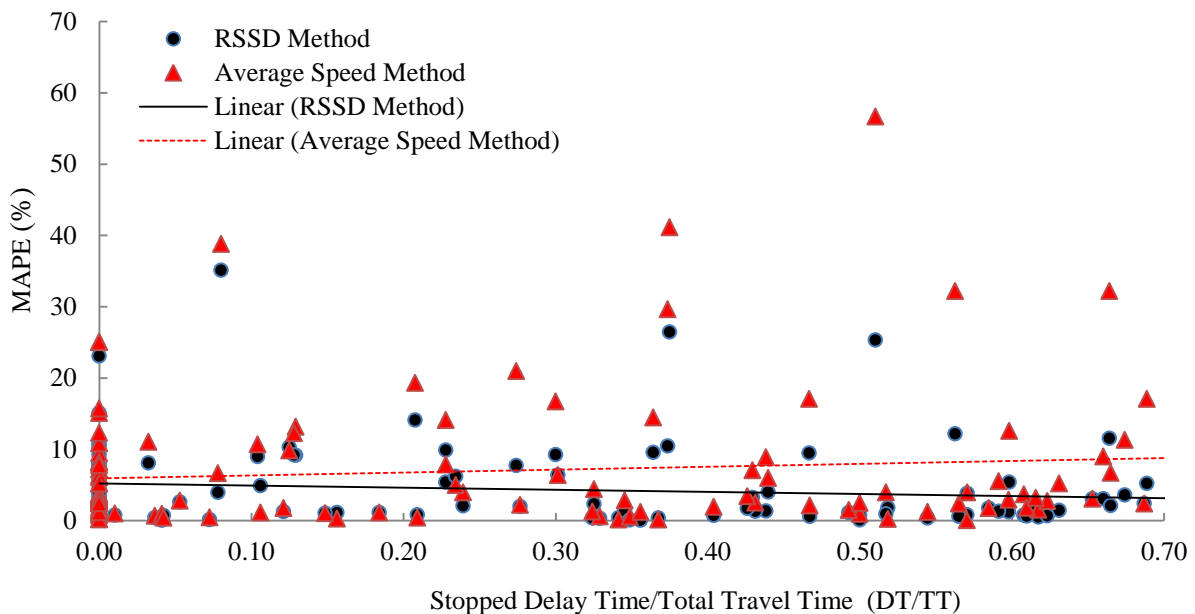

Figure 8. Relationship between MAPE from RSSD and average speed method and the DT/TT ratio (sampling period = 1 sec)

As aforementioned, two types of GPS were applied as the data collection devices in the study including; (1) Type 1 which provided the accuracy in position within 3 m range and accuracy in speed within 0.36 km/hr range, and (2) Type 2 provided 5 m range and 1 km/hr accuracy range in position and speed, respectively. Figure 9 illustrates the relationship between the MAPE values of the estimated travel time from RSSD technique and the DT/TT of each road segment. The trend lines constructed from the more precise GPS (Type 1) show the lower MAPE values in all DT/TT ratios (Noted that these linear trend lines were plotted only for comparison purpose not to explain or represent the real relationship between MAPE and DT/TT ratio). Moreover, the gap or spacing between these trend lines are fairly constant in the entire range of DT/TT ratios. At this stage, due to our study was conducted from only two GPS models and in one test corridor, it is too early to conclude about the real trend of the effect of GPS accuracy on travel time estimation. However, it is clear and could be concluded

that the estimated travel time using data from higher precision GPS provides more accurate result in all traffic conditions (the entire range of DT/TT ratios).
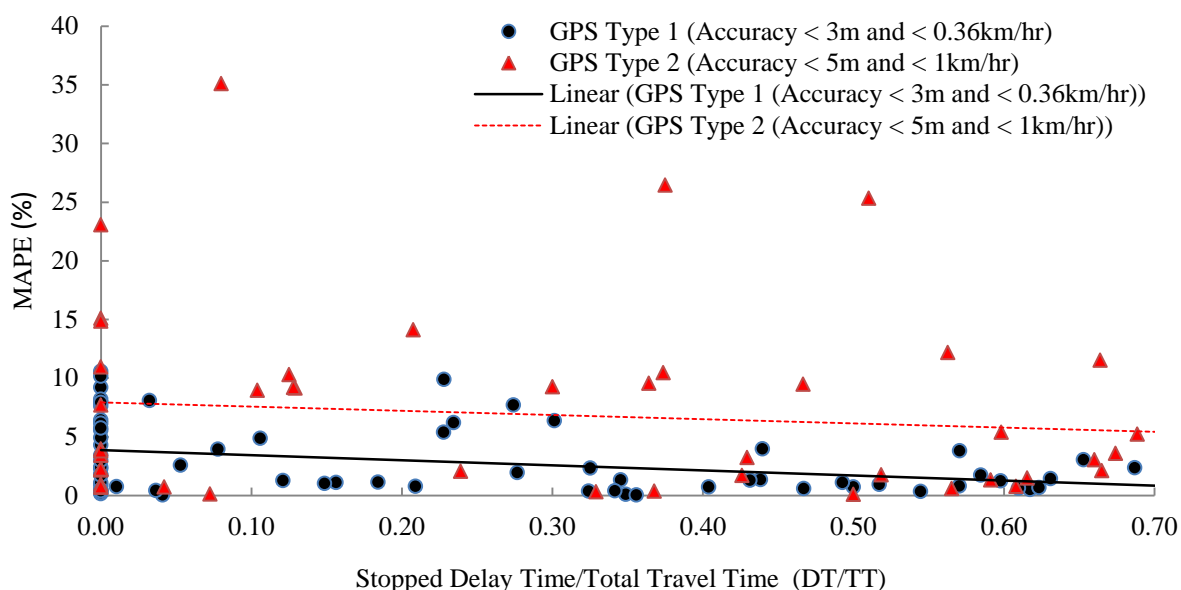

Figure 9. Relationship between MAPE of estimated travel time from RSSD method and the DT/TT ratio (sampling period = 1 sec)

5. CONCLUSION

In this paper, we have proposed the concept of Running Speed and Stopped Delay (RSSD) method for travel time estimation on urban arterial roads. The concept of RSSD approach is modified from the average speed method, due to benefit of moveable sensors in which the location and speed of tracked vehicle can be automatically detected. Therefore, the running speed and stopped delay time could be extracted from the total travel time.

The observed data from urban arterial roadways in Bangkok using GPS receivers sampling every one second were used to verify the accuracy and performance of proposed technique. Three testing scenarios with different sampling time interval were simulated from the observed dataset and used to test the applicability of proposed technique compared with the average speed methods.

Results demonstrate that the accuracy of RSSD method on travel time estimation outperforms average speed method in all road segments and all test scenarios. The analysis also shows the remarkably enhancement in accuracy when RSSD technique is employed in the congested condition or in the segment with high stopped delay time to the total travel time ratio (DT/TT). Once the congestion increases, the RSSD technique provides better estimation results than in the uncongested condition which is illustrated through the lower MAPE value. This is due to that the RSSD technique utilizes running speed in the estimation procedure which can neglect the effect of stopped delay time in the estimation process and could better represent the real vehicle movement through a road link.

The sampling time interval affects the accuracy of estimation. The longer sampling interval leads to the lower accuracy level. However, the RSSD technique offers the smaller rising rate of MAPE which indicates the superior behavior than the average speed method. Also, travel time estimation on longer segment or more data points provides the more accurate result than on the shorter ones. Moreover, the accuracy of GPS affects the

correctness of estimation. Using the higher accurate GPS device yields the better estimation result.

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