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MEASURING AND ANALYZING VEHICLE POSITION AND SPEED DATA AT WORK ZONES USING GLOBAL POSITIONING SYSTEM

by

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ABSTRACT

In order to analyze traffic characteristics at highway work zones, traffic flow has been measured through various types of traffic measuring devices. The limitations of the conventional traffic counters include: 1) it is not always easy to install and retrieve traffic measuring devices on highways because traffic conditions would pose a risk to traffic engineers; 2) they can only record traffic measurements at the places where the counters are installed. To overcome these shortcomings of the conventional traffic counters, a Global Positioning System (GPS) device was used in this study to measure traffic characteristics at Indiana freeway work zones.

This paper demonstrates that GPS is an efficient tool in recording vehicle position and speed values and it can provide accurate and detailed information on traffic characteristics at work zones. The dynamic feature of the GPS collected data enables the traffic engineers to obtain the precise profile of vehicle speed as well as the geometric layout of roadway sections and work zones. With the GPS data, the average travel speed on a given roadway section or work zone can be calculated. 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 delays and exact queue lengths at work zones can also be obtained through the GPS collected traffic data.

INTRODUCTION

In order to analyze traffic characteristics at highway work zones, traffic flow has been measured through various types of traffic measuring devices. Using these traffic counters, vehicle speed and volume can be recorded at select spots along roadways. However, there exist some common problems in use of the conventional traffic measuring devices. One of the problems is that it is not always easy to install and retrieve traffic measuring devices on highways, especially on high traffic volume highways, such as freeways and major arterials, because traffic conditions would pose a risk to traffic engineers. Another problem is that the conventional traffic counters can only record traffic measurements at the places where the counters are installed. Consequently, the collected traffic data reflects only the traffic conditions at isolated spots along a roadway. The traffic measurements at a few points on a roadway are often not adequate to depict the dynamic changes of traffic conditions on a whole section of the roadway. For example, at a highway work zone, traffic counters can not provide direct measurements of vehicle speed profile along the work zone and vehicle queue length caused by the work zone. Although these traffic conditions can be indirectly derived or estimated using traffic data from traffic counters, they usually are less accurate than desired due to limited number of points on a roadway that traffic counters can practically cover.

To overcome these shortcomings of the conventional traffic counters, a Global Positioning System (GPS) device was used in this study to measure traffic characteristics at Indiana freeway work zones. GPS technologies have provided traffic engineers a new tool for obtaining accurate measurements related to vehicle motions. In a previous study (*2*), the researchers in the Louisiana State University utilized GPS to record and analyze car following behavior. 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, they can also provide values of traffic delay, vehicle queue, average travel speed, and vehicle acceleration and deceleration before and after the work zone. It should be emphasized that, although some of the above mentioned values of traffic conditions can be estimated using traffic counter data, the estimated values from traffic counter data are far less accurate than the values provided by GPS.

DATA COLLECTION WITH GPS

Two basic types of work zones, partial closure and crossover work zones, are used in construction areas on freeways, as shown in Figures 1 and 2. They are defined as (*1*):

1. Partial Closure (or single lane closure) - when one lane in one direction is closed, resulting in little or no disruption to traffic in the opposite direction.
2. Crossover (or two-lane two-way traffic operations) - when one roadway is closed and the traffic which normally uses that roadway is crossed over the median, and two-way traffic is maintained on the other roadway.

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. Data collection with the GPS device was conducted in June 2000 at the selected work zones. A GPS device, connected to a laptop computer, was placed on a test vehicle (a normal size passenger car) to perform the data collection. The commercially available GPS device is not specifically for use of traffic data collection. To make it easy for traffic data collection, the GPS device was configured to record the vehicle positions and speeds at one-second time intervals. In addition, an interface program was written to control the operations of the GPS device and to mark the landmark points. The landmark points include the beginning of the work zone, the end of the taper area, the construction activity area, and the end of the work zone. With the created interface program, a person can hit a control button on the computer keyboard to mark the landmark points. 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.

The GPS device's error range is within one meter for distance measurements and is less than 0.16 km/h for speed measurements. This accuracy of the GPS device is considered very high for the purpose of traffic analysis. With vehicle position and speed data, a speed profile at a work zone can be obtained. Figure 3 presents an example of such a speed profile using the GPS data collected at a work zone on I-74 between the Indiana/Illinois State Line and the Wabash River. As can be seen, this vehicle speed profile captured the whole moving process of the traffic flow going through the work zone. The figure clearly shows that the traffic flow

decelerated when approaching to 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 work zone's geometric layout is also readily available from the GPS data. Figure 4 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.

APPLICATIONS OF VEHICLE POSITION AND SPEED DATA

The data collected with the GPS device contains highly accurate measurements of the test vehicle's position and speed at each second in time. As discussed above, a direct application of the GPS data is to obtain the vehicle speed profiles and the corresponding roadway layouts. In this section, it will be demonstrated that the GPS data can also be utilized to calculate the values of other traffic measures related to work zone traffic conditions, including average travel speeds, deceleration and acceleration rates, traffic delays, and vehicle queue lengths. The summarized values of the GPS data are included in Table 1 for the seven work zones. The information presented in this table contains work zone location, direction and merging type of the test vehicle when approaching to the work zone, values of various speeds, deceleration and acceleration rates, and delay caused by the work zone. Two merging types were considered according to if a merging maneuver was needed when the test vehicle

approached to a work zone. For example, it would be a "merging" if the test vehicle was on the driving lane before entering a work zone with the driving lane closed, because the vehicle must shift or merge into the passing lane to enter the work zone. However, if the test vehicle was on the passing lane when approaching to the work zone with the driving lane closed, it would be a "non-merging" because no merging maneuver was needed.

Vehicle Speed at Work Zones and on Freeway Sections

As discussed above and shown in Figure 3, at each second in time there is a GPS recorded value of vehicle speed and a value of distance. Apparently, 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,

$$\overline{V} = \frac{\sum V_i}{N} \tag{1}$$

where, $\overline{V}$ = average speed at work zone

V_i = the ith 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 (*3*) 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.

$$U = \frac{D}{T} = \frac{d_1 - d_0}{t_1 - t_0} \tag{2}$$

where, U = average travel speed at work zone

D = distance traversed

T = travel time

d_1 = 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

As an example, plotted in Figure 5 is a curve of distance versus time corresponding to the speed profile in Figure 3. It graphically shows the variables in Equation 2 and how to identify the values of these variables. As can be seen, $d_1 - d_0$ is the work zone distance and $t_1 - t_0$ is the total time that the vehicle spent to traverse the work zone.

Similarly, Equations 1 and 2 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 Table 1, these speed values are listed for each of the test sites for both work zones and freeway sections. At each site, the roadway section in the upstream of the work zone where vehicles have not started to decelerate was used to calculate "freeway speed". In general, Equations 1 and 2 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). Equation 1 can be written as

$$\overline{V} = \frac{\sum V_i}{N} = \frac{\sum \frac{d_i}{t_i}}{N}$$

If all time intervals are equal, or $t_i = t$ for all $i = 1, 2, 3, \ldots, N$, then

$$\sum \frac{d_i}{t_i} = \frac{\sum d_i}{t} = \frac{D}{t}$$

and

$$\overline{V} = \frac{\sum \frac{d_i}{t_i}}{N} = \frac{D}{N \times t} = \frac{D}{T}$$

This proves Equations 1 and 2 are the same under the condition of equal time intervals. Examining the speed values in Table 1, it can be found that the values calculated from individual speed data (Equation 1) are very close to those calculated from travel time (Equation 2). This is true for all of the test sites and for both work zone speed and freeway speed. The slight differences between the calculated values from the two equations are attributed to number round off in calculations. Therefore, the arithmetic mean of the GPS recorded speed values is also the average travel speed. This means that either of the two equations can be utilized to obtain the travel speed.

The values of standard deviations are calculated for each run at each study site as shown in Table 1. These values indicate that for every data set the work zone speed has a considerable higher standard deviation than the freeway speed. This implies that the vehicles traveled at more stable speed on freeway sections than at work zones. At the work zone on I-65 at SR-25, traffic congestion occurred during Run No. 4. The average speed at the work zone during the

congestion was 30.6 km/h, ranging from 0 to 48.6 km/h. The standard deviation of the work zone speed was 21.7. As expected, this standard deviation was significantly higher than the other seven runs at this work zone (ranging from 2.3 to 9.0). The above statistical information can only be calculated with the individual speed data. Although both Equation 1 and Equation 2 can be used to obtain the average travel speed, if a detailed speed study is needed, it is advantageous to use Equation 1 and 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.

Vehicle Deceleration and Acceleration

In an earlier study (*4*), 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

$$r_d = \frac{v_b - v_d}{t_b - t_d} \tag{3}$$

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

$$r_a = \frac{v_a - v_e}{t_a - t_e} \tag{4}$$

The calculated deceleration and acceleration rates are listed in Table 1. It should be noted that the deceleration rate could not be calculated for Run No. 4 at the I-65 work zone at SR-25 because the values required in Equation 3 could not be identified in the GPS data under traffic congestion. Using Equations 3 and 4, the mean values of the deceleration and acceleration rates for different work zone types are calculated and presented in Table 2.

Traffic Delay at Work Zones

Traffic flow is disrupted and delayed at a work zone because the number of available lanes to traffic is reduced and the traffic capacity and the vehicle speed are lower at the work zone section than at other portions of the roadway. As presented in Figures 3 and 4, the vehicle speed, location and time can be identified for any given moment through the GPS vehicle position and speed data. Therefore, 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 1 or Equation 2. 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 to 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

$$T_{delay} = (t_{fw2} - t_{fw1}) - \frac{d_{fw2} - d_{fw1}}{U_{fw}} \tag{5}$$

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. The calculated delay values for the seven work zones can be found in Table 1. Each of the listed delay values 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.

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 in the 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. To demonstrate how to identify vehicle queue length at a work zone, shown in Figure is the speed profile during the traffic congestion at the I-65 work zone. As indicated in this figure, 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

This paper presented the applications of GPS in traffic data collection and analysis at freeway work zones. It demonstrated that GPS is an efficient tool in recording vehicle position and speed values and it can provide accurate and detailed information on traffic characteristics

at work zones. To study the traffic patterns at the Indiana freeway work zones, seven work zones on Indiana's interstate highways were selected for traffic data collection. A GPS device was configured to record the vehicle positions and speeds at one-second time intervals. An interface program was written to control the operations of the GPS device and to mark the landmark points. With the created interface program, a person can hit a control button on the computer keyboard to mark the landmark points. Two persons, a driver and a GPS recorder, were needed to perform the data collection. The GPS device's error range is within one meter for distance measurements and is less than 0.16 km/h for speed measurements. This accuracy of the GPS device is considered very high for the purpose of traffic analysis.

The dynamic feature of the GPS collected data enables the traffic engineers to obtain the precise profile of vehicle speed along roadway sections and work zones. The geometric layout can also be drawn using the GPS positioning data. With the GPS data, the average travel speed on a given roadway section (freeway or work zone) can be calculated through Equation 1 or Equation 2. 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.

ACKNOWLEDGMENTS

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TABLE 1 Summarized GPS Collected Vehicle Speed Data at Freeway Work Zones

Work Zone	Run No., Direction, Merging Type	Work Zone Speed (km/h)					Deceleration (km/h/sec)	Acceleration (km/h/sec)	Freeway Speed (km/h)			Delay (sec)
		Max.	Min.	Avg.	Std Dev	Travel Speed			Avg.	Std Dev	Travel Speed	
I-65 (From Kessler Ave. to I-465) NB Crossover Length=11.4 km	1, NB, Merging	110.8	65.5	85.3	10.1	85.4	0.116	0.520	101.6	1.0	101.5	62.0
I-65 (at SR 25) NB Crossover Length=4.0 km	1, NB, Merging	83.6	54.8	71.0	8.1	71.0	1.988	0.540	104.7	3.6	104.5	40.2
	2, NB, Merging	93.7	60.1	83.1	9.0	83.2	1.390	1.121	106.6	3.9	108.6	24.1
	3, NB, Non-Merging	97.1	65.1	83.2	8.4	83.1	0.918	1.914	106.4	3.0	106.2	23.4
	4, NB, Non-Merging	48.6	0.0	30.5	21.7	30.6	N/A	1.041	106.4	3.0	106.2	453.0
	5, SB, Non-Merging	94.7	85.4	90.7	2.3	90.8	0.130	0.826	100.2	0.8	100.2	18.5
	6, SB, Non-Merging	100.8	80.8	92.6	5.3	92.5	0.298	0.096	109.8	4.4	109.5	16.3
	7, SB, Merging	104.9	79.1	93.5	7.7	94.6	0.124	0.440	106.0	2.2	105.7	13.0
	8, SB, Merging	96.7	72.4	89.1	6.7	91.1	0.249	0.617	98.6	2.5	98.4	12.8
I-69 NB (at US 24) Partial Closure Right Lane Closed Length=2.6 km	1, NB, Merging	89.4	54.2	71.2	8.4	71.1	0.788	0.951	97.1	3.8	96.9	9.7
I-69 SB (at US 24) Partial Closure Right Lane Closed Length=1.2 km	1, SB, Merging	95.4	82.9	86.8	2.9	86.6	0.224	0.519	104.2	1.0	104.0	8.7

(to be continued)

TABLE 1 (continued). Summarized GPS Collected Vehicle Speed Data at Freeway Work Zones

Work Zone	Run No., Direction, Merging Type	Work Zone Speed (km/h)					Deceleration (km/h/sec)	Acceleration (km/h/sec)	Freeway Speed (km/h)			Delay (sec)
		Max.	Min.	Avg.	Std Dev	Travel Speed			Avg.	Std Dev	Travel Speed	
I-69 (From CR11 to SR8) NB Crossover Length=12.6 km	1, NB, Merging	99.9	64.4	86.5	6.6	86.5	0.126	1.170	98.5	0.8	98.9	67.6
	2, NB, Merging	91.0	63.6	78.3	2.7	78.5	0.319	1.027	109.7	7.4	109.6	121.0
	3, NB, Non-Merging	92.8	52.7	80.1	7.8	80.1	0.760	1.221	115.1	1.9	115.1	134.2
	4, SB, Non-Merging	97.1	75.1	87.3	4.7	87.3	0.608	1.055	117.9	3.2	117.9	97.5
	5, SB, Non-Merging	107.5	79.6	94.0	6.9	94.0	0.390	1.074	116.9	3.7	117.1	77.2
	6, SB, Merging	101.0	70.7	91.5	5.0	92.0	0.761	1.122	123.3	2.4	123.2	102.5
I-74 EB (West of Indiana and Illinois State Line) Partial Closure Right Line Closed Length=7.3 km	1, EB, Merging	97.6	19.8	67.9	19.6	68.9	0.431	0.312	100.0	2.5	99.9	97.7
	2, EB, Merging	85.5	53.6	70.7	6.63	71.0	0.730	0.655	107.7	5.4	107.8	104.8
	3, EB Merging	95.0	41.5	70.0	14.0	69.9	0.619	0.820	99.2	6.5	99.3	88.0
	4, EB, Merging	85.4	0.5	65.8	16.1	68.0	0.137	0.901	103.8	3.0	103.8	119.7
	5, EB, Non-Merging	108.3	50.8	79.8	11.3	83.2	0.371	0.385	108.1	3.5	108.1	58.6
	6, EB, Non-Merging	95.5	10.2	67.5	15.0	67.9	0.692	0.879	107.6	3.1	109.4	117.7
	7, EB, Non-Merging	113.6	54.4	81.2	13.5	81.1	0.495	0.948	118.3	4.3	120.6	84.7

(to be continued)

TABLE 1 (continued) Summarized GPS Collected Vehicle Speed Data at Freeway Work Zones

Work Zone	Run No., Direction, Merging Type	Work Zone Speed (km/h)					Deceleration (km/h/sec)	Acceleration (km/h/sec)	Freeway Speed (km/h)			Delay (sec)
		Max.	Min.	Avg.	Std Dev	Travel Speed			Avg.	Std Dev	Travel Speed	
I-74 WB (West of Indiana and Illinois State Line) Partial Closure Right Line Closed Length=6.1 km	1, WB, Merging	97.2	79.5	90.6	4.6	90.6	0.473	0.894	98.2	0.8	98.2	18.3
	2, WB, Merging	106.2	63.1	88.2	9.4	88.1	0.690	0.364	102.7	4.2	102.8	38.0
	3, WB Merging	98.9	67.8	76.8	4.7	76.7	1.335	0.357	109.4	5.4	109.7	89.5
	4, WB, Non-Merging	98.0	46.7	74.8	12.6	74.8	0.363	1.512	104.9	2.8	104.9	91.2
	5, WB, Non-Merging	91.9	46.5	78.1	7.4	78.4	1.740	1.933	108.4	1.2	108.4	79.0

Note: NB = Northbound; SB = Southbound; EB = Eastbound; WB = Westbound.
Merging -- Test vehicle performed merging maneuver from the closed lane to the open lane when approaching to work zone.
Non-Merging – Test vehicle did not perform merging maneuver (approached to work zone from the open lane).

TABLE 2 Mean Values of Vehicle Deceleration and Acceleration Rate

Work Zone Type	Merging Type	Mean Deceleration Rate (km/h/s)	Mean Acceleration Rate (km/h/s)
Crossover (Median Crossover Direction)	Merging	0.788	0.876
	Non-Merging	0.839	1.392
Crossover (Opposite Direction)	Merging	0.378	0.726
	Non-Merging	0.366	0.763
Partial Closure	Merging	0.603	0.641
	Non-Merging	0.732	1.131

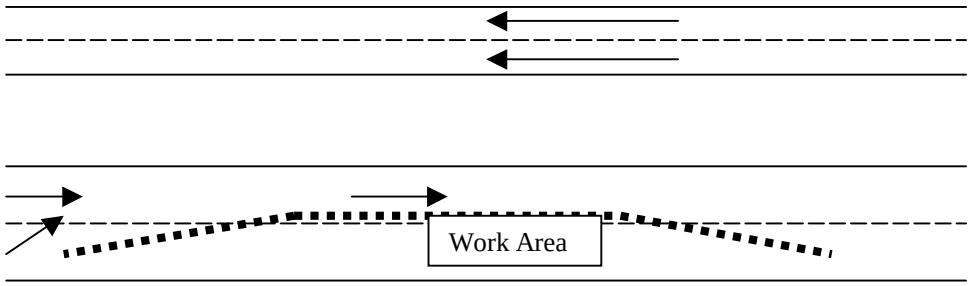

FIGURE 1 Partial Closure Work Zone

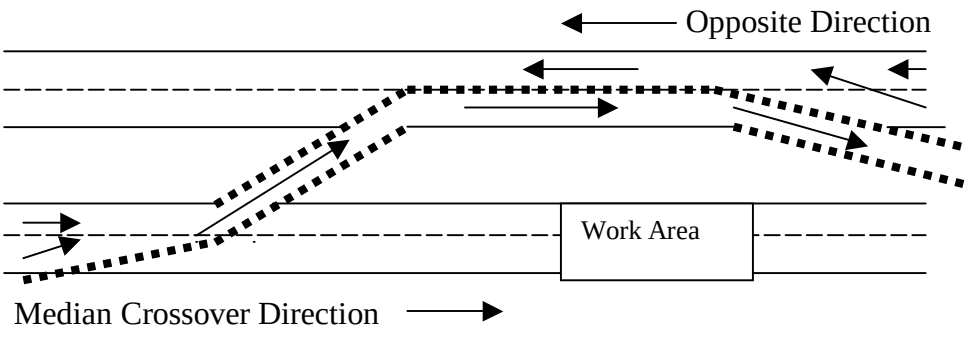

FIGURE 2 Crossover Work Zone

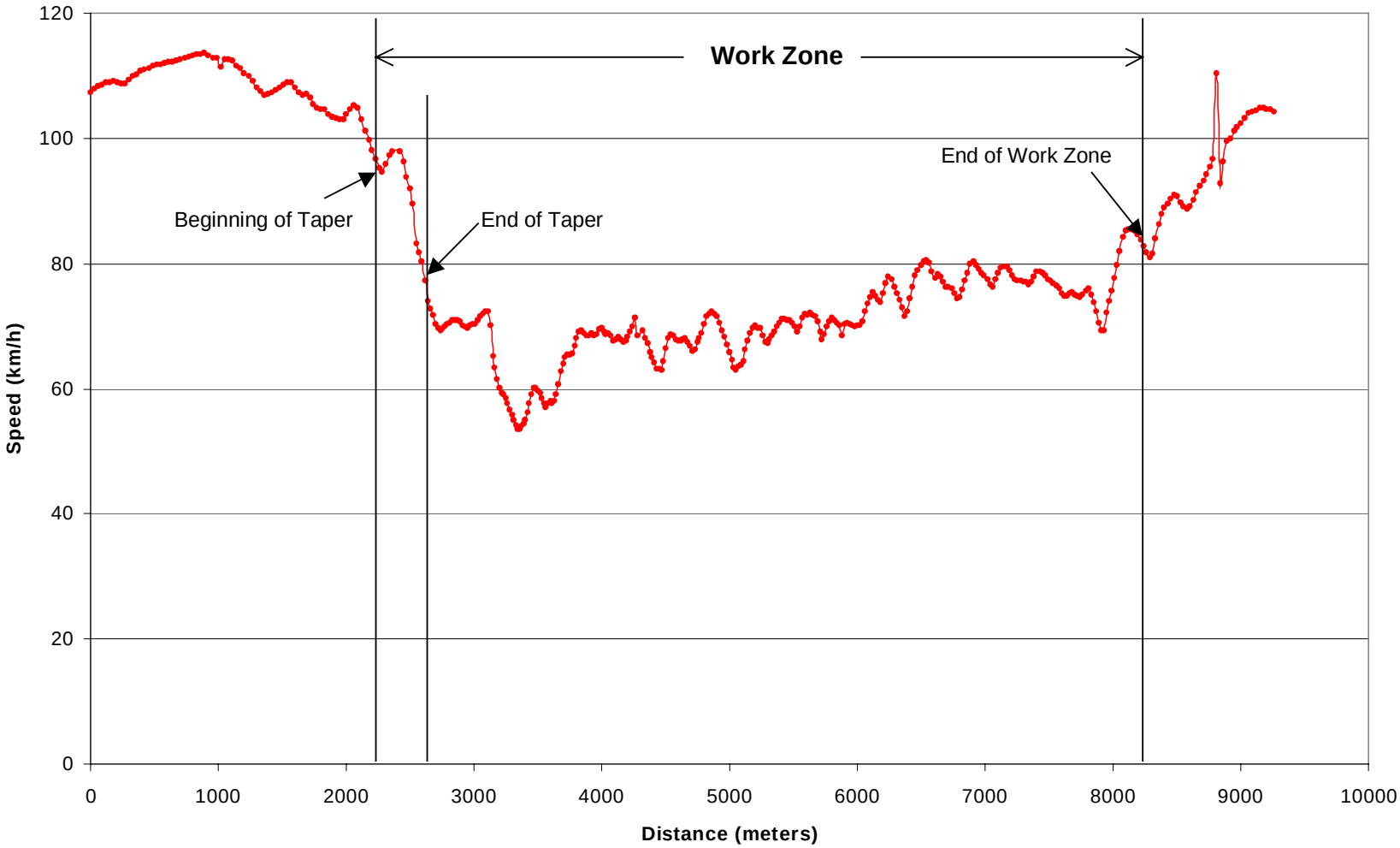

FIGURE 3 Vehicle Speed Profile at a Work Zone on I-74

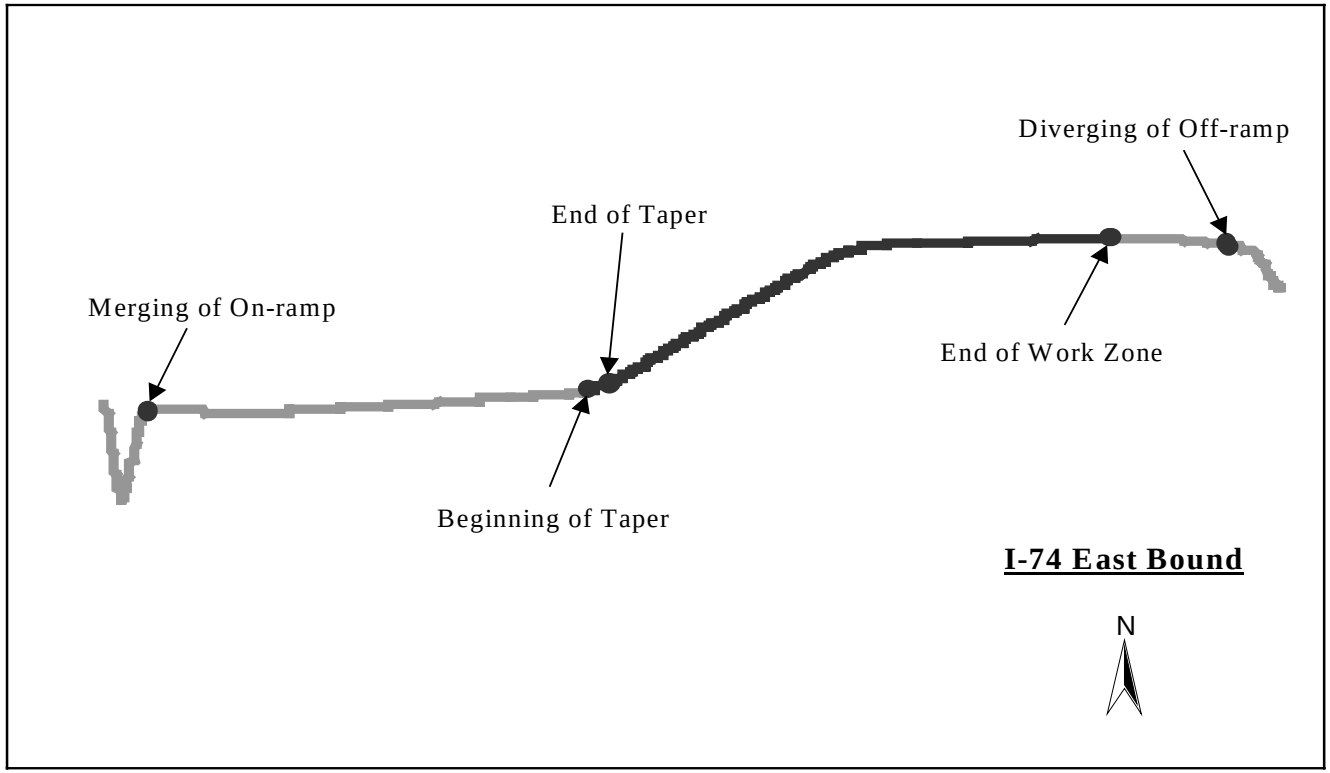

FIGURE 4 The Roadway Layout Created with GPS Data

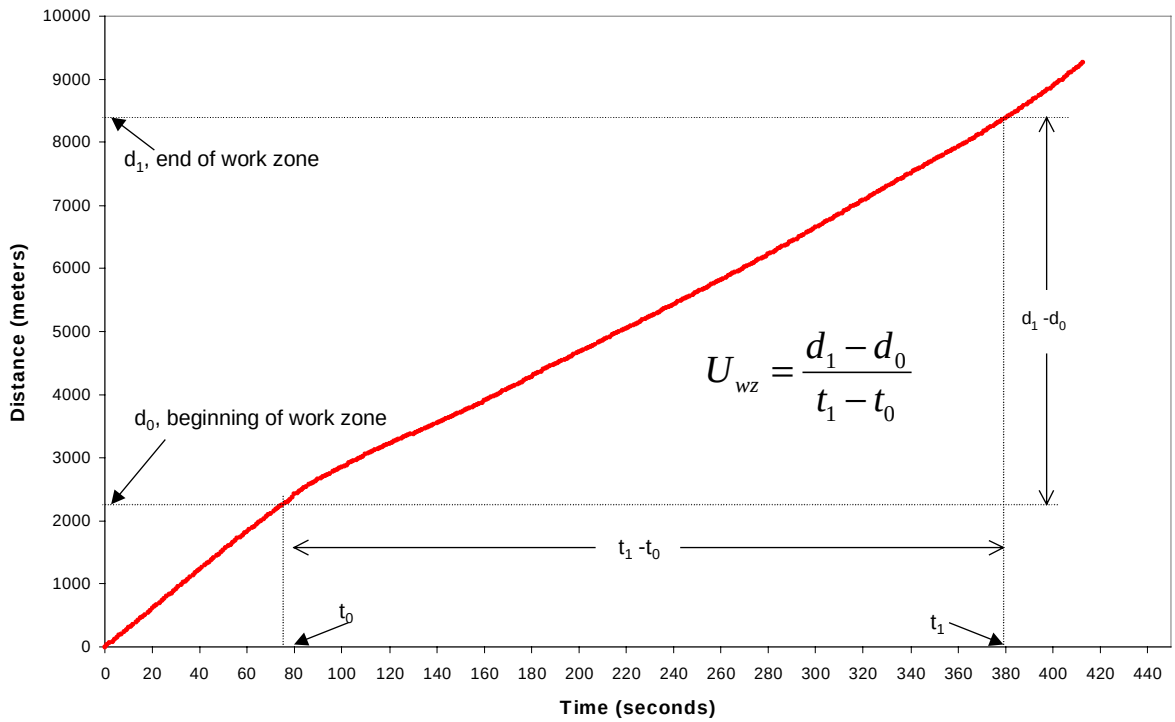

FIGURE 5 Average Travel Speed at Work Zone

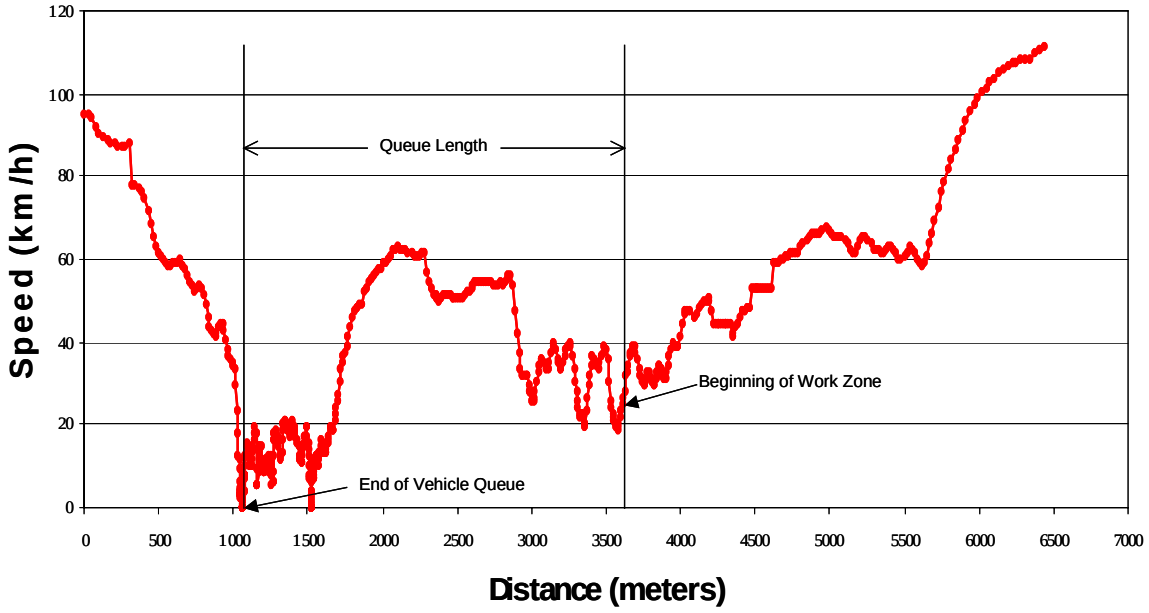

FIGURE 6 Identification of Queue Length