Traffic Information Deriving Using GPS Probe Vehicle Data Integrated with GIS

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Abstract

With the rapid vehicle volume growth on roads, the performance of urban road traffic systems is a major concern to transportation planners, road users, and all members of the urban community. The evaluation of the performance measures relies on the accuracy and reliability of the collected traffic data. This paper describes a method of extracting transportation information using global positioning system (GPS) receivers integrated with geographic information system (GIS) technology. An AgGPS132 DGPS receiver was used to collect probe vehicle data along several highways of interest in Columbus, Ohio for 2002 and 2003. A digital orthophoto quarter-quadrangle (DOQQ 2000) with a ground resolution of 0.5 ft (0.15 m) is used as a backdrop to develop the highway database. The collected GPS points were mapped to the highway using a "snapping" technique in a GIS environment. Travel time, speed and congestion index values were measured along selected highway segments for evaluating the traffic condition of the highways. The results of GPS data compared favorably with the corresponding loop detector data. For all runs, the average difference values between the GPS probe vehicle speed data and the loop detector speed data were less than 4 mph (6.4 km/hr).

1. Introduction

The volume of travel throughout the world has been increasing rapidly over recent decades. As a result, transportation-related problems are getting worse. Traffic volumes in Ohio corridors have grown at a rate greater than 20% over the past five years, with a projected growth of more than 50% within the next 20 years. “Commuters in the Columbus, Ohio metropolitan area waited an average of 29 hours in traffic tie-ups in 2002—making it the 39^{th} most congested large city in the nation” (Columbus Retrometro). The increase in traffic volume results in growing costs in terms of rapidly increasing congestion levels with associated environmental pollution and with a risk of accidents and time wasted during travel.

With the rapid vehicle volume growth on roads, the performance of urban road traffic systems is an important issue to transportation planners, road users, and all members of the urban community. The evaluation of the performance measures to some extent relies on the accuracy and reliability of the collected traffic data. There are various methods of traffic data collection. They include automatic traffic recording devices (ATRs), e.g., tripwire systems, loop detectors (Pushkar et al. 1994, Petty et al. 1997), sonic detectors (Polk et al.1996), video image processing systems (Michalopoulos et al. 1993), and other remote sensing techniques (Sastry 2000).

Most transportation services require spatial and temporal information. However, traffic monitoring detectors described above are localized and lack spatial coverage. Remote sensing imagery from satellites cannot provide time continuous transportation information. The repeat period of imaging from polar-orbiting satellites ranges from 16 to 26 days. High resolution imagery (1-4 m) is available on a 1 to 3 day revisit period. This lack of continuous information imposes a limitation on transportation applications of satellite image data.

On the other hand, Global Positioning Systems (GPS) provide a real-time spatial and time measurement of a location. GPS technology offers a low capital cost, a low installation cost, and a low data collection cost combined with a high location accuracy. GPS has been increasingly used in conducting transportation studies (Quiroga and Bullock 1998, D'Este et al. 1999, Li et al. 2002). As part of an effort for obtaining traffic data using remote sensing techniques integrated with GIS (Geographic Information System) (Roper 2003, Sivaram and Kulkarni 2001), this study investigates the use of GPS probe vehicle data as a part of the traffic data collection system.

In this study GPS data are collected and the errors associated with GPS data are analyzed. The highway with spatial properties, including lane information, on-ramp merging, and off-ramp exit are also modeled with the assistance of GIS, considering the fact that the functions of individual lanes are different. Several indices of congestion analysis based on Taylor (1992) are used to evaluate the congestion along the highway of interest. The next section provides a description of the study area, the GPS probe vehicle data acquisition, and the remote sensing and GIS data. Next a description of methods used to process the GPS probe vehicle data is given. Results and a discussion are presented and finally conclusions are developed.

2. Data collection

The area of interest for this study includes several freeways in Columbus, Ohio, including the southern part of SR 315, the I-70/ I-71 overlap where the two interstate highways merge in the downtown area (roughly bounded by I-670 to the north, I-70/I-71 to the south, SR 315 to the west, and I-71 to the east), and I-71 north of I-70, as shown in Figure 1. For these freeways, especially on the I-70/I-71 portion, there are problems of congestion, traffic delays and safety hazards (accidents and geometric problems). About 175,000 vehicles pass through the I-70/I-71 split every day, but the corridor was designed to handle only 120,000 vehicles. State highway officials call this area the most congested section of highway in the entire state. Besides being congested, the 1-1/2-mile split is dangerous, with an average of three accidents on the road every day. For only 6% of the freeway system in Ohio, 27% of all I-70/I-71 freeway accidents occur at this location (ODOT 2004). On an average day in 2003, approximately 52,000 vehicles traveled I-71 between Cleveland and Columbus, Ohio (FHWA 2004).

The GPS probe vehicle data were collected by the transportation group directed by Dr. Benjamin Coifman (The Ohio State University). An AgGPS132 receiver with sub-meter differential position accuracy was used for data collection. The data collection time includes the AM peak (7:00 AM to 9:00 AM) and the PM peak (4:00 PM to 6:00 PM) periods on Tuesday, Wednesday and Thursday, which are considered typical weekdays for traffic analysis, for both 2002 and 2003. The route that the GPS probe vehicle followed for each trip was fixed: the driver took the onramp to SR 315 SB from Lane Avenue, crossed the lanes of SR 315 to get onto I-70 EB/I-71 NB, drove onto I-71NB, took the off-ramp from the Polaris exit (end of the north run), drove to I-71 SB, I-70WB/I-71SB, and SR 315 NB back to the Lane Avenue exit (end of south run) (Figure 1). Normally for each peak period for the data collecting day, the driver would complete two runs. Table 1 shows the dates of probe vehicle data collection for 2002 and 2003.

The Trimble 5700 RTK receiver with sub-centimeter accuracy was borrowed from Dr. Charles Toth (Center for Mapping, The Ohio State University), to test the performance of the AgGPS132 DGPS receiver along the runs and to perform the highway linear referencing. During the AgGPS132 test, we placed the Trimble 5700 RTK and AgGPS132 DGPS receivers in the same van with the antennas separated by a distance of 2 ft (0.6 m). We did two AM peak runs on April 22, April 27, and two PM peak runs on April 23 and 27, 2004. Because the GPS receivers only record location as longitude-latitude pairs, the Trimble 5700 receiver was also used to collect the mile marker for the highway linear reference system. A post-processing technique with the Trimble Geomatics Office software and base station data was employed to determine the GPS position data from the Trimble 5700 RTK.

The Franklin County Digital Orthophoto Quarter Quadrangle (DOQQ) was used as the base (backdrop) to overlay the GPS transportation data (Figure 1) and develop GIS spatial information. The Franklin County DOQQ was compiled as a mosaic of 10,160 grayscale orthoimages that were obtained in 2000. The DOQQ offers a high resolution of 0.5 ft (0.15 m), which refers to the distance on the ground that is represented by each pixel in the x and y directions. Each “chip” involved in the DOQQ contains 2500 ×2500 pixels. The DOQQs are all referenced to the North American Datum of 1983 (NAD 83) and are cast on the State Plane Coordinate System (SPC) Ohio South FIPS (Federal Information Processing Standard) 3402 (units are in feet).

Loop detector data during 2002 were also obtained from Dr. Benjamin Coifman (OSU) for the highway of interest (Figure 2) for referencing the GPS probe vehicle data. In Figure 2 the points indicate where the loop detectors are located and the labeled points are the loop detectors where we have data. The loop detector data for the dates when the probe vehicle data were collected were extracted from the loop detectors. The loop detector data contain the velocity for each lane and the average velocity data over all the lanes for 5 minutes and 30 second intervals. The corresponding dates for the loop detector data were 14, 17, and 28 February, 30 April, 7, 15 and 22 May, 6 June, 31 July, 7, 8, 15 and 21 August, and 31 October, 2002.

2002 AM	2002 PM	2003 AM	2003 PM
020214	020213	030716	030520
020226	020213	030723	030520
020227	020214	030723	030527
020228	020227	030730	030529
020430	020228	030730	030618
020507	020423	030813	030619
020515	020425	030813	030701
020522	020502	030820	030703
020606	020509	030910	030716
020619	020516	030917	030805
020620	020530	030930	030805
020626	020606	031008	030813
020702	020618	031016	030819
020702	020625	031021	030819
020703	020627	031029	030826
020710	020702	031104	030904
020717	020702	031118	030910
020724	020709	031204	030917
020725	020711		030925
020731	020716		031002
020806	020723		031009
020807	020730		031016
020808	020801		031023
020814	020813		031030
020815	020815		031106
020821	020820		031113
020828	020827		031120
020904	020903		031202
020905	020905		
020911	020912		
020912	021031		
021016	021031		
021031	021106		
021107			
021120			

The first two numbers stand for the year, the next two numbers are the month, and the last two numbers are the day of the month.

Table 1. List of dates for the collected data for 2002 and 2003.

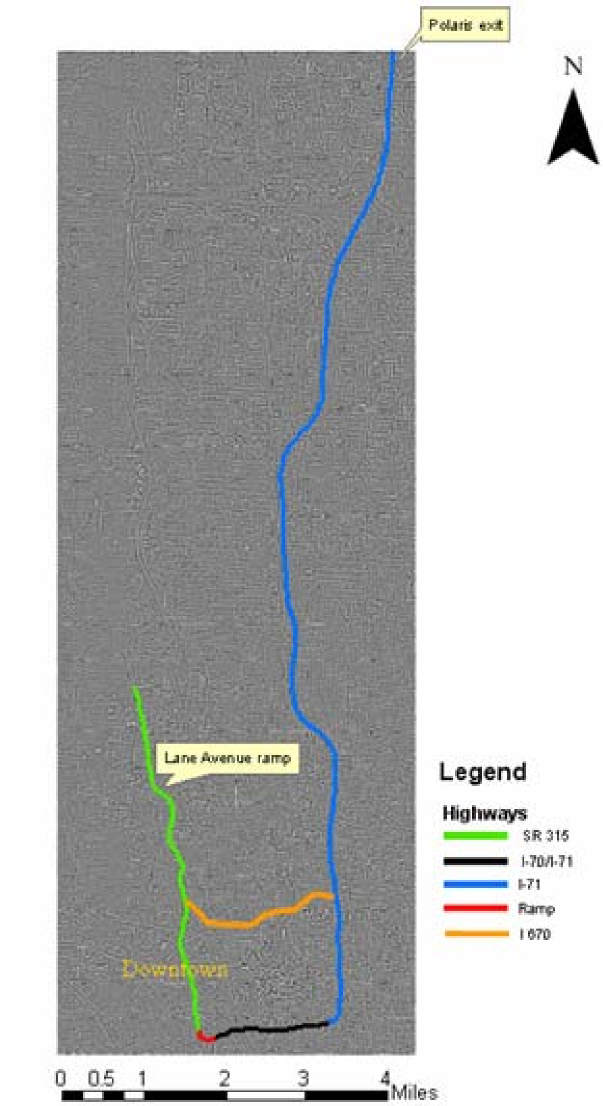

Figure 1. Study area of interest near Columbus, Ohio.

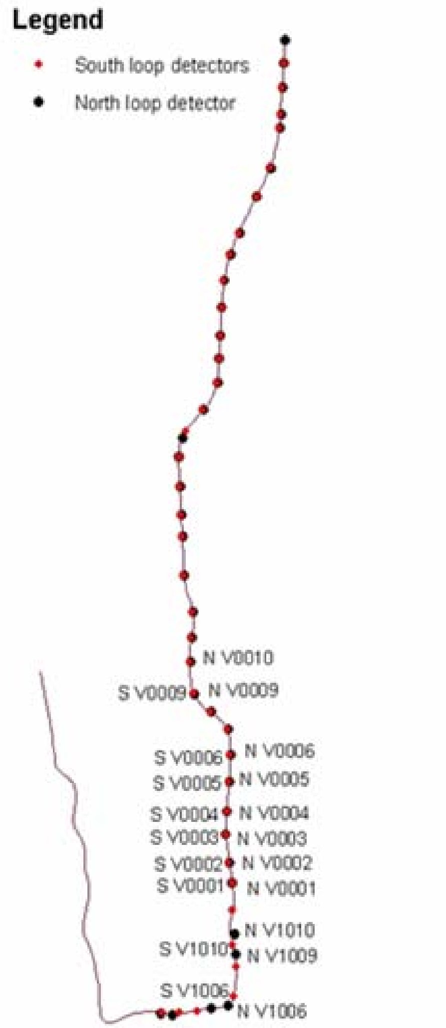

Figure 2. Loop detectors on the highways for the north and south runs.

3. Data processing

3.1. Highway frame

A digitized highway network was required to analyze the GPS probe vehicle data. One approach is to use existing data files, such as the Topologically Integrated Geographic Encoding and Referencing (TIGER) files developed by the U.S. Census Bureau. Unfortunately, such maps only provide a crude representation of the transportation corridor and the geometry is not accurate enough for this transportation engineering application. Alternatively, we can generate the road network of interest using a GPS receiver (Taylor et al. 2001). However, because this base map is constructed directly from the GPS data, the map contains the weaknesses that are inherent in GPS data. In fact, for this study much of the area of interest is in the downtown Columbus area, where tall buildings and overpass bridges can cause problems with multipath errors and missing data in collected GPS data. In fact, the collected GPS data show that the data contain these types of errors for the 2002 dataset. The acquired GPS data are better for the 2003 dataset, but still there are errors in the GPS points collected around the downtown area.

In this study, we used the method of digitizing the road centerline “heads-up” on the computer monitor using the Franklin County orthophoto as image backgrounds. With the distance of 12 ft (3.7 m) between two adjacent highway lanes, the spatial resolution of 0.5 ft (0.15 m) of the image was adequate for identifying and mapping the centerline. When digitizing, a node was placed at all the road changes, such as the lane change points, any change in posted speed limit, the on-ramps and off-ramps. Two centerline shape files were digitized, one for the north run and one for the south run of the GPS probe data. The north run contains the segments of SR 315SB, I-70EB/I-71EB, and I-71NB. The south run contains the route of I-71SB, I-70WB/I-71WB, and SR 315NB (Figure 1).

3.2. Linear reference system procedure

For linear referencing of the digitized highway network of this study, ODOT has a posted mile marker system that is used as the referencing network. We checked with ODOT individuals (J. McQuirt, pers. comm. 2004) to obtain the mile marker points information along the highways of interest. ODOT typically places mile markers on rural state routes at intervals of 1 mile. Mile markers start at 0 at the western or southern boundary of each county line. Mile markers of interstate routes are placed with intervals of 1 mile starting at 0 at the western or southern state line and continuing across the entire state or length of the route. With the milepoint linear reference method in this study, it was difficult to obtain the datum “mile 0” for the interstate highway. Instead, we used the mile marker posted along the highway as the measured anchor point for linear referencing. Locations of five mile-marker points were measured using the Trimble 5700 GPS receiver to establish the linear referencing system of SR 315SB/NB and I-71 SB/NB. A computer program was designed to calculate the segment distance along the highway and to assign the computed mile markers for each node of the digitized network. Thus the unassigned measures of a geometric node are automatically populated based upon their distance from the reference point. The measure of any point on the geometric segment can be obtained based upon a linear mapping relationship between the previous and the next known measure or location.

3.3. Map GPS probe vehicle points to the digitized centerline

After the linear referencing of the highway was established, the collected spatial GPS data needed to be integrated into the highway linear referencing system. For this purpose, we developed the "snap" program to snap a vehicle's position to its nearest location to highway centerline. The program was written in Visual Basic 6.0 using MapObjects. The program requires:

- Highway centerlines that were digitized previously; and
- GPS data shapefiles that were converted from the raw data collected from the GPS receiver.

The program logic is as follows:

1. Load the highway centerline shapefile.
2. Load a GPS shape file.
3. Create a new GPS shape file that stores the "snapped" point on the centerline.
4. Starting with the first point in the GPS shapefile, move through each point
    a. For each point, calculate the perpendicular distance (Point_Distance) (positive distance if the point is on the left side of the centerline, negative otherwise) between the GPS point and the highway centerline segment. If the absolute value of the distance is larger than 45 ft (13.7 m), discard this GPS point.
    b. Find the minimum absolute value of Point_Distance, the corresponding Closest_Segment and the corresponding point (Closest_Point) on the centerline

c. Calculate the longitude and latitude for the Closest_Point.

d. Record the new GPS shapefile:

- Closest_Point feature
- Centerline ID
- Point_Distance total length of the Closest_Segment
- Cumulative distance from the first centerline segment to the Closest_Segment
- Distance from the first node of the Closest_Segment to the current GPS point
- The linear reference calculated based on the distance generated in the last step

5. Repeat steps 2-4 for all the GPS shape files.

When snapping, the minimum distance of the point to the centerline and the nearest point ("snapped" point) on the centerline are recorded in the newly created GPS shape file. The minimum distances are calculated to determine which lane the vehicle is located on. Table 2 shows an illustration of which lane the GPS point would be located, knowing the distance between the GPS point and the highway centerline for a four-lane highway segment. The following facts were considered: the lane width for the standard interstate highway in Ohio is 12 ft (3.7 m); and there are at most four lanes on the highway of interest; the lateral offset of the GPS point from the centerline is 24 ft (7.3 m) at most. When the lateral distance is 45 ft (13.7 m), it is obvious that the GPS point is located outside of the projected road, either because of too much multipath interference in the downtown areas or the vehicle is on a local road instead of on the highway. We could give the exact bounds for the GPS point location for different lanes, but considering the multipath interference on the GPS we put some tolerance to allow more points to be included. At the same time the cumulative distance from the GPS point to the origin of the digitized route and the linear reference mile markers are based on a linear mapping relationship between the "from" node of the "Closest_Segment" and the distance to the node. Figure 3 shows how the GPS points are snapped to the highway segments using four lanes. In Figure 3, for GPS Point 1, the distance between the vehicle location and the centerline is 10 ft and is less than the 12 ft, which indicates that the vehicle is on the second lane. Point 2 is on lane 4, since the distance from the GPS point to the centerline is within the interval of -24 ft to -12 ft. We discarded Point 3 when doing the snapping, as Point 3 is located too far from the centerline (< -45 ft).

Distance between the GPS point and the highway centerline (ft)	Lane
12 < d <= 24	1
0 < d <= 12	2
-12 < d <=0	3
-24 <= d <= -12	4

d: the distance between the GPS point and the highway centerline.

Table 2. Illustration of GPS lane locations for a four-lane highway segment.

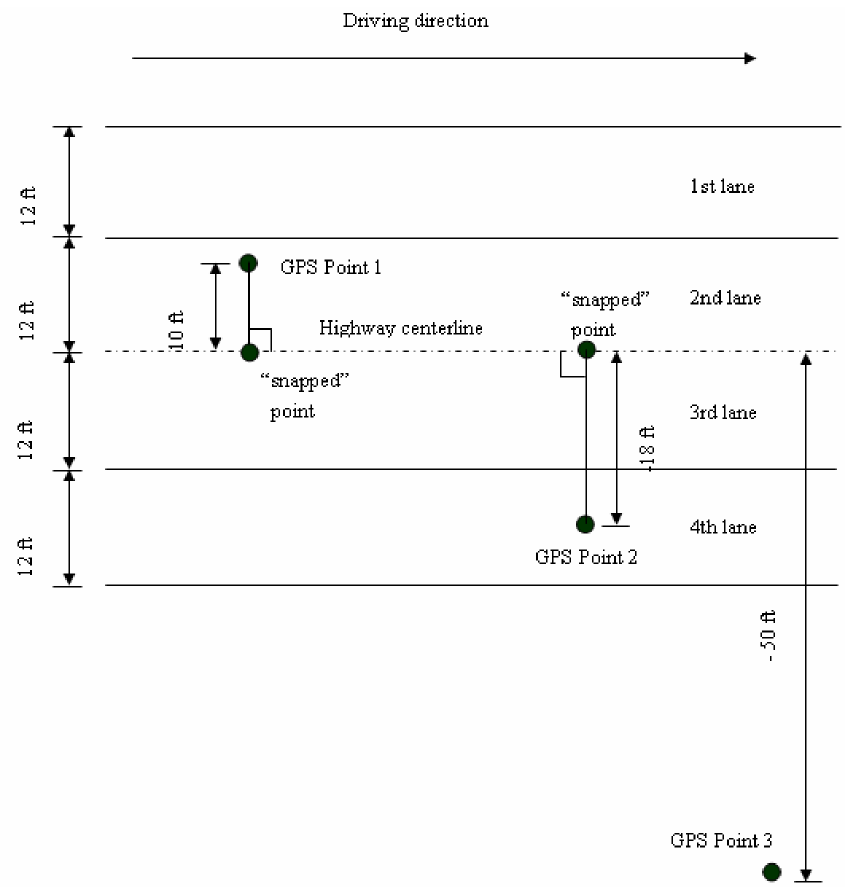

Figure 3. GPS probe vehicle points snapped to the highway centerline.

3.4. Segment highways to 0.5-mile in length

GPS probe vehicle data records the information for each point along the highway at every second of travel. It would not make sense to only look at one point along the highway. Therefore, we aggregate these points to find the traffic flow pattern. There are two ways to aggregate the GPS points. The first way is to aggregate all the points along the specified road segment. The second is to aggregate all the points for a fixed period of time. In this study, we are more interested in the traffic pattern along the road segment. Therefore, we used the first method to aggregate the GPS points. As a result, the highway needs to be segmented to a specific length. The segmentation could be either fixed-length or variable length.

Fixed-length segmentation controls the location (i.e., holds the spatial units constant) and measures the attributes of interest for each segment. This method imposes a fixed level of spatial resolution on the linear data and we cannot determine the spatial distribution of an attribute at a higher resolution than designated by the fixed segment length. Quiroga and Bullock (1999) did an analysis of the distributions of differences between original GPS speeds and aggregated speeds, and suggested that segments no longer than 0.5 mile (19.3 km) would be better to quantify the performance of congestion management measures. We use the fixed-length segmentation technique to subdivide the entire highway network into 0.5-mile segments.

3.5. Comparison of the GPS probe vehicle speed with the loop detector speed

The speed plotted from the GPS receiver was compared with the speed collected by the loop detectors (Figure 2). The 30-second speed data were used for the comparison with the GPS probe vehicle data. To do the speed comparison work, the two nearest GPS probe vehicle points to each loop detector station for each day when the GPS data were collected were determined. The time and the lane location for these two GPS points were checked and used to extract the corresponding speed data from the loop detector dataset. The time period of 30 sec containing that specific GPS probe vehicle point was also located for the lane location. Normally the time difference for these two GPS points is 1 sec and there is no lane change during such a short time period. If there is evidence of a lane change, the loop detector data for both lanes were considered for the comparison. The speeds from the two GPS points were averaged using a weighted distance. The GPS average speed was then compared with that derived from the corresponding loop detector. For example, in Figure 4 two GPS points - Point 1 and Point 2 - are identified for a loop detector station for a run. These two points are located on the second lane. Therefore, the speed data on the second lane are to be extracted. The speed data with the time period of 08:30:00-08:30:30 containing the time of the two GPS points 08:30:00 and 08:30:01 were extracted. The GPS average speed was calculated using the weighted distance, as shown in the formula (Figure 4).

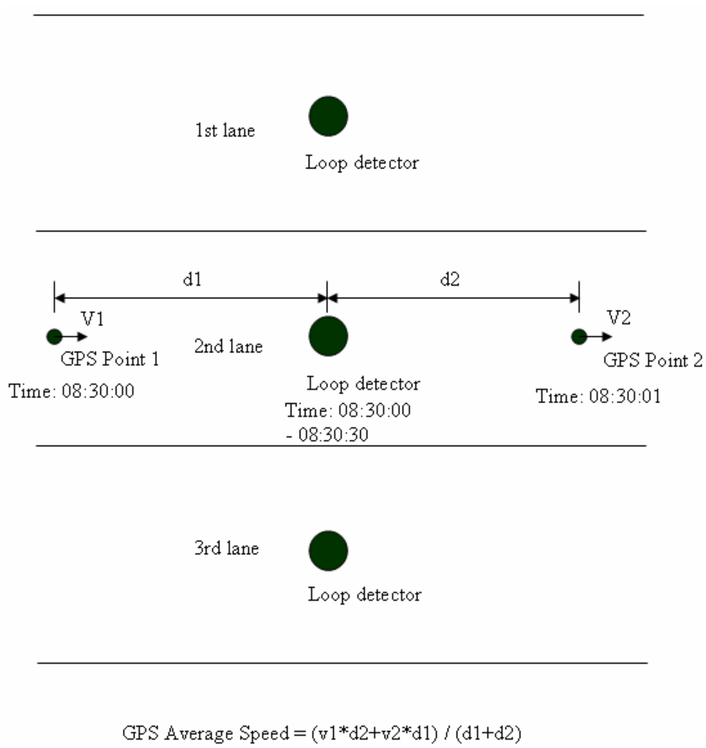

Figure 4. Speed comparison between GPS data and loop detector data.

4. Results and discussion

4.1 GPS errors

In our field data collection study, the bridge overpasses along the highways caused an abnormal and incorrect GPS measurement. Sometimes the bridge overpass completely blocked the GPS signal, which caused missing data or only allowed two or three satellite signals to be received, which reduced the GPS positional accuracy. On other occasions, the bridge overpass reflected the signals, resulting in multipath errors.

The Trimble 5700 GPS receiver has sub-centimeter accuracy and is generally used for survey purposes. In our study the Trimble 5700 GPS receiver was used for testing the accuracy and reliability of the AgGPS132 GPS receiver as a technique for obtaining positions of the probe vehicle along the fixed run. We overlaid the data collected by the AgGPS132 receiver with the data collected by the Trimble 5700 for the same time period and calculated the distance between the pairs of points. Table 3 shows the statistics information for the positional difference of the two GPS receivers after we removed the abnormal GPS points. The negative values indicate that the Trimble 5700 GPS receiver is behind the AgGPS 132 receiver, while the positive values indicate that the Trimble 5700 GPS receiver is in front of the AgGPS132 receiver. Compared with the measured actual distance of -2 ft (-0.6 m), the AgGPS132 unit provides reasonably accurate data for the probe vehicle analysis, as the data compares favorably with the survey receiver Trimble 5700, which is a highly accurate GPS receiver (Table 3).

Run	No. of points	Mean (ft)	Standard Deviation (ft)
042204 AM	3525	-2.05	1.85
042304 PM	3678	-1.92	2.69
042704 AM	3607	-2.08	2.65
042704 PM	3296	-2.09	2.76

Table 3. Statistics information for the calculated distance between the two GPS receivers.

4.2 Vehicle lane position tracking analysis

With the sub-meter accuracy of the AgGPS132 receiver, it is possible to identify the lane location of the vehicle on the highway. With the lane information in the highway network, we modeled a detailed highway frame in terms of lanes. Figure 5 displays the frame around the centerline that we digitized for the north run. The frame shows the location of the lanes and bridges along the highway for the north run traveling from the OSU campus to the Polaris Parkway. The frame is useful to identify which lane the vehicle is located within when we overlay GPS probe vehicle data. Figure 6 shows another configuration of the lane frame for the same run. This frame configuration is much more practical, since this frame specifies where the lane starts, continues and ends. Therefore, when we overlay GPS point information on this frame, it is easy to determine whether the vehicle continues in the same lane or makes a lane change. An example of a vehicle run is shown in Figures 7.

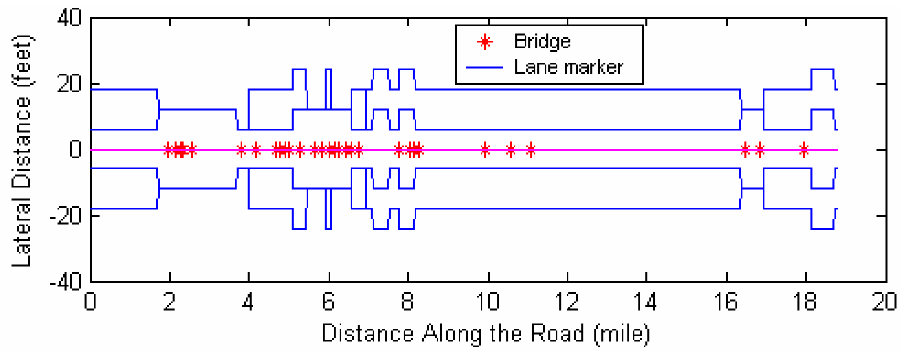

Figure 5. Lane frame along the highway with respect to the centerline for the north run.

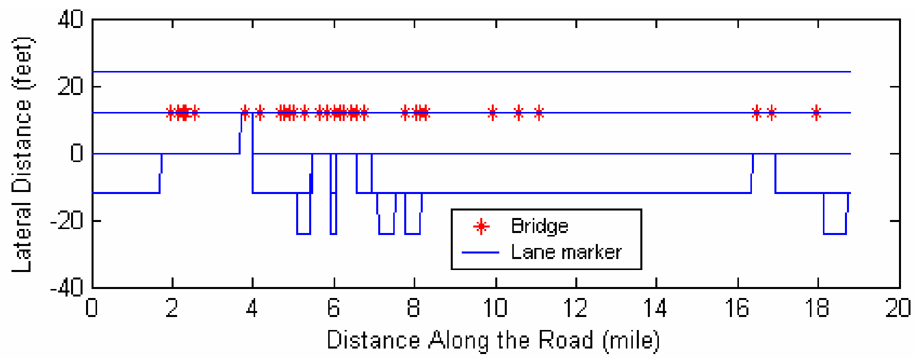

Figure 6. Another lane frame representation for the north run.

Figures 7 shows the data collected on 24 July 2003 overlaid on the second highway lane frame (Figure 6). The solid and dashed lines illustrate the vehicle positions with respect to the highway centerline for the first and second runs, respectively. It is easy to track the vehicle lane position using this frame representation. For example, the vehicle merges into the highway from the right on-ramp lane and crosses the second lane to the inner lane. We notice that there are several bridges and several abnormal GPS points that fall outside of the roadway because of signal blockage by the bridge overpasses and multipath interference, which causes additional abnormal GPS location points. After mile 7, the GPS points stay stable on the roadway in the center lane, which is in agreement with the instructions that were told to the driver. Around mile 16, the vehicle makes a lane change to the inner lane and crosses the lanes to exit the highway from the right off-ramp exit.

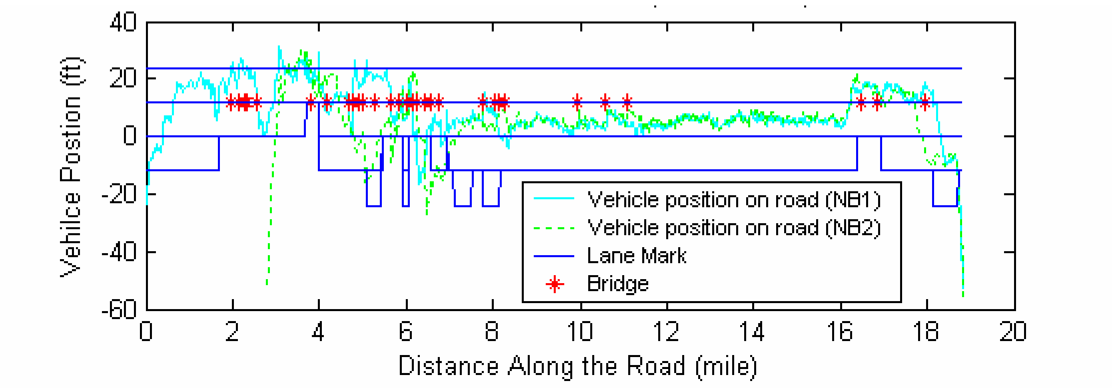

Figure 7. Vehicle position on highway for the north run (07/24/2002 AM).

With the high positional accuracy of the AgGPS132 receiver, it might be possible to gain some information about driver lane change behavior. In addition, the derived congestion parameters can be applied to the individual lane, which might be a help to analyze the effect of the on or off ramps during high traffic. However, a problem occurs when the vehicle is located in the downtown area. With the multipath errors, it is much more difficult to locate the true vehicle position. When operating in an open sky area, as noted from mile 8 to 18 in Figure 7, the GPS accuracy permits us to perform such an analysis.

4.3 Congestion analysis

Up-to-date congestion analysis is critical for evaluating road performance. Lomax et al. (1997) recommended that travel time-based measures should be used to estimate congestion levels. Measures related to travel time and speed are flexible and useful for a wide range of analyses. Since speed data can be determined from the time and locations provided by a GPS receiver, the travel time, average travel speed, and congestion index that is based on the travel time were selected for measuring the congestion for the Columbus study area.

The average travel times for the complete north and south runs for 2002 and 2003 were calculated and shown in Tables 4 and 5. For the calculation of travel time for the north run, the starting point is where Lane Avenue merges with SR 315 and the ending point is the Polaris exit. The total length of the route is 18.7 miles (30.1 km). The calculation for the south run starts where the Polaris on-ramp merges with I-71S and ends at the mile marker SR 315 1.4 mile mark. The total distance for the south run is 16.09 miles (25.89 km). Tables 4 shows that the average travel times during 2003 are less than those in 2002 for both the north and south runs. For example, the southbound route is about 2 mins faster in 2003 compared with 2002 for both the AM and PM runs. The northbound runs show little difference (<1 min) for both the AM and PM peak hours. The corresponding average travel speeds are greater in 2003 than those in 2002. These data indicate that the moving traffic is slower for the PM peak than in the AM peak.

Data collection period	North run		South run	
	Travel Time (minutes)	Speed (mph)	Travel Time (minutes)	Speed (mph)
2002 AM	18.89	59.44	19.09	50.56
2002 PM	22.67	49.54	20.20	48.57
2003 AM	18.38	61.09	16.64	57.99
2003 PM	21.72	51.70	18.37	52.54

1 mph=1.61 km/hr

Table 4. Average travel times for the north run and south run.

The average speed results for each 0.5 mile segment are shown in Figure 8 (north run) and Figure 9 (south run). The speeds decrease dramatically around the I-70/I-71 split areas (mile 4 to 6 for the north run and mile 13.5 to 15.5 for the south run) for all the runs, especially during the PM peak hours. The morning runs and afternoon runs almost follow a similar morning or afternoon pattern, except that there is more traffic congestion around the downtown areas for the afternoon runs. Figures 10 and 11 show the average speed display maps for the 2003 PM north and south runs. These two maps illustrate the low average speeds around the downtown area.

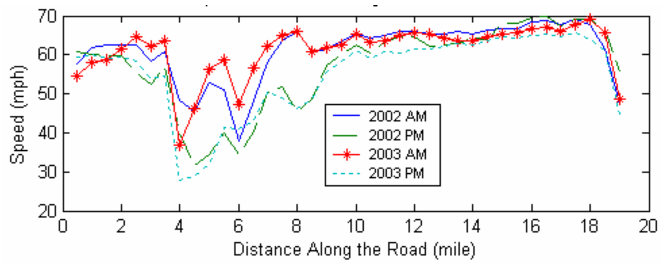

Figure 8. Average travel speeds for 0.5-mile segments for the north run.

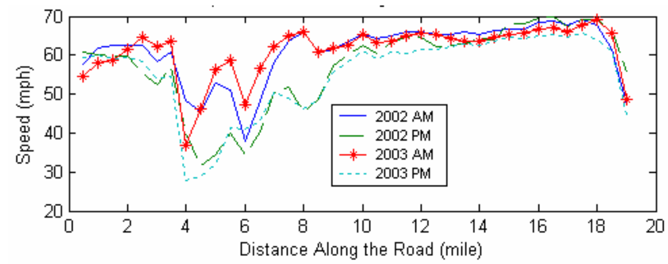

Figure 9. Average travel speeds for 0.5-mile segments for the south run.

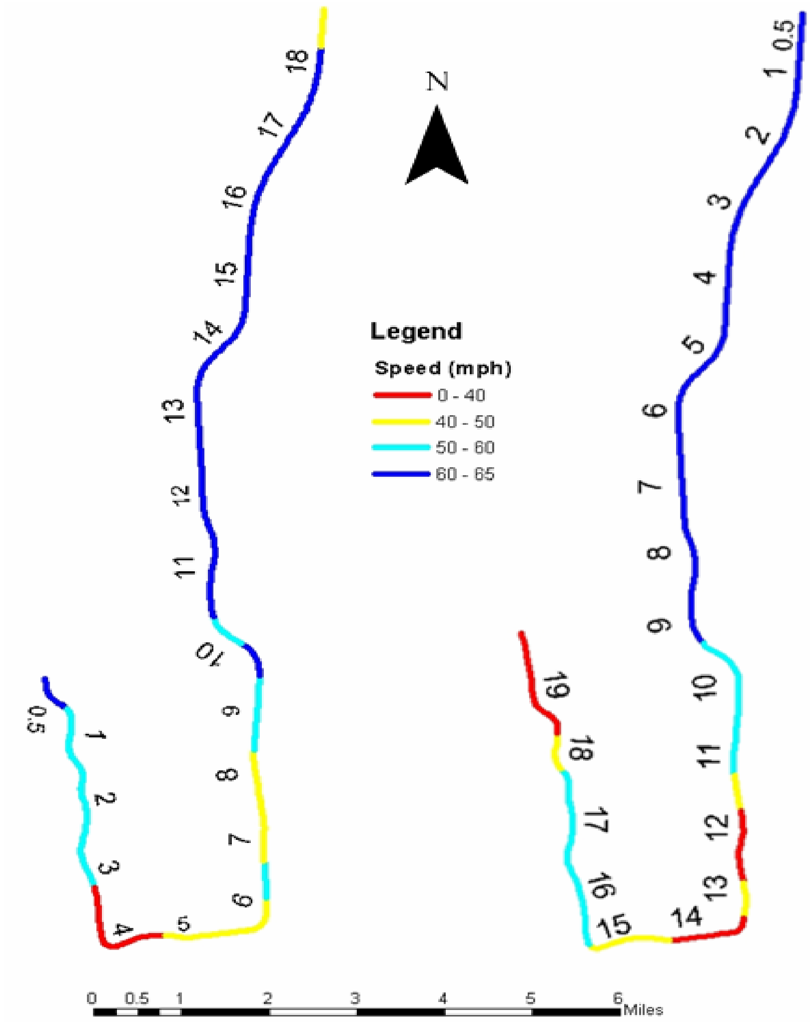

Figure 10. Average speed mapping for the 2003 PM north runs.

Figure 11. Average speed mapping for the 2003 PM south runs.

Considering the effect of different speed limits on the travel speeds, we also calculated the congestion index, which is defined as $(C - C_0)/C_0$ where C is the actual travel time and C_0 is the free flow travel time (Taylor 1992). A congestion index near zero will indicate very low levels of congestion, while an index greater than 2 will generally correspond to congested conditions. In this study, we assume that the driver will observe the speed limit and thus the speed limit is adopted for calculating the free-flow travel time. Since the speed limits attribute has been incorporated into the GIS when we established the highway network previously, the travel time for different segments can be derived.

The congestion indices are calculated for each 0.5 mile segment. Figure 12 shows a plot of the congestion index values for each segment for the north runs. In 2002 AM, the congestion indices at mile 5.5 to mile 6.5 (around I-71N 107to I-71N 109 on the I-70/I-71 split) are higher than the other segments. For the PM runs in 2002 and 2003, the area with large congestion indices are located from mile 4 to mile 8.5, including the I-70/I-71 split area and miles north along I-71. The downtown areas have slower traffic conditions, especially for PM runs. This is due to more drivers leaving work in the downtown area and heading north.

Figure 13 shows the congestion index for the south runs. For the south runs of 2002 AM, the segments around I-71S 114 to I-71S 108 have relatively high positive congestion indices. For the PM runs in 2002, the segments from I-71S 110.5 to SR 315S 0.9 have higher congestion indices. These segments also have relatively positive congestion indices for 2003 PM, particularly at segments starting at I-71S 109, throughout most of the I-70/I-71 split. Comparing the AM and PM runs for the south run, the traffic congestion for the AM runs occurs mostly along I-71 for a length of six miles, while for the PM runs the congestion occurs along I-71 and the I-70/I-71 split to SR 315 for around five miles. For the morning runs, people come to the downtown area for work and form congestion around the downtown areas. For the afternoon runs, people leave downtown Traffic congestion is not only formed around the downtown area, but also spreads outward from the downtown area.

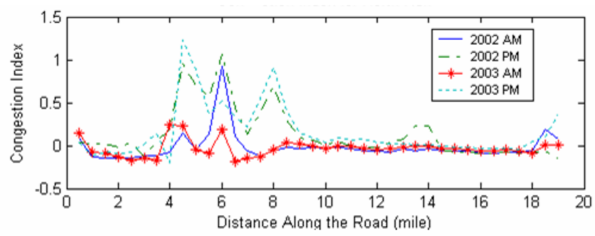

Figure 12. Congestion index for the north run.

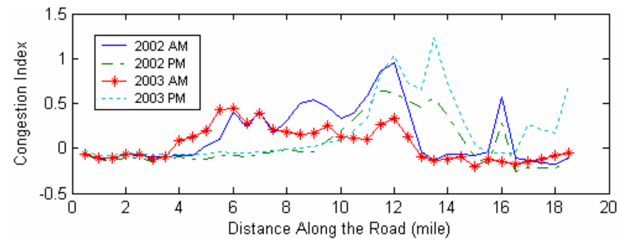

Figure 13. Congestion index for the south run.

4.4. Speed comparison between the GPS probe vehicle data and the loop detector

Speed data directly read from the GPS receiver were also compared with the speed data derived from the loop detectors. The analysis for the AM time period for both the north and south runs were determined. Tables 5 and 6 show the average speed difference between the data derived from the loop detectors and those from the GPS probe vehicle that pass over the loop detectors. For all the runs, the difference values between the two sources of data are less than 4 mph (6.4 km/hr), with most differences around 1 mph (1.61 km/hr). Figure 14 shows the comparison for one day in 2002 for the north runs, with most of the speeds derived from the loop detectors comparing well with those read from the GPS receivers.

Loop Detector	V1006	V1009	V1010	V0003	V0004	V0005	V0009
No of points	24	26	26	24	22	24	24
Average Difference (mph)	3.29	-0.32	-0.45	0.4	1.14	0.57	0.72
Stdev (mph)	6.84	2.04	2.37	1.42	5	3.92	3.1

Table 5. Average speed difference between the loop detector data and the GPS probe vehicle data for the north run.

Loop Detector	V1006	V1010	V0001	V0003	V0004	V0005	V0006	V0009
No of points	26	19	24	24	22	23	24	24
Average Difference (mph)	0.42	0.97	3.62	1.92	0.75	1.33	0.74	0.68
Stdev	2.11	5.23	5.28	4.2	3.75	2.71	1.56	3.14

Table 6. Average speed difference between the loop detector data and the GPS probe vehicle data for the south run.

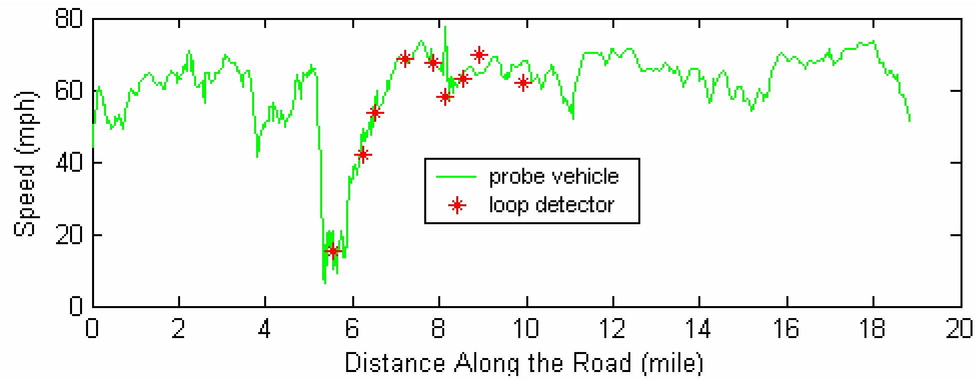

Figure 14. Speeds from the GPS probe vehicle compared with the loop detector data for the first north run on February 14, 2002.

5. Conclusions

In this paper we described an integrated GPS-GIS methodology for traffic information data extraction. The spatial characteristics for the highways of interest were developed using a GIS based on the Franklin County DOQQ with a high resolution of 0.5 ft (0.15 m). Linear referencing, which is used by highway professionals to express a location as a distance from a known starting point in a given direction, was also used in the GIS. The AgGPS132 GPS receiver was used in the data collection procedure to automatically record time, local coordinates and speed of a probe vehicle every 1 sec along the highways of interest for both 2002 and 2003. The collected data were then snapped to the highway centerlines for use in a GIS database for further analysis. Another survey was performed with a Trimble 5700 GPS receiver, along with the AgGPS132 receiver, for two days in 2004 to test the accuracy and reliability of the AgGPS132 receiver. GPS errors were evaluated. Multipath errors and signal blockage were found to be common throughout the downtown area of Columbus. The comparison results between the two GPS receivers showed that the AgGPS132 receiver provided reasonably accurate data positions. When multipath errors occur in future studies, it will be necessary to supplement the GPS receiver data with a secondary positioning system that can be used to fill in the gaps. For example, a dead reckoning (DR) device can be used to record the physical movements of the vehicle to estimate locations within GPS gap areas.

To illustrate vehicle lane tracking ability with the sub-meter accuracy of the collected GPS data, a highway lane frame was also developed for the north run as an illustration. The lane frame can be used as the background for plotting the GPS probe vehicle data. This technique can provide microscopic behavior information for additional driver behavior analysis on highways and can be useful for a lane-based navigable data model for ITS (Fohl et al. 1996). For example, the lane changing behavior of the probe vehicle could be evaluated based on this highway frame.

With the collected GPS probe vehicle data we evaluated travel time, average travel speed, and the congestion index to measure the traffic congestion for the highways of interest. After the analysis of travel time and speed with the GPS probe vehicle data, we found that there were no large differences between 2002 and 2003. The most congested areas were identified along the highways for both the north and south runs. For the north run, the congested areas occur mostly on the I-70/I-71 split. However, for the south run, the most congested areas for the AM time period were mainly located on I-71S moving towards the downtown area, and for the PM time period these areas occur from I-71 to part of SR315N.

To calculate the travel time and to estimate the vehicle speed data, we segmented the route into segment lengths of 0.5 mile (804.7 m) in length. However, traffic flow is essentially dynamic in both space and time. It may be more appropriate to use either shorter or longer segments than those defined by the 0.5 mile fixed-length segmentation process. Therefore dynamic segmentation techniques could be used to aggregate data for different lengths along the highways. For less congested areas, the segment length might be longer, whereas for the congested areas, the highway segment may need to be shorter in length to better locate the traffic bottlenecks. Since in this study each GPS data point was also assigned a milepost or cumulative linear distance tag along the route of interest during the GPS data mapping process, we could use dynamic segmentation to calculate the speed and travel time for any highway segmentation scheme.

The methodology we illustrated in this paper can be used for a large highway network. Considering the fact that installing loop detectors or other monitoring detectors on all arterial and collector links of a network is very costly, using GPS probe vehicle data may be an alternative for traffic data collection in some areas. The developed system derived in this study could be a complementary tool to acquire more accurate traffic information.

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