Tracking Vehicles with GPS:

Is it a Feasible Solution?

Jianyang Zheng

Box 352700

Department of Civil and Environmental Engineering

University of Washington

Seattle, WA 98195-2700

Tel: (206) 543-8033

Jianyang@u.washington.edu

Yinhai Wang

Box 352700

Department of Civil and Environmental Engineering

University of Washington

Seattle, WA 98195-2700

Tel: (206) 616-2696

Fax: (206) 543-5965

yinhai@u.washington.edu

Nancy L. Nihan

Box 352700

Department of Civil and Environmental Engineering

University of Washington

Seattle, WA 98195-2700

Tel: (206) 543-8255

nihan@u.washington.edu

ABSTRACT

Global Positioning Systems (GPS) is widely used in tracking vehicles and is superior to conventional technologies based on certain important criteria. This article investigates the feasibility of tracking vehicles with regular GPS devices. Since downtown is generally the "heart" of a city with high density of vehicles and activities, locating vehicles precisely there is extremely important. Our field tests, however, find that GPS cannot efficiently track vehicles in downtown streets, although it works well on freeways. In this paper, we specifically analyze errors of GPS measured positions and the availability of satellite signals in both freeway and downtown scenarios.

INTRODUCTION

In the recent years, new technologies such as Differential Global Positioning Systems (DGPS) and Real Time Kinematic (RTK) have been developed and applied in the Global Positioning Systems (GPS). Consequently, GPS error has been reduced to the order of centimeters. The new features of GPS make many applications possible, such as emergency notification, roadside assistance, stolen vehicle recovery, navigation assistance, real-time traffic alerts, and mobile “yellow pages”. Furthermore, new vehicle management systems has been developed and deployed across America with GPS based Computer Aided Dispatch/Automatic Vehicle Location (CAD/AVL) systems, geographic information system (GIS), and/or communication links to the Internet. Local transit systems, for example, are seeing payoffs from investment in GPS and AVL technology. Milwaukee County Transit cut off-schedule buses by 40% after the systems enabled them to spot chronic bottlenecks causing delays. Onboard navigation systems can give novice drivers or paratransit operators point-by-point directions and instant connectivity to control center in case of trouble. Another development is using IT to get more information to the riding public about bus availability, service and routes (*Carter 2002*). Other similar systems include Central Ohio’s Transit Authority (COTA) in Central Ohio, Blacksburg Transit in Virginia, and Bus Dispatching System (BDS) in Portland.

Like most of the electronics products, the cost of the basic GPS chipset keeps on declining steadily. In fact, the profit margin of the basic GPS chipset is quite thin at present. Many GPS products with lower prices and smaller, lighter units are available today in the market. On the other hand, specialized software and integrating GPS on platforms typically cost much more than the GPS equipment itself. For example, a $65 chip set provided by a GPS original equipment manufacturer may be the core of a $600 car navigation device that pays for itself in saved time and driver convenience (*International Trade Administration Office of Telecommunications 1998*).

STATE OF THE ART

Many tracking techniques have been studied and developed in the past a few years. Popular tracking systems include Dead Reckoning (DR), signpost system, Inertial Navigation System (INS), and GPS. DR uses a magnetic compass and wheel odometers to determine the vehicle's route and position. The data from compass and odometers are input into an on-board computer, which computes the vehicle's location coordinates. DR system accuracies are expressed as a percent of distance traveled; ordinary systems will achieve accuracies in the 2~5% range (Vlcek 1993). The problem of dead reckoning is that its errors will accumulate without upper limit as travel distance increases.

Another AVL technology is the signpost system. The required infrastructure of signpost systems consists of beacons (signposts) placed at roadside locations and an in-vehicle receiver. The vehicle receives a signal each time it passes a signpost. The signal contains information related to the location identity. The vehicle responds by transmitting this signal along with its own identifier information to the Dispatch Center (Zografos 2001). An in-vehicle receiver is relatively cheap, however, the roadside signposts need more investment. The location of the signposts also limits the effective area of AVL. Furthermore, different areas (cities, counties, or states) may adopt different standards of signposts and signals, which make the cross-boundary tracking operation more complex.

INS relies on knowing the initial position, velocity, and attitude and thereafter measuring the attitude rates and acceleration. INS is the only form of navigation system that does not rely on external references (Grewal 2001). An Inertial Measurement Unit (IMU) and navigation computers comprise INS. IMU contains a cluster of sensors of accelerometers and gyroscopes, which measure acceleration and rotation based on Newton's First Law of Motion. Nevertheless, the error of INS will also increase without upper limit as time goes by.

GPS identifies the vehicle's location based on the technique of "Time-Difference-Of-Arrival"(TDOA). This technique calculates the delays of the consecutive signals transmitted by the satellites. GPS signal covers everywhere on the earth's surface. With the Differential GPS (DGPS) or Real Time Kinematic (RTK) technology, the accuracy can reach to centimeter level. DGPS is widely used now because of the moderate receiver cost, the implemented nationwide DGPS (NDGPS) infrastructure, and the systems used to provide the differential information. DGPS can take out most of the GPS bias errors based on the theory that if a receiver knows its position, it can calculate the bias contributed by each satellite signal. A DGPS reference receiver observes the bias of each satellite and transmits the corrections based on the differences between observed signals and predicted signals to any remote GPS receiver within its communication coverage. However, a GPS or DGPS receiver needs at least four satellites to calculate the 3D position. In locations near or on the ground, the satellites are often blocked by terrain factors, buildings, foliage, etc. The requirement of line-of-sights for satellites limits the application area of GPS/DGPS.

RESEARCH APPROACH

Objectives

The objective of this study is to explore whether GPS is statistically a sufficient solution for tracking vehicles in urban areas. To successfully track a vehicle, we should locate the vehicle to the correct street. Considering the typical street spacing of 300 feet (or 91.44 m) in the City of Seattle, a position error of less than 150 feet (or 45.72 m) would be acceptable for a correct vehicle-to-street mapping (Weiss 1998).

Downtown is typically the “heart” of a city with many important government and business agencies concentrated in a small area. Most of the bus lines run through this area with considerable passengers boarding on or off here. The fleet management and traveler information systems need not only accurate position of the vehicle, but also frequently updated position data. However, due to the high density of high-rise buildings in downtown areas, an in-vehicle GPS device may not be able to receive enough satellite signals to produce a location update in an interval of several-minutes when traveling in such urban canyons. Besides transit management, many other applications also require frequently updated position data, such as route guidance or navigation of vehicles, HAZMAT vehicle tracking. To address this problem, we also quantitatively analyzed location update interval length using data collected in downtown Seattle.

Study Area and Data Collection

We chose three study routes for data collection. The first route, as shown in Figure 1, is a closed loop of 21.04 miles (or 33.85 km) comprised of freeway sections of I-5, SR520, I-405, and I-90. This route is selected because it goes through downtown Bellevue and downtown

Seattle, and contains many kinds of typical freeway canopies such as tunnels, overpasses, and bridges. Figure 2 shows routes 2 and 3, which were intentionally selected to analyze the effects of high-rise building and altitude. They are comprised of local streets in downtown Seattle. Route 2, the shorter route, was selected to test the effect of road surface elevation on location accuracy. Route 3 trespass both an urban canyon area and a non-canyon area, which are shown in Figure 2. In a non-canyon area, there are few or no tall buildings compared to an urban canyon area. Data from Route 3 can be used to compare GPS errors and satellite signal availability between an urban canyon area and an urban non-canyon area.

The GPS antenna was fixed on the vehicle roof. The interval of logged points was one second. The real-time differential correction was set to automatic mode. In the automatic mode, when the GPS receiver receives a correction signal from the base station, it will automatically perform differential correction and log the DGPS data; when it receives no correction signal, only GPS data are logged. All the field tests were done on one sunny weekday. In the morning, the test vehicle conducted four runs along Route 1. The position mode was set to 3D, which means that the GPS receiver needs at least signals from four satellites to produce the vehicle position. In the afternoon, our data collection work focused on Routes in the downtown area. Our test vehicle ran eight times along route 2 and 12 times along route 3. We used 3D mode and 3D/2D mode alternately for each test run. The 3D/2D mode is identical to the 3D mode when the GPS receiver can receive signals from four or more satellites at a time. The difference between the two modes is that 3D/2D mode is able to calculate position when only three satellite signals are available. Such a calculation is based on the assumption that object elevation does not change from the last calculation. In reality, however, object elevation changes from point to point, and the accuracy of the position calculated in 3D/2D mode may be degraded. Hence, the 3D/2D mode provides a tradeoff between accuracy and location data availability.

Analysis

Figures 3 and 4 show the logged trajectories of the field tests on freeways and in downtown Seattle, respectively.

The logged GPS observations should be mapped to the corresponding streets. It is difficult to map the position automatically with an algorithm (Greenfeld 2002). However, in this case, the trajectory is already known, and we can visually resolve this problem with less effort. To analyze the GPS accuracy, we need to know the error of each position. Since we do not know the exact location of the test vehicle at a particular time, obtaining the exact error for each GPS location data is impossible. However, we use the across-track error defined as the perpendicular distance from a GPS observed position to the corresponding street the test vehicle is traveling along. Correspondingly, we define the along-track error as the distance of the projected point to the real position of the vehicle. Figure 5 shows the relationship of across-track error and along-track error. When the projected point of an observed position is located on the extent part of the street, the error should change to be the distance from the observed position to the corresponding street corner. Both the cross-track error and the along-track error should be smaller than the actual GPS observation error. Using the cross-track error for the analyses is conservative. If the reduced error is still too large for accurately tracking vehicles at street level, a conclusion can be safely drawn.

RESULT AND DISCUSSION

The GPS data collected in Route 1 show that most of the observed positions match the freeway location fairly well. Nearly all of the observed positions are located on the freeway in most of the areas. Nevertheless, when the vehicle is under bridges, the satellite signal availability is very poor. There are nearly no signals when the vehicle travels in tunnels.

The data collected at Routes 2 and 3 do not match downtown streets well. Our analysis focuses on these two routes. The descriptive statistics for Routes 2 and 3 data are shown in Table 1.

In route 2, the surface elevation changes more dramatically than in route 3. For the 3D/2D mode, these changes would decrease the position accuracy. However, the test result shows that most of the 3D/2D errors in route 2 are not significantly larger than errors in the urban canyon area of route 3. The change of altitude would not significantly affect the GPS positioning error in 3D/2D mode. For the same area on the same route, the error in 3D/2D mode is always larger than in 3D mode.

The maximum errors in most urban areas are much larger than the 150 feet (or 45.72 m) criteria. The frequency of errors exceeding the criteria is significantly higher in the urban canyon area than the urban non-canyon area. This is probably caused by the multi-path effect, in which GPS devices used satellite signals reflected by high-rise buildings for location calculation. Since there are many high-rise buildings in downtown central business district, such multi-path effect is not negligible. Another effect of the high buildings on GPS performance is that they block the satellite signal and decrease the number of available satellites to the receiver, which leads to poor satellite geometries and high position error.

In the urban non-canyon area, the errors are smaller, especially for 3D mode. However, these errors are just the across-track errors, and no along-track errors are accounted. Considering that the along-track errors are probably of the same order of magnitude as the across-track errors (Melgard 1994), we strongly doubt if the GPS device alone can track vehicles at street level even in this tested urban non-canyon area.

The problem of 3D mode is its dependency on signals available from at least four satellites. As aforementioned, satellite signal availability is poor in urban canyons because of the blocking effect of high-rise buildings. Thus, we expect longer GPS location update intervals in urban canyons than urban non-canyons. In addition, since the 3D/2D mode reduces the required number of visible satellites from four to three, it should have shorter update intervals than the 3D mode.

Table 2 shows the number of observed update intervals longer than 1 minute. It is obvious that for both route 2 and route 3, the observed update intervals longer than 1 minute are much more when running in 3D mode than in 3D/2D mode. Since the western part of route 3 lies in an urban non-canyon area and the eastern part in an urban canyon area, we are able to compare how an urban canyon impacts the satellite signal availability and, hence, the length of the GPS location update interval. Under 3D mode, 20 intervals were observed to be longer than 1 minute in the urban canyon area, but only 2 intervals were observed in the urban non-canyon area. The difference between the two areas, 8 in the urban canyon area vs. 0 in the urban non-canyon area, is also significant when running under 3D/2D mode. The data in Table 2 are consistent with our error analysis results shown in Table 1.

CONCLUSION AND RECOMMENDATION

The results of the tests show that GPS may not have big problems when tracking vehicles on freeways. In urban areas, however, serious problems need to be solved before using GPS as a sufficient solution for accurately tracking vehicles. The accuracy of GPS in the urban area is not high enough to map vehicle location correctly on local streets, especially in the urban canyon environment. Because of the high-rise buildings' multi-path effect and the possible blockage of the satellite signals, it may be very difficult to improve the location accuracy to an acceptable range using only GPS device. A feasible solution is to integrate GPS with other navigation systems. INS would be a good candidate, because it can carry the navigation solution without external references, which could be the case when the GPS signals are absent.

ACKNOWLEDGEMENTS

This research is sponsored by the Transportation Northwest Research Center and the Precision Forestry Cooperative. The effort of Mr. Mark E. Hallenbeck, director of Washington State Transportation Center (TRAC), is also sincerely appreciated.

REFERENCES

1. Carter, A. "GPS KEEPS TRANSIT AGENCIES ON TRACK". Metro Magazine, Volume: 98 Issue: 3. 2002.
2. International Trade Administration Office of Telecommunications. "Executive Summary: GPS Market Projections and Trends in the Newest Global Information Utility". U.S. Department of Commerce. http://telecom.ita.doc.gov. 1998.
3. Vlcek, Charles, Patricia McLain, and Michael Murphy. "GPS/Dead Reckoning for Vehicle Tracking in the ' Urban Canyon' Environment". IEEE Vehicle Navigation & Information Systems Conference, Ottawa-VNIS'93.
4. Zografos, K.G.and K.N. Androutsopoulos. "Assessing The Impacts From The Introduction Of Advanced Transport Telematics Technologies In Hazardous Materials Fleet Management". National Research Council U S Transportation Research Board 80th Annual Meeting, 2001
5. Grewal, Mohinder S., Lawrence R. Weill, and Angus P. Anderews. "Global Positioning Systems, Inertial Navigation, and Integration". New York, NY: John Wiley & Sons, Inc., 2001
6. Weiss, J. David and Frank Shields. "GPS/INS Integration in a Severe Urban Environment". IEEE 1998.
7. Greenfeld, S. Joshua. "Matching GPS Observations to Locations on a Digital Map". Transportation Research Board, the 81st Annual Meeting, 2002.
8. Melgard, T. E., G. Lachapelle, and H. Gehue. "GPS Signal Availability in an Urban Area-Receiver Performance Analysis". IEEE, 1994.

LIST OF FIGURES

LIST OF TABLES

1 feet = 0.305 meter

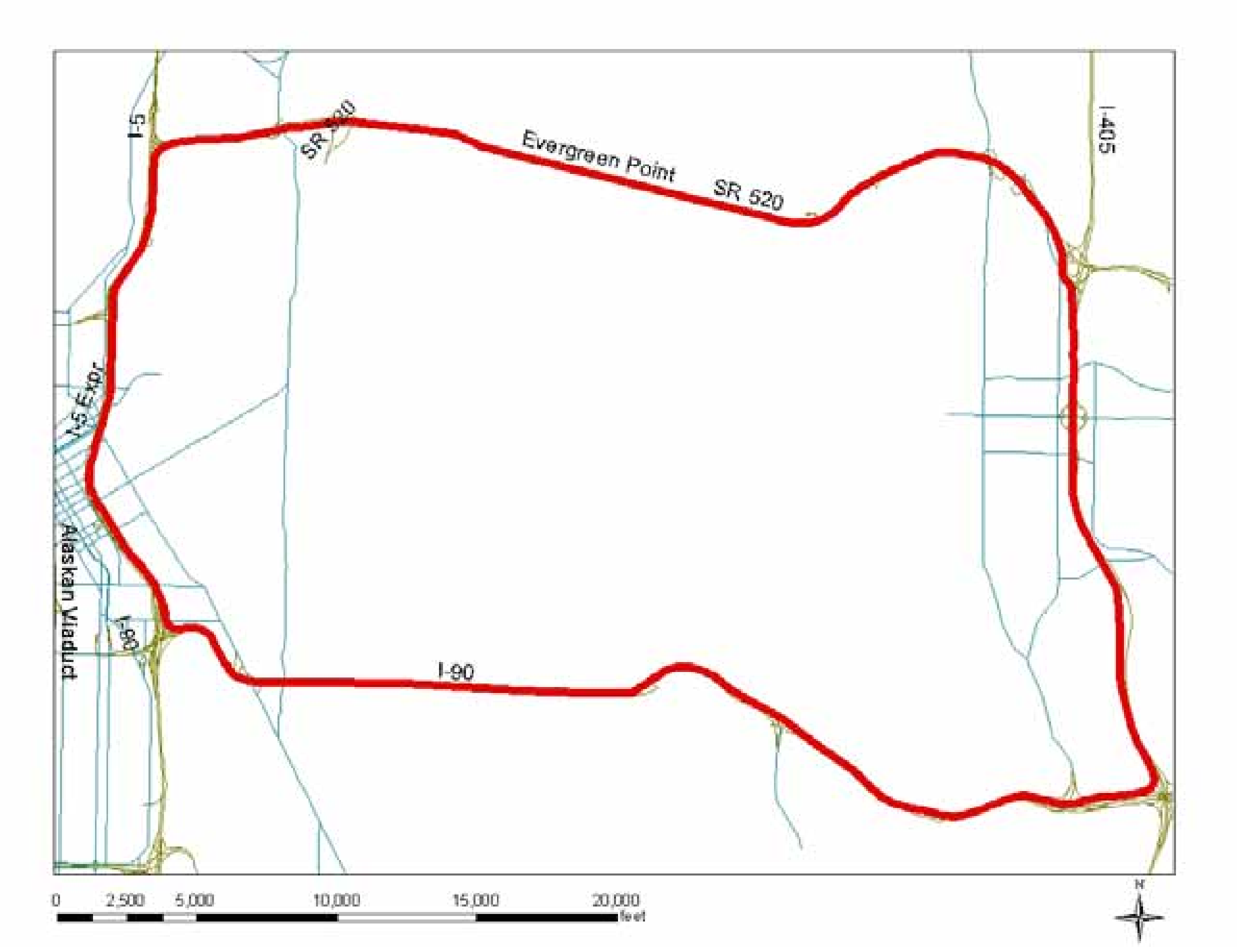

FIGURE 1: TEST ROUTE 1

1 feet = 0.305 meter

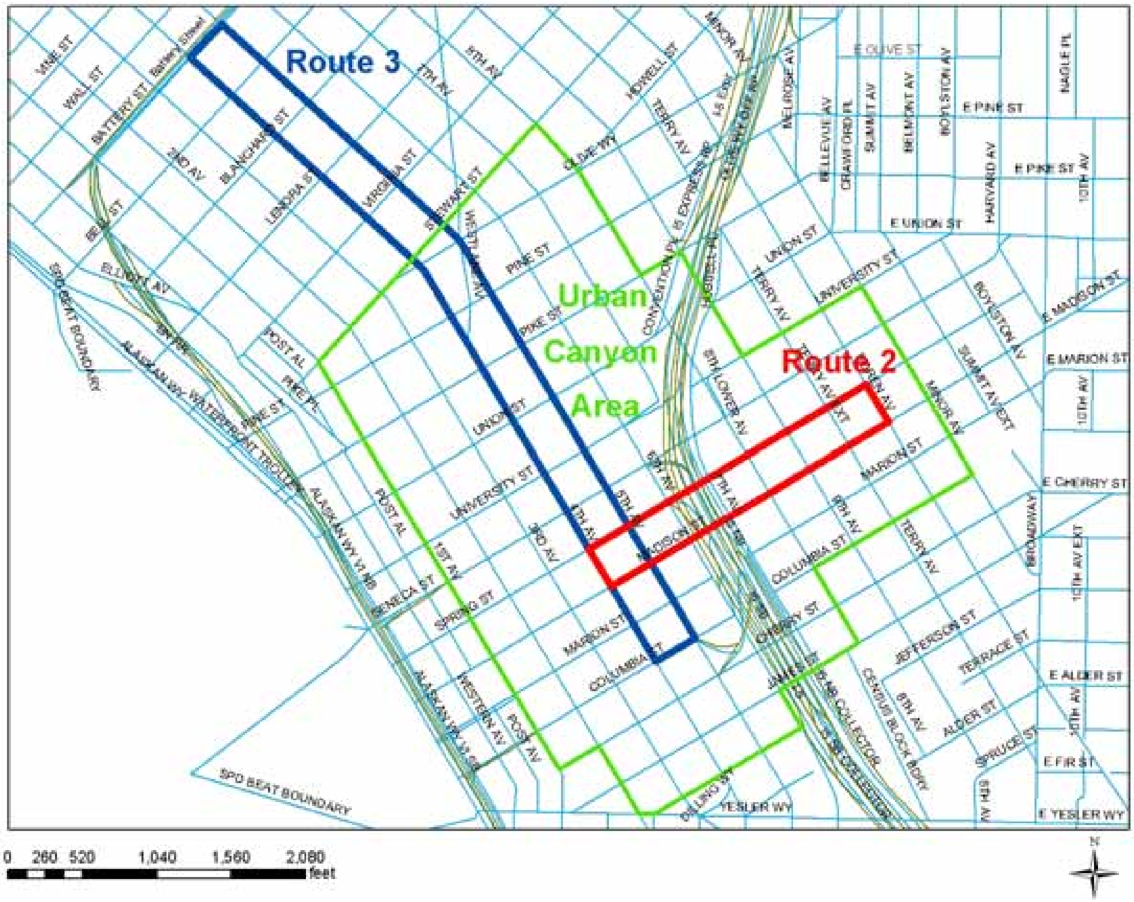

FIGURE 2: TEST ROUTE 2 AND ROUTE 3 IN DOWNTOWN AREA

1 feet = 0.305 meter

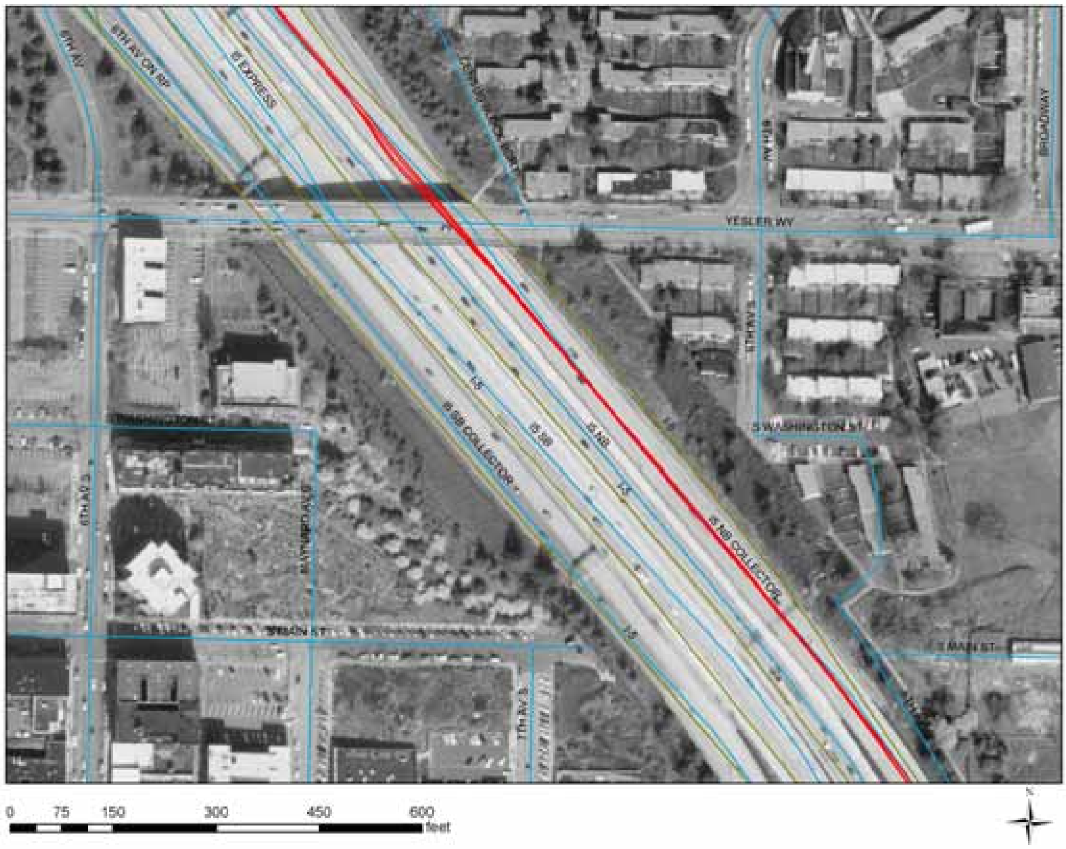

FIGURE 3: PART OF THE RESULT OF FIELD TEST ON FREEWAY

1 feet = 0.305 meter

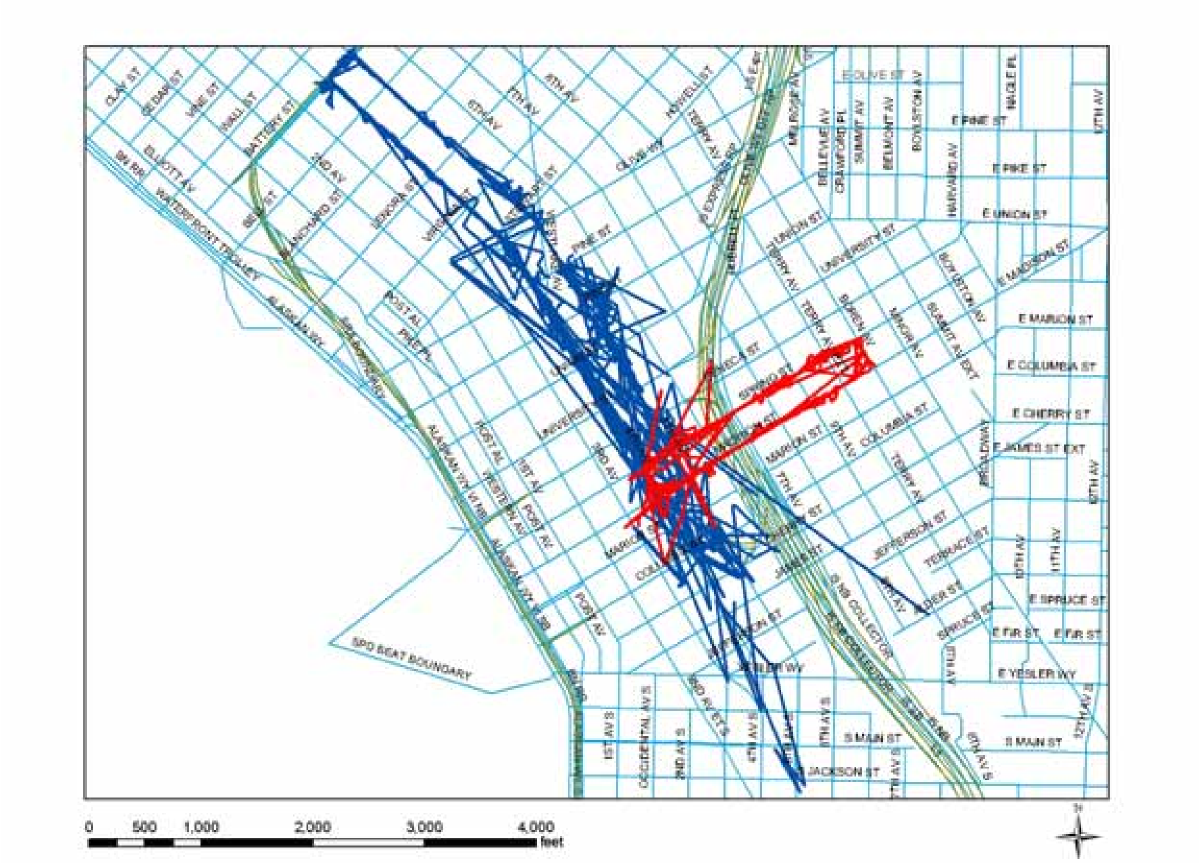

FIGURE 4: RESULT OF FIELD TEST IN DOWNTOWN SEATTLE

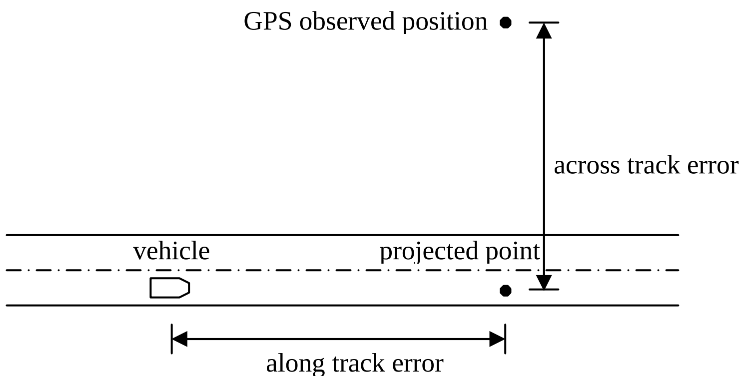

FIGURE 5: ACROSS TRACK ERROR AND ALONG TRACK ERROR

1 feet = 0.305 meter

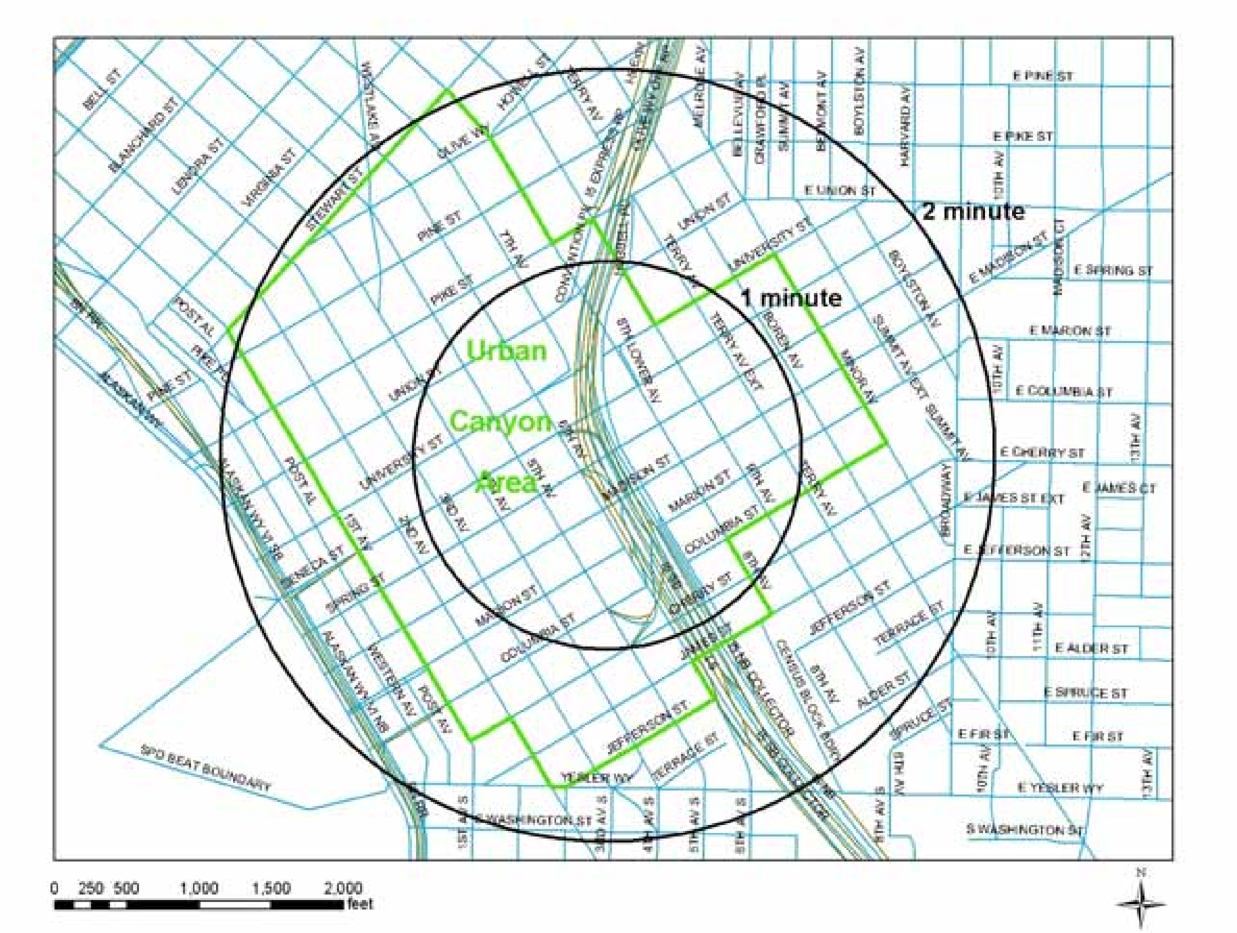

FIGURE 6: POSSIBLE LOCATION OF HAZMAR VEHICLE IN THE LONG LOCATION-UPDATE INTERVAL

TABLE 1: ERROR IN DOWNTOWN AREA

ROUTE	AREA	POSITION MODE	TOTAL GPS OBSERVED POSITION	ERROR (FEET)				
				Mean	Standard deviation	Maximum	Minimum	Probability of error >150 ft
Route 2	Urban canyon	3D	465	23.55	46.48	492.05	0.13	1.08%
		3D/2D	953	26.21	73.87	811.76	0.02	2.41%
Route 3	Urban canyon	3D	850	47.61	67.02	584.19	0.02	6.35%
		3D/2D	495	98.41	152.76	2175.50	0.02	22.42%
	Urban non-canyon	3D	1324	14.01	13.34	144.17	0.02	0%
		3D/2D	545	20.16	26.92	218.53	0.06	0.37%

1 feet = 0.305 meter

TABLE 2: LONG LOCATION-UPDATE INTERVAL IN DOWNTOWN AREA

ROUTE	AREA	POSITION MODE	TOTAL TRAVEL TIME (minute)	NUMBER OF OBSERVED LONG UPDATE INTERVALS			
				1~2 (minute)	2~3 (minute)	3~4 (minute)	>4 (minute)
Route 2	Urban canyon	3D	22.72	5	2	0	0
		3D/2D	24.72	1	0	0	0
Route 3	Urban canyon	3D	64.75	15	2	2	1
		3D/2D	24.38	7	0	1	0
	Urban non-canyon	3D	28.07	1	0	1	0
		3D/2D	10.30	0	0	0	0