National-scale Level of Service Determining of Urban Streets Using Online Traffic Data

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Abstract

Level of service (LOS) is one of the widely used highway performance measurements. Road authorities can develop road improvement programs for roadways with poor levels of service, such as upgrading the road infrastructure or optimizing traffic signal timings. However, traditional methods of determining the level of service at a regional or national scale could be costly and time-consuming, and they cannot determine the priority of road subsections that require improvement. To implement the challenges of high cost and time-consuming data collection, using online traffic data such as Google Maps can provide real-time and comprehensive traffic information at a relatively low cost and without the effort of collecting large amounts of field data. In this paper, we propose a methodology to determine the level of service of the urban streets of road network at a national scale using online traffic data, i.e., travel speed and free-flow speed with traffic condition from Google Maps. The methodology includes road subsections, data input preparation, and level of service determination. The analysis is divided into three time periods (i.e., AM, MD, and PM) for both weekdays and weekends. The analysis results yielded a level of service from A to F for urban street links in Thailand. The challenges and limitations of this proposed methodology were also discussed in the paper. Road authorities can use the proposed methodology as a screening tool to identify links with the level of service issues at a regional/national scale to improve the roadway network.

Keywords: Level of service (LOS), Online traffic data, Urban Streets, Travel speed, Free-flow speed

1. Introduction

Level of service (LOS) is one of the widely used highway performance measurements. LOS is easy for the decision-makers to determine the road service quality and how likely any changes are to create perceived improvements for travelers [1]. The service level is indicated by six letters from A to F. LOS is used to translate complex numerical performance results into a simple A–F system representative of the travelers' perceptions of the quality of service provided by a facility or service [2].

Determining the level of service at a national level is important for planning resources and budgets for highway agencies. However, traditional traffic data collection can be expensive and time-consuming. Smartphones can be used to collect traffic data more easily and accurately than before [3]. Novel technologies are used for traffic management, including big data [4]. Online traffic data, such as Google Maps, provide live traffic data [5]. Thus, it is possible to use Google Maps with real-time traffic condition to determine the level of service on the roads.

In this study, we focus on the level of service for motorized vehicles on urban street facilities. The methodology for the urban street's level of service at a national level is presented. The objectives of this paper are: 1) to develop a framework analysis of the level of service for the national level using online traffic data and 2) to implement the proposed methodology for urban streets facilities in Thailand. The results from the analysis demonstrated the road subsections with poor levels of service at the nationwide level. Road agencies can use this data to screen road networks with issues of traffic congestion.

2. Literature Review

2.1 Level of service analysis for urban streets

The Highway Capacity Manual (HCM) [7] defines LOS as the combinations of travel modes (such as automobile, pedestrian, bicycle, and transit) and roadway system elements (such as freeway, urban streets, and intersection). Six levels are defined, ranging from A to F, each level indicating a different quality of road service. Level A represents the best operating conditions from the traveler's perspective, while Level F represents the worst. Summaries of the service measures are used by the HCM for different combinations of transportation system elements and travel modes. The level of service can be measured using different values, such as density, follower density, speed, and delay, depending on the system element as shown in Table 1.

Table 1 Service measures by system element [2]

System element	Service measures of motorized vehicle
Freeway facility	Density
Multilane highway	Density
Two-lane highway	Follower density
Urban street facilities	Speed
Urban street segments	Speed
Signalized intersection	Delay

To assess the level of service (LOS) for urban street subsections, two performance measures are utilized. The first measure is the traveling speed. The second measure is the volume-to-capacity ratio. The travel speed LOS threshold value is shown in Table 2 to be dependent on the base free-flow speed and the travel speed.

Table 2 LOS criteria for urban street facilities: motorized vehicle mode adapted from exhibit 18-1 of HCM [7]

LOS	Travel speed threshold by base free-flow speed (km/h)							Volume-to capacity ratio
	89	80	72	64	56	48	40	
A	>71	>64	>58	>51	>45	>39	>32	≤1.0
B	>60	>55	>48	>43	>37	>32	>27	
C	>45	>40	>37	>32	>29	>24	>21	
D	>35	>32	>29	>26	>23	>19	>16	
F	>27	>24	>23	>19	>18	>14	>13	
Any								>1.0

2.2 Free-flow speed

The free-flow speed is computed using Eq. 1. The determination of free-flow speed is based on the calculation of the base free-flow speed and an adjustment factor for signal spacing [7].

$$S_f = S_{f0} f_L \geq S_{pl} \qquad (1)$$

where

S_f = the free-flow speed (mi/h),

S_{f0} = base free-flow speed (mi/h),

S_{pl} = the posted speed limit, and

f_L = signal spacing adjustment factor.

Factors that influence the base free-flow speed include the speed limit, access point density, median type, curb presence, and on-street parking presence. The free-flow speed is calculated using Eq. 2 [7].

$$S_{f0} = S_{calib} + S_0 + f_{cs} + f_A + f_{pk} \qquad (2)$$

where

S_{calib} = base free-flow calibration factor (mi/h),

S_0 = speed constant (mi/h),

f_{cs} = adjustment for cross section (mi/h),

f_A = adjustment for access points (mi/h), and

f_{cs} = adjustment for on-street parking (mi/h).

Empirical research has shown that shorter subsection lengths tend to affect the driver's choice of free-flow speed when defined by signalized border junctions. In shorter subsections, a slower free-flow speed has been observed, all other factors being equal. To account for this influence, the adjustment factor is calculated using Eq. 3 [7].

$$\mathrm{f_L} = 1.02 - 4.7\frac{\mathrm{S_{f0}} - 19.5}{\mathrm{max(L_s, 400)}} \leq 1.0 \qquad (3)$$

where

L_s = distance between adjacent signalized intersection (ft).

2.3 Travel speed

The travel speed for the subject of travel along the subsection is computed using Eq. 4 [7].

$$\mathrm{S_{T,seg}} = \frac{3{,}600\ \mathrm{L}}{5{,}280\ (\mathrm{t_R} + \mathrm{d_t})} \qquad (4)$$

where

$\mathrm{S_{T,seg}}$ = travel speed of through vehicle for the subsection (mi/h),

L = length of subsection (ft),

$\mathrm{t_R}$ = running time of subsection (s), and

$\mathbf{d_t}$ = through delay (s/veh).

2.4 Online traffic condition data

Traffic congestion is one of the most significant problems faced by road users. There are several methods to collect traffic data to solve congestion. Formerly, traffic data was collected by infrastructure such as cameras or sensors, which are expensive and take a long time to collect. Consequently, applications have been developed that collect data easily and efficiently. Google Maps provides live traffic data, the real-time travel time data can represent the traffic situation on the road and can be used to determine the congestion between the origin and the destination. Google traffic maps show the different colors, and we can estimate the average speed of traffic [3,8].

In this study, we were interested in urban roads because they have more congestion than other types of roads. Also, the data from Google Maps depends on the number of smartphone users, so city streets are full of Google data from city street users' smartphones.

3. Data

3.1 Urban streets selection

Base Map from ROADNET [9]. In this study, we only consider urban street facilities. We divided the facilities by the difference in areas, including urban areas and non-urban areas, using the GIS database from the Department of Highways (DOH) [10]. The land use layer contains five different land use types including urban, suburban, suburban town, rural, and rural town (see Fig. 1). For the urban areas, the road subsections within the layers of urban, suburban, and suburban were defined. According to the study results, the project is called the study and data preparation project hierarchical classification of national highway networks throughout the country to increase the efficiency of highway development planning and management [9].

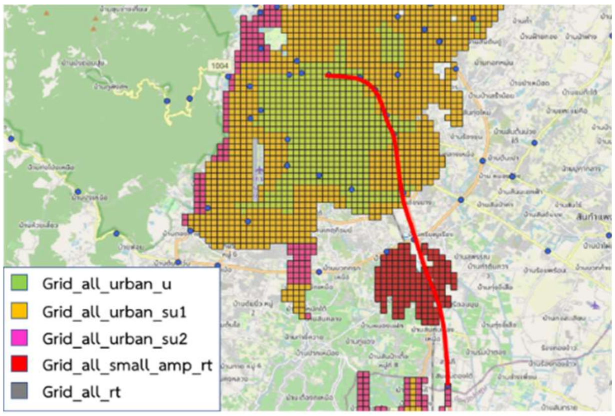


Fig. 1 land use layer [10]

Second, we used the signalized intersection data to break down the control sections into subsections. The road subsections in urban areas are bounded by either the end of the control section or the signalized intersection. When the distance between two traffic signal lights is less than 3.2 kilometers (2 miles), the subsegment would be classified as an urban street facility (See Fig. 2).

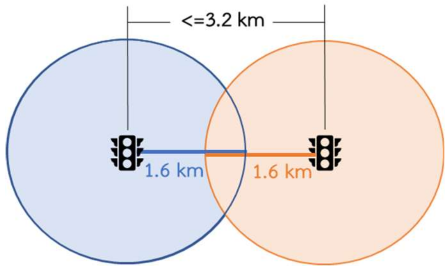


Fig. 2 The road segment with traffic signal spacing < 3.2 km was identified as an urban street facility.

Out of 51,271.67 km of highways in Thailand, we selected 2,848.63 km of the urban street facilities for this study. There is a total of 1,196 subsections*2 directions = 2,261 subsections. The average subsection length is 2.39 km.

3.2 Travel time data collection

In this study, we focus on the level of service of urban street facilities for motorized vehicles. The key data used in this analysis includes free-flow speed and travel speed. The literature review found that the determination of free-flow speeds and travel speeds required many factors to be analyzed. Therefore, the speed data can be obtained from the survey to determine free-flow speed and travel speed.

We collected the free-flow speed and travel speed data from the Google Maps database. The speed data was collected consecutively for 5 days to represent the data on weekdays and weekends. For the subsections as in urban street facilities, during the peak hours, travel time data were collected every 15 minutes, every 60 minutes during off-peak in the day, and every 2 hours during off-peak in the night, respectively, as shown in Table 3.

Table 3 Data sampling frequency for the Google Maps API

HR	Period	Frequency in urban areas (requests/hr)
00:00	Night	-
01:00	Night	1
02:00	Night	-
03:00	Night	1
04:00	Night	-
05:00	Off peak-AM	1
06:00	Off peak-AM	1
07:00	AM	4
08:00	AM	4
09:00	AM	4
10:00	Off peak-Midday	1
11:00	Midday	4
12:00	Midday	4
13:00	Off peak -PM	1
14:00	Off peak -PM	1
15:00	Off peak -PM	1
16:00	PM	4
17:00	PM	4
18:00	PM	4
19:00	Evening	1
20:00	Evening	1
21:00	Evening	1
22:00	Night	-
23:00	Night	1
Total		44

Travel time data (in seconds) was collected periodically from the Google Maps API. The travel time data was then converted into travel speeds for each highway subsection by Eq. 5.

$$v = \frac{s}{t} \quad (5)$$

where:

v = Speed (kph),

s = Distance (km), and

t = travel time (hr)

The Google Maps travel times were validated with the travel times collected from the floating car method. As a result, the mean absolute percentage error (MAPE) was approximately 12 percent, which is acceptable for the purpose of this study [11] (See Fig. 3).

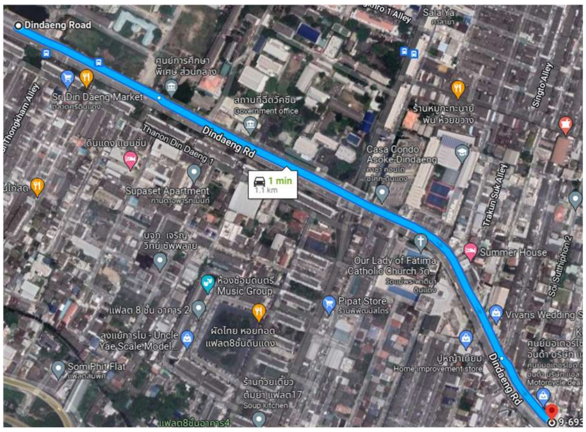


Fig. 3 Example of travel time data from Google Maps

Based on this data collection plan, we queried the travel time data from the Google Maps API from July to October 2021, a total of 497,420 requests for 2,261 road segments. There are two types of speed data: (1) free-flow speeds and (2) travel speeds for a specific hour.

3.3 Free-flow speed calculation

In this study, the travel speed during the off-peak period is assumed to be the free-flow speed of the highway segments. We selected the minimum travel time from Google Maps travel time because the minimum travel time represents the maximum speed, i.e., the maximum speed that the vehicle can achieve along the route. Therefore, we selected the data from 10 a.m. to 3 p.m. to explain maximum speeds.

3.4 Travel speed calculation

In this study, we focus on three periods including AM period, MD period, and PM period. We selected the maximum travel time from Google Maps travel time because the maximum travel time represents the minimum speed. Therefore, we selected the data in each period to explain the average speeds.

4. Level of Service (LOS) Analysis

This study is composed of three key tasks, including facility determination, travel time collection, and the level of service analysis based on the simplified version of the Highway Capacity Manual [6]. Several assumptions were made when data could not be directly obtained. The details are as follows:

4.1 Level of service of urban street facilities determination

The level of service of urban street facilities can be estimated using free-flow speed and travel speed, which can be identified from online traffic data as shown in Fig. 4. The level of service criteria of urban street facilities is shown in Table 2.

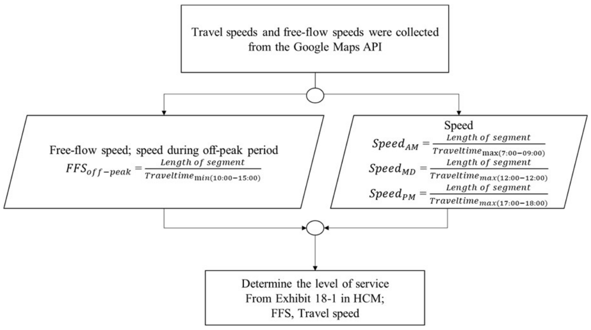


Fig. 4 Level of service determination for urban streets

4.2 Capacity determination of urban street facilities

The capacity of urban street facilities can be estimated by using the equation from the Highway Capacity Manual (HCM), Equation 18-2 [6] as shown in Eq. 6.

$$C_{th} = 1800\ (N_{th} - 1 + p^*_{0,j}) \qquad (6)$$

where:

C_{th} = through-movement capacity (veh/h),

N_{th} = number of through lanes (shared or exclusive) (ln), and

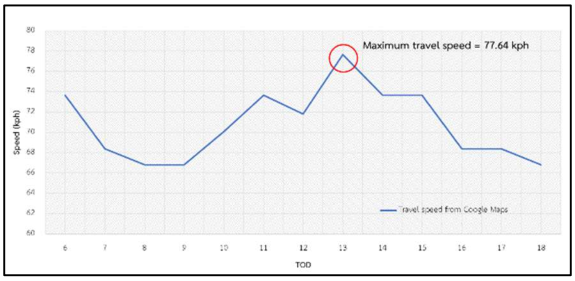
$p^*_{0,j}$ = probability that there will be no queue in the inside through lane.

In this study, we assumed all urban streets in this study do not have pocket lanes because of the limitation of the data source. The number of through lanes can be identified from ROADNET database and probability $p^*_{0,j}$ is equal to 1.0 [2].

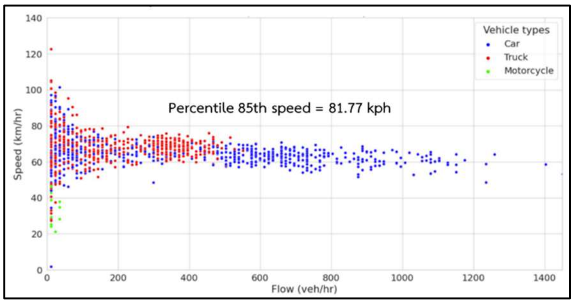
5. Results

5.1 Speed data accuracy

In this study, we used speed data from Google to determine the free-flow speed and travel speed. To check the accuracy of the Google Maps travel time data, we compared them with the speed data from the microwave radar data collection. An example is shown in Fig. 5. We collected travel speed data from two sources including Google Maps and microwave radar. For the Google Maps database, we requested travel time and direction data for numerous pairs of start and end points as scheduled in Table 3. Additionally, free-flow speed values were determined from the maximum travel speed between 6:00 a.m. and 6:00 p.m. For the microwave radar, we collected data for four consecutive days and determined the free-flow speed data from the 85th percentile speeds during the free-flow condition. The comparison found that the free-flow speed data from Google Maps is similar to the free-flow speed data obtained from the microwave radar.



(A)



(B)

Fig. 5 Travel speed (A) travel speed from Google Map and (B) speed flow curve from microwave radar

5.2 Level of service of urban street facilities results

Based on the results, there are 2,248.63 kilometers classified as urban street facilities. The level of service was determined by two conditions, including time and day of the week. For time periods, there were determined to be three periods: the AM period (7:00–9:00 a.m.), the MD period (11:00–1:00 p.m.), and the PM period (4:00–6:00 p.m.). There were two types of days of the week: weekday and weekend.

The subsections of urban street facilities are identified as LOS A to LOS F. From 2,248.63 kilometers of urban street facilities, we found that the road has a service level of A to F. For the weekday, the majority of roads in urban street facilities have a LOS A of 62% during the AM period, 71% during the MD period, and 51% during the PM period; a LOS B of 15% during the AM period, 9% during the MD period, and 18% during the PM period; and a LOS F of 17% during both the AM period and MD period and 18% during the PM period. For the weekend, the majority of roads in urban street facilities have a LOS A of 75% during the AM period, 71% during the MD period, and 66% during the PM period; a LOS B of 6% during the AM period, 7% during the MD period, and 11% during the PM period; and a LOS F of 17% during the AM period and 18% during both the MD period and PM period, as shown in Table 4 to Table 5.

Table 4 Percentage of LOS of urban street facilities by distance (km); weekday

LOS	AM period (7-9 A.M.)	MD period (11 A.M.-1 P.M.)	PM period (4-6 P.M.)
A	61.65%	70.65%	51.32%
B	14.83%	8.85%	18.11%
C	3.87%	2.53%	8.18%
D	1.74%	0.82%	2.62%
E	0.70%	0.49%	1.85%
F	17.21%	16.65%	17.92%
Total	100%	100%	100%

Table 5 Percentage of LOS of urban street facilities by distance (km); weekend

LOS	AM period (7-9 A.M.)	MD period (11 A.M.-1 P.M.)	PM period (4-6 P.M.)
A	74.68%	70.72%	65.54%
B	6.20%	7.43%	11.46%
C	1.33%	2.70%	3.13%
D	0.34%	0.90%	1.26%
E	0.21%	0.69%	0.77%
F	17.23%	17.56%	17.84%
Total	100%	100%	100%

From the LOS results, we designed the map display to provide an easy-to-see overview of the results. The map shows the color line differently for each service level. The olive-green line is LOS A, and the red line is LOS F, as shown in Fig. 6.

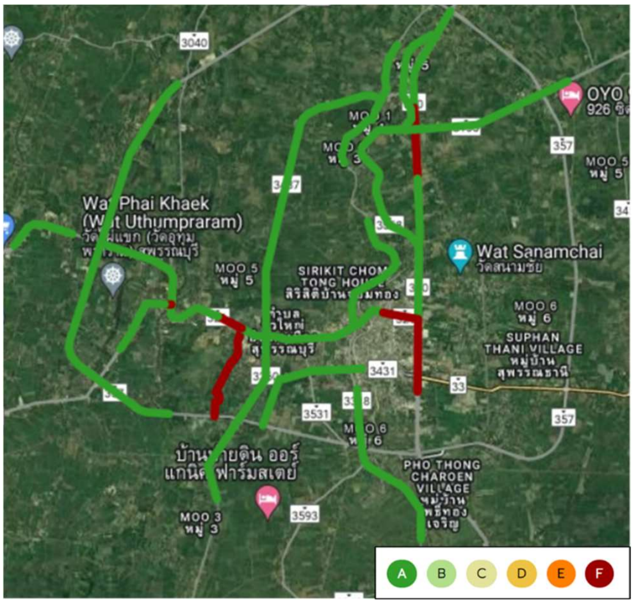


Fig. 6 Resulting LOS of urban street facilities in Suphan Buri

In addition, we identified the relationship between the level of service and the annual average daily traffic (AADT). And we also identify the relationship between the level of service and the length of an urban road segment. We found that the relationship between the level of service and AADT does not have a significant effect on service levels in each period, as shown in Table 6 to Table 8. For the relationship between the level of service and the length of a subsection, the subsections with a length less than 3.2 kilometers have a poorer level than those with a length greater than 3.2 kilometers, as shown in Table 9 to Table 11.

Table 6 LOS of urban street facilities by AADT (veh/day) during the AM period

LOS	AADT (veh/day/direction)					
	0-2,000	2,001-5,000	5,001-10,000	10,001-20,000	20,001-30,000	>30,000
A	3.51%	8.89%	2.18%	13.05%	2.67%	2.06%
B	1.17%	2.22%	0.89%	3.76%	0.77%	0.89%
C	0.24%	0.53%	0.16%	1.21%	0.65%	0.65%
D	0.00%	0.04%	0.04%	35.22%	0.28%	0.36%
E	0.00%	0.04%	0.00%	0.20%	0.08%	0.32%
F	0.40%	3.07%	0.61%	7.88%	3.76%	2.22%

Table 7 LOS of urban street facilities by AADT (veh/day) during the MD period

LOS	AADT (veh/day/direction)					
	0-2,000	2,001-5,000	5,001-10,000	10,001-20,000	20,001-30,000	>30,000
A	4.04%	9.94%	2.63%	14.99%	3.31%	3.19%
B	0.77%	1.37%	0.61%	2.67%	0.73%	0.61%
C	0.12%	0.32%	0.04%	0.85%	0.40%	0.28%
D	0.00%	0.04%	0.00%	34.75%	0.20%	0.28%
E	0.00%	0.00%	0.00%	0.16%	0.08%	0.16%
F	0.40%	3.11%	0.61%	7.88%	3.47%	1.98%

Table 8 LOS of urban street facilities by AADT (veh/day) during the PM period

LOS	AADT (veh/day/direction)					
	0-2,000	2,001-5,000	5,001-10,000	10,001-20,000	20,001-30,000	>30,000
A	4.04%	9.94%	2.63%	14.99%	3.31%	3.19%
B	0.77%	1.37%	0.61%	2.67%	0.73%	0.61%
C	0.12%	0.32%	0.04%	0.85%	0.40%	0.28%
D	0.00%	0.04%	0.00%	34.75%	0.20%	0.28%
E	0.00%	0.00%	0.00%	0.16%	0.08%	0.16%
F	0.40%	3.11%	0.61%	7.88%	3.47%	1.98%

Table 9 LOS of urban street facilities grouped by segment length during the AM period

LOS	<3.2 km	>3.2 km
A	27.57%	21.70%
B	11.31%	3.54%
C	4.24%	0.66%
D	1.46%	0.49%
E	0.62%	0.18%
F	26.43%	1.81%

Table 10 LOS of urban street facilities grouped by segment length during the MD period

LOS	<3.2 km	>3.2 km
A	33.14%	24.08%
B	8.57%	1.81%
C	2.78%	0.44%
D	0.84%	0.22%
E	0.49%	0.09%
F	25.81%	1.72%

Table 11 LOS of urban street facilities grouped by segment length during the PM period

LOS	<3.2 km	>3.2 km
A	20.64%	18.74%
B	12.59%	4.77%
C	7.42%	1.77%
D	2.30%	0.62%
E	1.55%	0.49%
F	27.13%	1.99%

6. Discussion and conclusion

The main objective of this study is to develop a level of service analysis for the national level using online traffic data to implement the proposed methodology in urban street facilities in Thailand. We developed the framework to analyze the level of service, including road segmentation, data input, capacity determination, and level of service determination.

The road sections were segmented based on area type and traffic signal spacing. Travel time data was collected automatically from the Google Maps API with traffic condition data. The travel speed and free-flow speed data derived from the travel time data were then used to determine the level of service for urban street facilities according to the HCM methodology.

The weekday and weekend data yielded a similar result. That is, the morning and evening peak hours are more congested than the midday period due to higher travel demand during both AM and PM periods.

Considering the color-coded map, most of the urban streets with LOS F (red lines) can be found in the big cities such as Bangkok, Chiang Rai, Samut Prakan, Samut Songkhram, and Phuket. These cities are characterized by LOS F for all three periods (the AM, MD, and PM periods).

We also analyzed the relationship between the level of service and the length of subsection. From the results, short subsegments tend to have worse LOS than long segments. In this study, urban streets were segmented using signalized intersections. Therefore, short subsections represented roads with short traffic signal spacing and tended to have congested traffic conditions.

Regarding the travel time data query, there are two levels of travel time data. One is the travel time from the distance matrix while the other is the travel time from the direction matrix. The distance matrix only provides the travel time from the starting point to the end point. However, it is possible that Google Maps algorithm selected an alternative route (rather than the subsegment of interest). Therefore, it is important to determine whether the route provided by the Google Maps algorithm is on the subsegment of interest. As a result, it is recommended to use the direction matrix because it provides the turn-by-turn directions with travel time for each turning point.

In addition, one of the problems in analyzing the data is road coordinates from ROADNET and Google Maps are not consistent. The road coordinates of ROADNET are the centerline on the road but Google Maps Road layer is directional, i.e., the road segment with median will be modeled as two separated lines. Occasionally, the beginning points fall into the wrong side of the road, affecting the calculation of the routing algorithm. Therefore, manual adjustment is required for some starting/ending points (See Fig. 7).

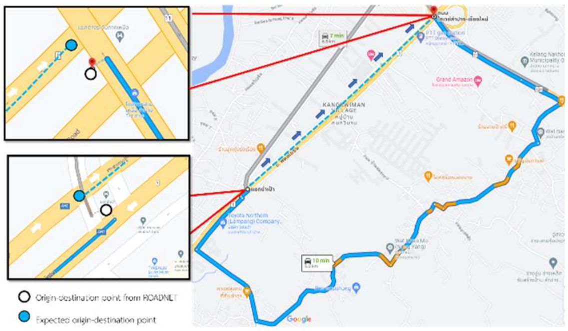


Fig. 7 Coordinate consistency issue between Google Maps and ROADNET road layers. The dash line is the correct path, and the blue line is the directions given by Google Maps

The road agencies can use this online traffic data to identify the road networks with traffic congestion. Detailed investigation should be conducted at these segments to determine the cause and the countermeasures of the congestion problems.

The future research should investigate the use of the online travel time data to analyze the level of service of other type of road facilities such two-lane highways facility and the multilane highways facility in the national scale.

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