Applications of Global Positioning System in Traffic Studies

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Introduction

A Global Positioning System (GPS) device was used in this study to measure traffic characteristics at highway intersections and freeway work zones in Indiana, USA. GPS technologies have provided traffic engineers a new tool for obtaining accurate measurements related to vehicle motions. The GPS device used on a test vehicle is capable of recording the test vehicle’s positions (latitudinal and longitudinal coordinates) and speeds at specified time intervals. When the test vehicle travels at the normal speeds of the majority of the vehicles in a traffic flow (perceived by the test vehicle driver), the exact trajectory of the test vehicle is identified through satellite signals and recorded by the GPS device. Each data point recorded by the GPS device includes the vehicle position, speed, time, and the distance between the current and the last time points. Because the test vehicle travels at the representative speeds of the traffic flow, the GPS data depicts a speed profile of the traffic flow as well as the test vehicle on the traversed highway section. In addition, when GPS data is used at a work zone, the data can also provide values of traffic delay, vehicle queue, average travel speed, and vehicle acceleration and deceleration before and after the work zone.

Data Collection With GPS

A section of SR-26 (State Road 26) in Lafayette, Indiana, USA, was selected for data collection with GPS to study traffic delay at intersections. The length of this roadway section is about three kilometers (from US-52 to I-65) and there are a series of ten intersections on the section. To examine the traffic patterns at the Indiana freeway work zones, seven work zones (three crossover work zones and four partial closure work zones) on Indiana’s interstate highways were selected for traffic data collection.

A GPS device, connected to a laptop computer, was placed on a test vehicle (a normal size passenger car) to perform the data collection. Two persons, a driver and a GPS recorder, were needed to perform the data collection. The driver drove the test vehicle at his perceived speed of the traffic flow to obtain a speed profile pertinent to the traffic flow. The GPS recorder’s task was to control the GPS program and to record each landmark point by pressing a specified button on the computer keyboard. Figures 1 and 2 present some examples of such speed profiles. Figure 1 is a speed profile along the roadway section on SR-26 and Figure 2 is a speed profile at a work zone on I-74 (Interstate 74) between the Indiana/Illinois State Line and the Wabash River. As can be seen, the vehicle speed profiles captured the whole moving process of the traffic flow going through the roadway section with ten intersections as well as along the work zone on I-74. Figure 1 depicts the vehicle speed changes when

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passing the intersections. Figure 2 clearly shows that the traffic flow decelerated when approaching the work zone, and traveled at lower speeds within the work zone, and accelerated after exiting the work zone.

In addition to the speed profile, the roadway geometric layout is also readily available from the GPS data. Figure 3 depicts a plan view of the test vehicle’s course of travelling through the I-74 work zone. The recorded test vehicle’s travelling route is nothing but the geometric layout of the work zone and the adjacent roadway. It shows that the test vehicle started at the on-ramp to merge into the roadway, passed through the work zone, and then exited the roadway at the off-ramp. With this layout, the traffic engineers can easily locate the prominent features along the roadway, such as curves, ramps, and work zone limits. The locations of these features are often useful or even essential for analyzing traffic characteristics.

Traffic Conditions at Intersections

1. Total Delay Caused by Intersections:

   The speed limit on this road was 64 kilometers per hour (40 miles per hour). The GPS collected data indicates that the average speed was lower than the speed limit on most of the sections with a few exceptions (three out of nine sections) where it was higher than the speed limit. The values of average speeds can be used to estimate traffic delays if the travel speed when vehicles are unaffected by intersections are known. The unaffected travel speed can be measured where the distance between two intersections are relatively far away. The total delay can be calculated using the following equation:

   \[ D_{\text{total}} = T - \frac{S}{V_u} \]  

   where   
   \( T \) = the GPS recorded travel time to traverse the roadway section with intersections.  
   \( S \) = the distance of the roadway section.  
   \( V_u \) = the unaffected travel speed.

   With the GPS data and observed unaffected travel speed, the total delays of the whole roadway section of any section between two intersections can be obtained through Equation 1. Table 1 presents the delay values on the SR-26 section, including delays on individual sections between any two consecutive intersections as well as on the whole section with 10 intersections.

2. Stopped Delay at Intersections:

   In addition to total delays, stopped delays are also important for measuring the efficiency of traffic control facilities. The duration of each vehicle stop is nothing but a stopped delay. Therefore, the values of the stopped delays can be read directly from the GPS recorded data. In this case, the vehicle stopped in front of the sixth and the seventh intersections. The values of the stopped delays are 41 seconds for the sixth
intersection and 15 seconds for the seventh intersection. These are the recorded time durations corresponding to the speed values of zero.

Traffic Conditions at Freeway Work Zones

1. Vehicle Speed at Work Zones and on Freeway Sections:

As discussed above and shown in Figure 2, at each second in time there is a GPS recorded value of vehicle speed and a value of distance. The average speed at a work zone can be obtained by calculating arithmetic mean of all the speed values within the work zone. That is,

\[ \bar{V} = \frac{\sum V_i}{N} \]  

(2)

where,

- \( \bar{V} \) = average speed at work zone
- \( V_i \) = the \( i \)th speed value within work zone
- \( N \) = total number of speed values or total number of data points within work zone

On the other hand, the average travel speed at a work zone can also be calculated with the values of distance and time, which is the value of work zone length divided by travel time. Travel time is defined (McShane and Roess 1990) as the total time to traverse a given highway segment, including the time during which the vehicle is stopped and the time during which the vehicle is in motion. With the GPS data, the average travel speed at a work zone is computed with the following equation.

\[ U = \frac{D}{T} = \frac{d_1 - d_0}{t_1 - t_0} \]  

(3)

where,

- \( U \) = average travel speed at work zone
- \( D \) = distance traversed
- \( T \) = travel time
- \( d_i \) = distance at the end of work zone
- \( d_0 \) = distance at the beginning of work zone
- \( t_1 \) = time at the end of work zone
- \( t_0 \) = time at the beginning of work zone

Similarly, Equations 2 and 3 can also be used to compute the average speed (the arithmetic mean) and the average travel speed on the freeway sections without work zones. In general, Equations 2 and 3 are not equivalent. However, it can be shown that, with the GPS data obtained in this study, the two equations are equal because the GPS data was recorded at equal time intervals (one-second intervals).
Although both Equation 2 and Equation 3 can be used to obtain the average travel speed, if a detailed speed study is needed, it is advantageous to use Equation 2 with the individual speed data to calculate travel speed and other related statistical values. This is because it can provide more information on speed characteristics, such as speed consistence or fluctuation in terms of standard deviation, distribution, maximum and minimum values.

2. Vehicle Deceleration and Acceleration:

In an earlier study (Jiang 1999), it was found that traffic delays at a work zone include delays caused by deceleration of vehicles while approaching the work zone, reduced vehicle speed through the work zone, time needed for vehicles to resume freeway speed after exiting the work zone, and vehicle queues formed at the work zone. Vehicle deceleration and acceleration rates are needed to estimate the delays before the vehicle enters the work zone and after the vehicle exits the work zone. However, at the time of that study, the values of deceleration and acceleration could not be precisely measured and determined and the delays were calculated with assumed deceleration and acceleration rates. Now, with the GPS vehicle position and speed data, the vehicle deceleration and acceleration rates can be readily and accurately calculated.

If a vehicle started to decelerate at time $t_d$ with a speed $v_d$ and it arrived at the beginning of the work zone at time $t_b$ with a speed $v_b$, then the deceleration rate of the vehicle was

$$ r_d = \frac{v_b - v_d}{t_b - t_d} \quad (4) $$

Similarly, if a vehicle arrived at the end of the work zone at time $t_e$ with a speed $v_e$ and it accelerated to its freeway speed $v_a$ at time $t_a$, then the acceleration rate was

$$ r_a = \frac{v_a - v_e}{t_a - t_e} \quad (5) $$

Using Equations 4 and 5, the mean values of the deceleration and acceleration rates for different work zone types are calculated and presented in Table 2.

3. Traffic Delay at Work Zones:

The GPS data contains the information of the distance between any two points on a roadway section and the actual time taken for the test vehicle to traverse the distance. In addition, as previously shown, the average travel speed on freeway sections can be calculated with the GPS data using Equation 2 or Equation 3. To calculate the delay caused by a work zone, two points should be chosen along the roadway, one before the vehicle started deceleration when approaching the work zone and the other after the vehicle resumed freeway speed after exiting the work zone. That is, the two points should be chosen on the freeway sections (one before and one after the work zone) where the vehicle travels at the freeway speed. Because the work zone is within the roadway section between the two points, the delay caused by the work zone is the difference between the actual travel time and the estimated travel time for
the vehicle to pass the two points at the freeway speed. If the average travel speed on a freeway sections is \( U_{fw} \), the GPS distance and time values for the two points are \( d_{fw1} \) and \( t_{fw1} \), and \( d_{fw2} \) and \( t_{fw2} \), respectively, then the equation for the work zone delay is

\[ T_{\text{delay}} = (t_{fw2} - t_{fw1}) - \frac{d_{fw2} - d_{fw1}}{U_{fw}} \] (6)

In this equation, \((t_{fw2} - t_{fw1})\) is the actual travel time, \((d_{fw2} - d_{fw1})\) is the distance between the two points, and \(\frac{d_{fw2} - d_{fw1}}{U_{fw}}\) is the time needed to traverse the same roadway section if there is no work zone. This delay value from this equation is the delay experienced by one vehicle at the work zone. Such a value should be multiplied by the corresponding hourly traffic flow rate to obtain the total vehicle delay per hour at the work zone.

4. Vehicle Queue Length under Traffic Congestion:

Traffic congestion occurs when the traffic flow rate exceeds the work zone capacity. Once the flow rate of arrival vehicles exceeded the work zone capacity, the number of vehicles arriving would be larger than the number of departing at the work zone. Then a vehicle queue would form upstream of the work zone. The length of a vehicle queue can be estimated through the values of traffic flow rates and work zone capacity. Because of the complexity and randomness of traffic conditions, the estimation of vehicle queue length is usually not as accurate as desired. Furthermore, the vehicle queue length can not be measured with the conventional traffic counters. However, with the GPS recorded data, a vehicle queue can be identified on the speed profile curve.

Traffic congestion occurred at the work zone on I-65 at SR-25 during the data collection. The recorded GPS data indicated that the test vehicle stopped (with a speed value of 0) at the distance point of 1066.9 meters. At that moment, the test vehicle was the latest vehicle joining the vehicle queue and therefore the location was the end of the vehicle queue in front of the work zone. From the marked points in the GPS data, it can also find that the beginning of the work zone was at the distance point of 3593.3 meters. Thus, the vehicle queue length is the distance between the end of the vehicle queue and the beginning of the work zone. That is, the vehicle queue length was 3593.3-1066.9=2526.4 meters at the moment when the test vehicle joined the queue. If the time when the vehicle joined the queue is of interest, it can also be found from the GPS recorded data. In this example, the test vehicle joined the queue at 10:03:57 a.m., June 28, 2000. Through this example, it is clearly shown that the GPS position and speed data can provide very precise and detailed information on vehicle queues at work zones.

Conclusions

The dynamic feature of the GPS collected data enables the traffic engineers to obtain the precise profile of vehicle speed along roadway sections with intersections and
work zones. The geometric layout can also be drawn using the GPS positioning data. With the GPS data, several essential traffic characteristics of intersections can be obtained, such as the average travel speed, total travel delays and stopped delays caused by intersections. The average travel speed on a given roadway section with work zones can be calculated through Equation 2 or Equation 3. The two equations would yield the same results because the GPS position and speed values are recorded at equal time intervals. It is also presented that the vehicle deceleration and acceleration rates, which could only be roughly estimated in an earlier study, can be readily calculated with high accuracy using the GPS data. Moreover, traffic delay at a work zone can be obtained by comparing the GPS recorded actual travel time through a roadway section with the work zone and the travel time needed to traverse the same section at the freeway speed. In addition, under traffic congestion condition at a work zone, the GPS data provides the precise values of time, position and speed of the test vehicle’s movement to identify the exact queue length in front of the work zone.

References


Table 1. Travel Delays at Intersections

<table>
<thead>
<tr>
<th>Section</th>
<th>Delay between Intersections (seconds)</th>
<th>Average Delay (seconds/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From intersection 1 to 2</td>
<td>9.94</td>
<td>28.05</td>
</tr>
<tr>
<td>From intersection 2 to 3</td>
<td>0.72</td>
<td>4.98</td>
</tr>
<tr>
<td>From intersection 3 to 4</td>
<td>0.31</td>
<td>1.66</td>
</tr>
<tr>
<td>From intersection 4 to 5</td>
<td>15.80</td>
<td>44.22</td>
</tr>
<tr>
<td>From intersection 5 to 6</td>
<td>64.38</td>
<td>110.99</td>
</tr>
<tr>
<td>From intersection 6 to 7</td>
<td>58.45</td>
<td>88.90</td>
</tr>
<tr>
<td>From intersection 7 to 8</td>
<td>5.16</td>
<td>28.90</td>
</tr>
<tr>
<td>From intersection 8 to 9</td>
<td>3.70</td>
<td>10.62</td>
</tr>
<tr>
<td>From intersection 9 to 10</td>
<td>1.83</td>
<td>7.67</td>
</tr>
</tbody>
</table>

Total Delay = 137.1 seconds  
Average Total Delay = 45.01 seconds per kilometer

Table 2. Mean Values of Vehicle Deceleration and Acceleration Rate

<table>
<thead>
<tr>
<th>Work Zone Type</th>
<th>Merging Type</th>
<th>Mean Deceleration Rate (km/h/s)</th>
<th>Mean Acceleration Rate (km/h/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossover</td>
<td>Merging</td>
<td>0.788</td>
<td>0.876</td>
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<tr>
<td>(Median Crossover Direction)</td>
<td>Non-Merging</td>
<td>0.839</td>
<td>1.392</td>
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<tr>
<td>Crossover</td>
<td>Merging</td>
<td>0.378</td>
<td>0.726</td>
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<tr>
<td>(Opposite Direction)</td>
<td>Non-Merging</td>
<td>0.366</td>
<td>0.763</td>
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<tr>
<td>Partial Closure</td>
<td>Merging</td>
<td>0.603</td>
<td>0.641</td>
</tr>
<tr>
<td></td>
<td>Non-Merging</td>
<td>0.732</td>
<td>1.131</td>
</tr>
</tbody>
</table>
Figure 1. Vehicle speed profile along roadway with intersection

Figure 2. Vehicle speed profile at a work zone on I-74

Figure 3. The roadway layout created with GPS data