Global Positioning: Application to the Intelligent Transportation System

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GLOBAL POSITIONING: APPLICATION TO THE INTELLIGENT TRANSPORTATION SYSTEM

BY

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Overview

Global Positioning Systems (GPS) will play a significant role in the emerging Intelligent Transportation System. Global Positioning Systems allow accurate tracking of the location and status of every "intelligent" vehicle in real time. This capability will allow, through the use of computers and specialized algorithms, the efficient routing of vehicles to avoid and reduce congestion. Safety will be enhanced by more rapid dispatch of emergency and service vehicles to the scene of accidents and to disabled vehicles. This paper will discuss the origin and uses of the Global Positioning System, analyze its potential uses in the development of the Intelligent Transportation System, and discuss a small case study performed in the Fargo-Moorhead area using a low-end GPS unit.

Development and Installation of GPS Technology

The Global Positioning System, during first developmental stages, was intended to replace outdated Celestial Navigation, LORAN, and Sat-Nav systems with a comprehensive and accurate means of determining the location of moving objects on the Earth's surface. Global positioning technology was developed by the United States Department of Defense (DOD) to determine the location of nuclear submarines to allow accurate missile launches. Since the end of the Cold War, the restraints on the use of the GPS technology have been loosened considerably, making the system available for public use.

Although GPS is now available for civilian use, several measures have been taken to protect the national security of the United States by preventing foreign military usage. Two separate codes are emitted by GPS satellites. The Precision code (abbreviated as P-code) is intended for exclusive use by the United States Military and is encrypted to prevent unauthorized usage. The Course Acquisition code (C/A-code) is available for use by the general public, including foreign countries. Selective Availability (SA) is applied to this code to limit the precision of the system. Should world conditions require the interruption of the C/A code, the Department of Defense has the capability of turning the C/A system off. Under normal conditions the maximum error induced into the C/A system by Selective Availability is about 120 feet.

The fully operational GPS consists of twenty-seven satellites-twenty-four active and three reserve-orbiting the Earth in fixed paths at a rate of two times per day. The orbits have sufficient altitude to minimize wandering of the satellites from their predicted paths. The DOD continuously monitors each satellite and maintains an almanac for each satellite. A Satellite's almanac contains information about its position at all times as well as any scheduled maintenance or adjustments to be performed on the satellite in the future. Data from the almanac are downloaded into the GPS receiver and are used to determine the best possible combination of satellites for determining the position of the receiver. (See Appendix A for November 11, 1993, Fargo almanac information.)

Operation of Global Positioning System

To obtain the location of a receiver, signals from at least three satellites are required for a two-dimensional, and in most circumstances, a three-dimensional location. However, more accurate results are obtained by using at least four satellites. By the end of 1993, all satellites were expected to be in orbit and three dimensional location should be available twenty-four hours a day, anywhere in the world.

Each satellite emits a unique pseudo-random code that travels at the speed of light. The code contains information about the satellite's identity, and the precise time of day that the signal was emitted, according to the satellite's onboard atomic clocks. The codes are long sequences of binary data that are compared with similar binary data preprogrammed into each GPS receiver. In the comparison process, the receiver looks for matches between the incoming signal and the preprogrammed codes. After several matches are received within a given time period, the receiver determines the time delay between emission and reception of the signal (See figure 1.1). Based on the computed time delay, the receiver calculates its distance from the satellite using the following equation:

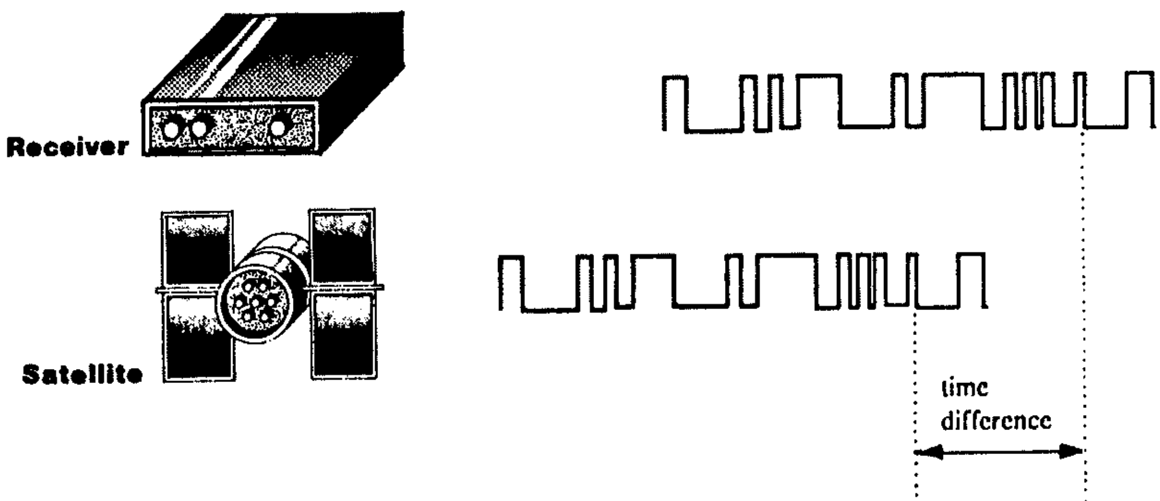
$$d = c \bullet t \tag{1.1}$$

where: $d = distance$

$c = Speed\ of\ light = 186282.39697\ miles\ per\ second$

$t = time\ delay\ between\ emission\ and\ reception\ of\ signal$

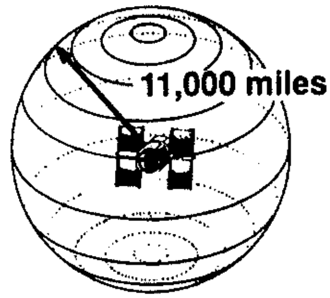
Figure 1.1 Illustration of Time Delay Between Emission and Reception of Signal[1]



For an overhead satellite, it takes about 0.0595050130 seconds for the signal to reach the receiver. The digits expressed are significant for reasons that will be described later. Using equation 1.1, the distance between the satellite and the receiver can be calculated to be 11,000 miles. Based on geometric principles, the receiver has to be somewhere on a sphere of 11,000 mile radius, with its center located at the satellite (See figure 1.2). Recall that the receiver has information regarding the position of all satellites stored in its almanac.

[1] Jeff Hurn, *GPS, A Guide To the Next Utility*, (Sunnyvale, California: Trimble Navigation Ltd., 1989), 20.

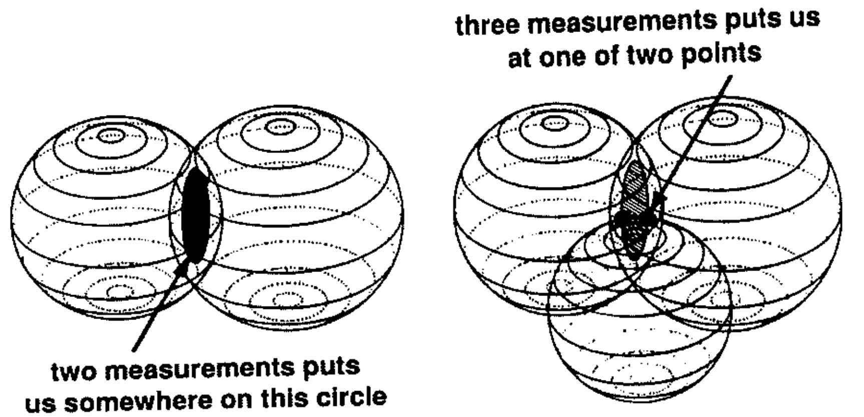
Figure 1.2 Sphere Defining Possible Locations of Receiver Based On One Satellite[2]



As the receiver is determining its possible locations based upon one satellite, it is also using other satellites to further narrow the range of possible locations of the receiver. Using two satellites the receiver finds that the intersection of two spheres defines a circle of possible locations. A third measurement from another satellite will define only two possible points at the intersection of three spheres for the receiver's location (see figure 1.3). While it still seems that another satellite is needed to determine which point is the actual location of the receiver, the correct point can be selected by deductive reasoning. Usually one of the two points is off the surface of the Earth or subsequent readings will indicate a ridiculously high velocity. Most receivers identify and eliminate these points when determining locations.

Figure 1.3 Zones of Potential Receiver Locations:[3]

a) based on two satellites b) based on three satellites



[2] Hurn, 15.
[3] Hurn, 15.

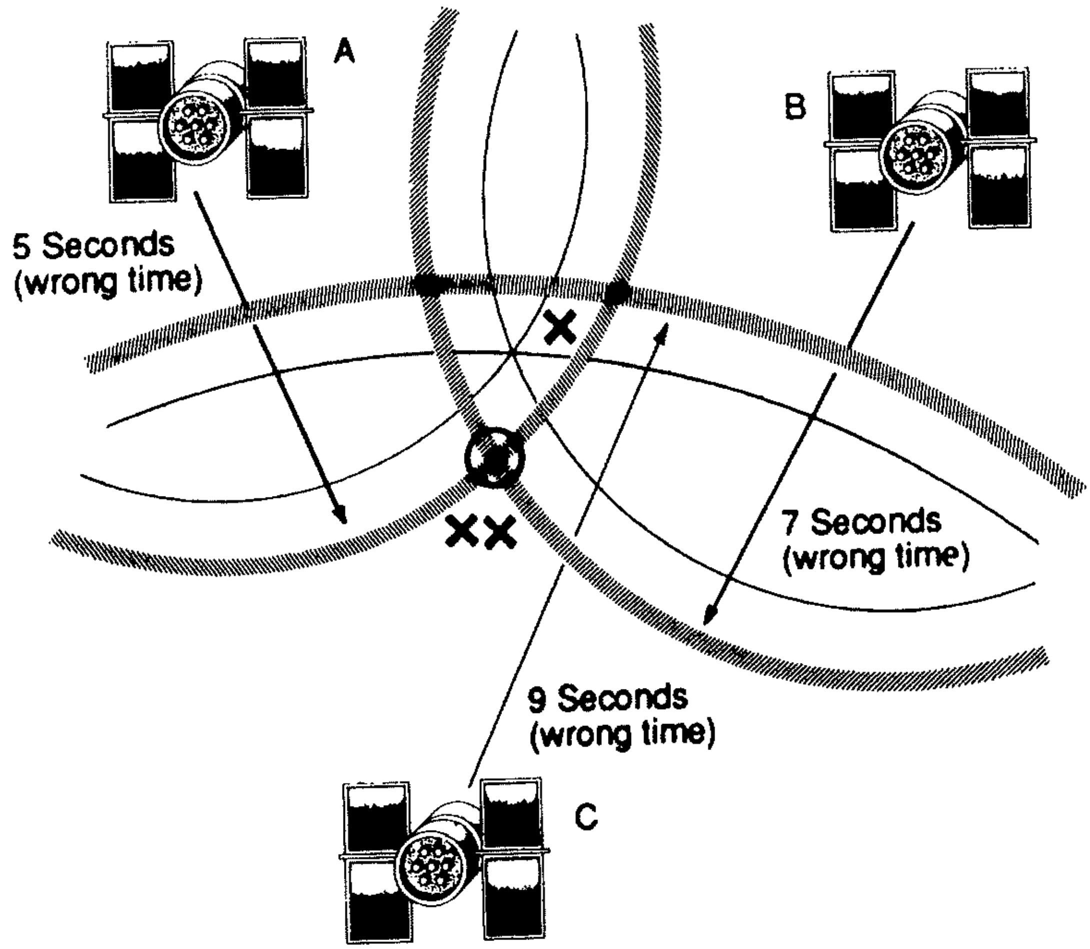
Accuracy of GPS

As previously indicated, satellite signals travel at the speed of light. Therefore, essentially no error can be tolerated in a satellite's emissions. An error of even 1/1000th of a second in transmission of the signal will induce an error in the calculated distance of nearly 186 miles. However, the speed of light is only constant in a vacuum and can be quite random when traversing varying atmospheric conditions. Furthermore, some errors, although very slight, do exist in atomic clocks. Given these facts, the system is subject to some inherent inaccuracies. Figure 1.4 illustrates the intersection of three spheres described by erroneous information. The intersection is actually given as a range of possible points at which the receiver could be located. To resolve this ambiguity in location, the receiver performs iterations on the radius of each sphere to determine the only possible point where all three spheres can intersect. In this example it is quite evident that the best solution is obtained by subtracting one second from each reading. This calculation results in a point where all three spheres intersect, and minimizes the possibility of error. While this process may seem inaccurate, it can be proven geometrically that this method is in fact effective and accurate. Note that in this example whole number values were used for illustrative purposes only.

A fourth satellite reading is used to further increase the accuracy of the system. This reading is further added to the system to assist in determining the reliability of the signal of the satellites. The fourth reading is used as a check for the entire system.

Differential correction is a method of taking GPS readings relative to a receiver set up over a known landmark (a point with known geographic coordinates). The error between the reading and the actual coordinates is used as a correction factor and is transmitted in real time to all connected receivers in the area (called rovers) to similarly correct their location. This correction system allows sub-centimeter accuracy and can operate over a range approximately 300 miles in radius.

Figure 1.4 Actual Location of the Receiver After Iteration[4]



Application of GPS Technology to the ITS

GPS technology can be applied to many aspects of the evolving Intelligent Transportation System. Freight and shipping industries could use GPS to locate and route containers and trucks from origin to destination. Using GPS, accurate and dependable destination times could be determined and scheduling problems could be quickly resolved.

[4] Hurn, 29.

GPS will also work for passenger vehicles. Accurate and dependable real-time location of passenger vehicles can be determined using systems that may reside either in individual automobiles or in a traffic monitoring and routing system. Small personal systems are currently showing up in automobiles as first-generation systems. These systems can determine the location of the vehicle and then locate it in a Geographic Information System (GIS) roadway network. The GIS is a software package that contains information about land features and associated attribute data in a user-friendly map-based format. After the vehicle is located in the GIS network, the software can then make recommendations on optimal routes to the desired destination. Tests have been performed using systems in Florida and other regions of the U.S., and have been very successful.[5] Recommended routes may be displayed on a flat screen monitor, or instructions on where to turn may be given by a computer-generated voice.

On the macroscopic level, entire areas may be monitored by a central computer. Vehicle location information can be translated into traffic volume information. This information can be used by a congestion management system to reroute traffic to minimize congestion in the entire transportation system. The congestion management system may be either active or passive. An active system may direct the driver of an automobile to take a specific route to reach his or her destination. A passive system would make recommendations on alternate routes with potential time savings.

Colorado is currently developing a Mayday service using the GPS to locate stranded or disabled vehicles.[6] The Mayday system is designed to allow motorists to call for help; or the system will call automatically in the event of an accident. Calls are routed to a control center and then to the state patrol, emergency dispatch center, or road service dispatch center, as appropriate. The Colorado system is currently being tested.

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[5] Ben G. Watts, *Technology and the New Transportation*, (Washington D.C.: The Washington Times, May 23, 1994), 15.
[6] *Inside IVHS, Intelligent Vehicle/Highway Systems Update*, (New York, New York: Waters Information Services, July 4, 1994), Vol. 4, No. 14, pp. 1-3.

A Case Study in GPS

In developing this paper, a small case study involving GPS in the Fargo, North Dakota, area was performed on November 11, 1993. A Trimble Pathfinder Professional GPS receiver was used to take readings along the interstate highway system in the Fargo-Moorhead area. This receiver is a low-end, three-channel GPS receiver. It's primary use is for navigational purposes; it is not intended to provide highly accurate readings. The accuracy of this receiver is intended to be within 300 feet, including Selective Availability.

Data was observed regarding the position, direction of travel, and speed of the vehicle. The position data were collected and plotted on United States Geological Survey Quadrangle maps and compared with the actual location of the roadways and geological features.

The direction of travel and speed data from the receiver appeared to correlate quite well with the actual situation. In fact, the receiver was capable of detecting variations in speed of one or two miles per hour. This indicates that the system is relatively precise in its readings, even though the position data may not be entirely accurate. The position data (see appendix B) compared very well with the quadrangle maps at times but was off by nearly seven hundred feet in locating the Red River of the North. The source of this error is unclear, but may have been caused by a shift in the river's position between the generation of the maps in 1976 and the collection of the GPS data. The remainder of the errors were within the three-hundred-foot limits allowed by selective availability. In traversing curves, the system was very impressive. It followed the curves on the I-94 to I-29 interchange, and I-29 to 13th Avenue South to I-29 off- and on-ramps very well. With the use of differential correction, these results could be used with high levels of accuracy.

Conclusions

Using the Global Positioning System in development of the Intelligent Transportation System is a feasible solution to the problem of monitoring traffic conditions in real time. The Global Positioning System can be used for locating and tracking individual vehicles from origin to destination. Some of these functions are currently performed through the use of existing traffic monitoring devices such as loop-detectors and video cameras. However, these methods are primarily demand-based and do relatively little for reducing congestion. Using GPS to locate automobiles and allowing a centralized computer system to route traffic has the potential to significantly reduce congestion, save highway operating costs, and minimize travel time.

The Intelligent Transportation System will be capable of monitoring congestion and incident information. Based on detected traffic information and destination information for each vehicle, the system will make intelligent decisions on how to route vehicles to avoid congested links of the roadway network. The primary benefit of this system is that rather than all vehicles taking a single detour-which may not be capable of handling the incremental traffic load-each vehicle will be routed seperately to the best detour, based upon the vehicle's anticipated destination.

Although the benefits of full-scale implementation are quite appealing, the cost of implementing the system into the ITS is of concern. Even though the satellite system is now operational, the cost of computer and communications equipment, as well as GPS receivers for every vehicle, will make this system difficult to implement without proof of substantial benefits.

Appendix A

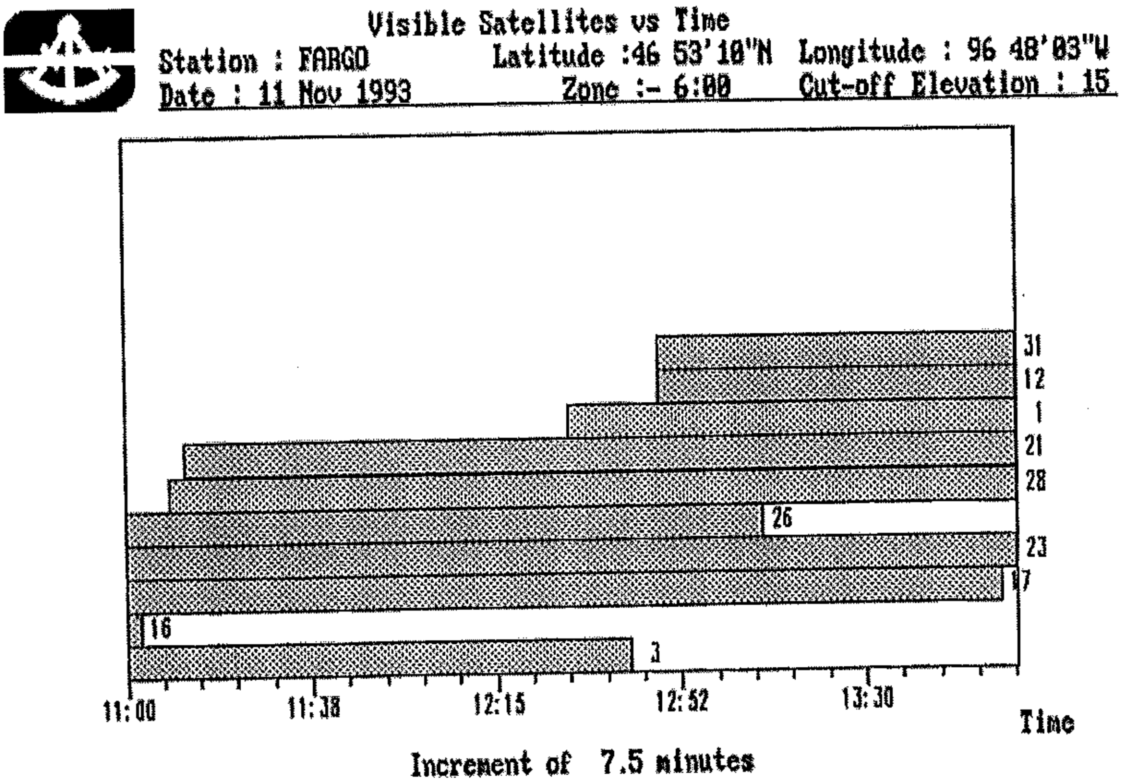
Almanac Information for

November 11, 1993

Fargo, North Dakota

The following figure illustrates the availability of each satellite throughout the data collection period. Shaded regions indicate that satellite is available. Pages 12-16 give location information for each visible satellite.

Figure A.1 Availability of Satellites[7]



[7] Trimble Navigation, *PF Basic Release 2.00 Software*, (Sunnyvale, California: Trimble Navigation, January, 1992).

Table of Azimuth, Elevation and Time for Fargo										
Date: 11 Nov 1993						Latitude: 46°53'10"N				
Time: 11:00 → 14:00						Longitude: 96°48'03"W				
Cut-off Elevation: 15°						Zone: -6:00				
Time	Satellite 1		Satellite 2		Satellite 3		Satellite 4		Satellite 7	
	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL
11:00	-	-	-	-	169°	71°	-	-	-	-
11:05	-	-	-	-	169°	68°	-	-	-	-
11:10	-	-	-	-	170°	65°	-	-	-	-
11:15	-	-	-	-	170°	62°	-	-	-	-
11:20	-	-	-	-	171°	59°	-	-	-	-
11:25	-	-	-	-	171°	56°	-	-	-	-
11:30	-	-	-	-	172°	54°	-	-	-	-
11:35	-	-	-	-	172°	51°	-	-	-	-
11:40	-	-	-	-	173°	48°	-	-	-	-
11:45	-	-	-	-	173°	45°	-	-	-	-
11:50	-	-	-	-	174°	42°	-	-	-	-
11:55	-	-	-	-	174°	40°	-	-	-	-
12:00	-	-	-	-	175°	37°	-	-	-	-
12:05	-	-	-	-	175°	34°	-	-	-	-
12:10	-	-	-	-	176°	32°	-	-	-	-
12:15	-	-	-	-	176°	29°	-	-	-	-
12:20	-	-	-	-	176°	26°	-	-	-	-
12:25	-	-	-	-	177°	24°	-	-	-	-
12:30	214°	15°	-	-	177°	21°	-	-	-	-
12:35	214°	17°	-	-	177°	19°	-	-	-	-
12:40	215°	19°	-	-	177°	16°	-	-	-	-
12:45	216°	22°	-	-	-	-	-	-	-	-
12:50	217°	24°	-	-	-	-	-	-	-	-
12:55	218°	26°	-	-	-	-	-	-	-	-
13:00	219°	28°	-	-	-	-	-	-	-	-
13:05	219°	30°	-	-	-	-	-	-	-	-
13:10	220°	33°	-	-	-	-	-	-	-	-
13:15	221°	35°	-	-	-	-	-	-	-	-
13:20	223°	37°	-	-	-	-	-	-	-	-
13:25	224°	39°	-	-	-	-	-	-	-	-
13:30	225°	12°	-	-	-	-	-	-	-	-
13:35	226°	44°	-	-	-	-	-	-	-	-
13:40	227°	46°	-	-	-	-	-	-	-	-
13:45	229°	48°	-	-	-	-	-	-	-	-
13:50	230°	51°	-	-	-	-	-	-	-	-
13:55	232°	53°	-	-	-	-	-	-	-	-
14:00	234°	55°	-	-	-	-	-	-	-	-

Table of Azimuth, Elevation and Time for Fargo

Date: 11 Nov 1993 Latitude: 46°53'10"N

Time: 11:00 → 14:00 Longitude: 96°48'03"W

Cut-off Elevation: 15° Zone: -6:00

Time	Satellite 12		Satellite 14		Satellite 15		Satellite 16		Satellite 17	
	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL
11:00	-	-	-	-	-	-	63°	16°	328°	79°
11:05	-	-	-	-	-	-	-	-	335°	81°
11:10	-	-	-	-	-	-	-	-	347°	83°
11:15	-	-	-	-	-	-	-	-	5°	85°
11:20	-	-	-	-	-	-	-	-	34°	85°
11:25	-	-	-	-	-	-	-	-	65°	85*
11:30	-	-	-	-	-	-	-	-	87°	83°
11:35	-	-	-	-	-	-	-	-	100°	82°
11:40	-	-	-	-	-	-	-	-	108°	79°
11:45	-	-	-	-	-	-	-	-	114°	77°
11:50	-	-	-	-	-	-	-	-	118°	75°
11:55	-	-	-	-	-	-	-	-	122°	73°
12:00	-	-	-	-	-	-	-	-	125°	70°
12:05	-	-	-	-	-	-	-	-	127°	68°
12:10	-	-	-	-	-	-	-	-	129°	65°
12:15	-	-	-	-	-	-	-	-	131°	63°
12:20	-	-	-	-	-	-	-	-	133°	61°
12:25	-	-	-	-	-	-	-	-	135°	58°
12:30	-	-	-	-	-	-	-	-	136°	56°
12:35	-	-	-	-	-	-	-	-	137°	53°
12:40	-	-	-	-	-	-	-	-	139°	51°
12:45	-	-	-	-	-	-	-	-	140°	49°
12:50	115°	16°	-	-	-	-	-	-	141°	46°
12:55	113°	18°	-	-	-	-	-	-	142°	44°
13:00	112°	20°	-	-	-	-	-	-	143°	42°
13:05	110°	22°	-	-	-	-	-	-	144°	39°
13:10	108°	24°	-	-	-	-	-	-	145°	37°
13:15	106°	25°	-	-	-	-	-	-	146°	35°
13:20	104°	27°	-	-	-	-	-	-	147°	32°
13:25	102°	29°	-	-	-	-	-	-	148°	30°
13:30	100°	31°	-	-	-	-	-	-	148°	28°
13:35	97°	32°	-	-	-	-	-	-	149°	25°
13:40	95°	33°	-	-	-	-	-	-	150°	23°
13:45	92°	35°	-	-	-	-	-	-	151°	21°
13:50	89°	36°	-	-	-	-	-	-	151°	19°
13:55	86°	37°	-	-	-	-	-	-	152°	17°
14:00	83°	38°	-	-	-	-	-	-	-	-

Table of Azimuth, Elevation and Time for Fargo

Date: 11 Nov 1993 | Latitude: 46°53'10"N

Time: 11:00 → 14:00 | Longitude: 96°48'03"W

Cut-off Elevation: 15° | Zone: -6:00

Time	Satellite 18		Satellite 19		Satellite 20		Satellite 21		Satellite 22	
	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL
11:00	-	-	-	-	-	-	-	-	-	-
11:05	-	-	-	-	-	-	-	-	-	-
11:10	-	-	-	-	-	-	252°	15°	-	-
11:15	-	-	-	-	-	-	253°	16°	-	-
11:20	-	-	-	-	-	-	255°	18°	-	-
11:25	-	-	-	-	-	-	256°	20°	-	-
11:30	-	-	-	-	-	-	257°	22°	-	-
11:35	-	-	-	-	-	-	259°	24°	-	-
11:40	-	-	-	-	-	-	260°	25°	-	-
11:45	-	-	-	-	-	-	262°	27°	-	-
11:50	-	-	-	-	-	-	263°	29°	-	-
11:55	-	-	-	-	-	-	265°	31°	-	-
12:00	-	-	-	-	-	-	266°	33°	-	-
12:05	-	-	-	-	-	-	268°	34°	-	-
12:10	-	-	-	-	-	-	269°	36°	-	-
12:15	-	-	-	-	-	-	271°	38°	-	-
12:20	-	-	-	-	-	-	273°	40°	-	-
12:25	-	-	-	-	-	-	274°	42°	-	-
12:30	-	-	-	-	-	-	276°	44°	-	-
12:35	-	-	-	-	-	-	278°	46°	-	-
12:40	-	-	-	-	-	-	280°	47°	-	-
12:45	-	-	-	-	-	-	282°	49°	-	-
12:50	-	-	-	-	-	-	283°	51°	-	-
12:55	-	-	-	-	-	-	285°	53°	-	-
13:00	-	-	-	-	-	-	287°	55°	-	-
13:05	-	-	-	-	-	-	290°	57°	-	-
13:10	-	-	-	-	-	-	292°	59°	-	-
13:15	-	-	-	-	-	-	294°	61°	-	-
13:20	-	-	-	-	-	-	297°	63°	-	-
13:25	-	-	-	-	-	-	299°	65°	-	-
13:30	-	-	-	-	-	-	302°	67°	-	-
13:35	-	-	-	-	-	-	306°	69°	-	-
13:40	-	-	-	-	-	-	309°	71°	-	-
13:45	-	-	-	-	-	-	314°	73°	-	-
13:50	-	-	-	-	-	-	319°	75°	-	-
13:55	-	-	-	-	-	-	325°	77°	-	-
14:00	-	-	-	-	-	-	333°	79°	-	-

Table of Azimuth, Elevation and Time for Fargo

Date: 11 Nov 1993 | Latitude: 46°53'10"N

Time: 11:00 → 14:00 | Longitude: 96°48'03"W

Cut-off Elevation: 15° | Zone: -6:00

Time	Satellite 23		Satellite 24		Satellite 25		Satellite 26		Satellite 27	
	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL
11:00	251°	45°	-	-	-	-	91°	57°	-	-
11:05	253°	47°	-	-	-	-	87°	57°	-	-
11:10	255°	49°	-	-	-	-	83°	56°	-	-
11:15	257°	51°	-	-	-	-	79°	55°	-	-
11:20	259°	53°	-	-	-	-	75°	54°	-	-
11:25	261°	55°	-	-	-	-	72°	53°	-	-
11:30	264°	56°	-	-	-	-	69°	52°	-	-
11:35	266°	58°	-	-	-	-	66°	51°	-	-
11:40	269°	60°	-	-	-	-	63°	49°	-	-
11:45	272°	62°	-	-	-	-	61°	48°	-	-
11:50	275°	64°	-	-	-	-	59°	46°	-	-
11:55	278°	66°	-	-	-	-	57°	44°	-	-
12:00	282°	68°	-	-	-	-	56°	42°	-	-
12:05	286°	70°	-	-	-	-	55°	40°	-	-
12:10	291°	71°	-	-	-	-	53°	39°	-	-
12:15	296°	73°	-	-	-	-	53°	37°	-	-
12:20	302°	74°	-	-	-	-	52°	35°	-	-
12:25	310°	76°	-	-	-	-	51°	33°	-	-
12:30	318°	77°	-	-	-	-	51°	31°	-	-
12:35	328°	78°	-	-	-	-	50°	29°	-	-
12:40	339°	79°	-	-	-	-	50°	27°	-	-
12:45	352°	79°	-	-	-	-	50°	25°	-	-
12:50	4°	79°	-	-	-	-	50°	23°	-	-
12:55	17°	79°	-	-	-	-	50°	21°	-	-
13:00	28°	78°	-	-	-	-	50°	19°	-	-
13:05	37°	77°	-	-	-	-	50°	17°	-	-
13:10	45°	75°	-	-	-	-	51°	15°	-	-
13:15	52°	74°	-	-	-	-	-	-	-	-
13:20	58°	72°	-	-	-	-	-	-	-	-
13:25	63°	71°	-	-	-	-	-	-	-	-
13:30	68°	69°	-	-	-	-	-	-	-	-
13:35	72°	67°	-	-	-	-	-	-	-	-
13:40	76°	65°	-	-	-	-	-	-	-	-
13:45	79°	63°	-	-	-	-	-	-	-	-
13:50	82°	62°	-	-	-	-	-	-	-	-
13:55	85°	60°	-	-	-	-	-	-	-	-
14:00	87°	58°	-	-	-	-	-	-	-	-

Table of Azimuth, Elevation and Time for Fargo											
Date: 11 Nov 1993						Latitude: 46°53'10"N					
Time: 11:00 → 14:00						Longitude: 96°48'03"W					
Cut-off Elevation: 15°						Zone: -6:00					
Time	Satellite 28		Satellite 29		Satellite 31						
	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL	
11:00	-	-	-	-	-	-					
11:05	-	-	-	-	-	-					
11:10	321°	15°	-	-	-	-					
11:15	320°	17°	-	-	-	-					
11:20	319°	19°	-	-	-	-					
11:25	317°	20°	-	-	-	-					
11:30	316°	22°	-	-	-	-					
11:35	314°	23°	-	-	-	-					
11:40	313°	25°	-	-	-	-					
11:45	311°	26°	-	-	-	-					
11:50	309°	27°	-	-	-	-					
11:55	307°	28°	-	-	-	-					
12:00	305°	29°	-	-	-	-					
12:05	303°	30°	-	-	-	-					
12:10	301°	31°	-	-	-	-					
12:15	298°	32°	-	-	-	-					
12:20	296°	32°	-	-	-	-					
12:25	293°	33°	-	-	-	-					
12:30	290°	33°	-	-	-	-					
12:35	288°	33°	-	-	-	-					
12:40	285°	33°	-	-	-	-					
12:45	282°	33°	-	-	-	-					
12:50	279°	33°	-	-	319°	16°					
12:55	277°	32°	-	-	317°	17°					
13:00	274°	32°	-	-	315°	17°					
13:05	271°	31°	-	-	313°	18°					
13:10	269°	30°	-	-	311°	19°					
13:15	266°	29°	-	-	309°	19°					
13:20	264°	28°	-	-	307°	20°					
13:25	262°	27°	-	-	305°	20°					
13:30	259°	26°	-	-	303°	20°					
13:35	257°	25°	-	-	301°	21°					
13:40	255°	23°	-	-	298°	21°					
13:45	253°	22°	-	-	296°	20°					
13:50	251°	20°	-	-	294°	20°					
13:55	249°	19°	-	-	292°	20°					
14:00	248°	17°	-	-	289°	19°					

Appendix B

GPS Data for Interstate Highway System Near Fargo, North Dakota

Time (HH:MM:SS UTC)	Latitude (DD:MM:SS)	Longitude (DD:MM:SS)
17:22:48.000	46°52'35.22269"N	96°55'30.38257"W
17:25:00.844	46°52'31.92921"N	96°56'42.88854"W
17:27:06.656	46°51'44.98518"N	96°55'43.54833"W
17:28:07.938	46°51'10.03206"N	96°54'49.18815"W
17:28:44.625	46°50'51.21684"N	96°54'16.10733"W
17:28:55.031	46°50'48.51158"N	96°54'04.28267"W
17:29:06.156	46°50'47.69089"N	96°53'50.65928"W
17:29:10.406	46°50'47.89112"N	96°53'45.47813"W
17:30:14.281	46°50'49.79141"N	96°52'29.42439"W
17:30:51.406	46°50'49.84151"N	96°51'44.11157"W
17:31:17.000	46°50'49.43027"N	96°51'12.91750"W
17:31:56.094	46°50'48.49779"N	96°50'26.03483"W
17:32:59.281	46°50'47.40821"N	96°49'10.25602"W
17:34:04.969	46°50'53.98280"N	96°47'54.87338"W
17:34:54.313	46°50'52.31110"N	96°46'58.96768"W
17:36:35.281	46°50'48.85805"N	96°46'05.63158"W
17:38:35.063	46°50'56.22780"N	96°47'51.71942"W
17:39:39.406	46°50'51.36198"N	96°49'08.35552"W
17:40:18.688	46°50'51.15985"N	96°49'54.60576"W
17:40:28.656	46°50'51.43248"N	96°50'05.59349"W
17:40:39.344	46°50'54.46898"N	96°50'15.76114"W
17:40:46.469	46°50'57.75080"N	96°50'20.85428"W
17:40:56.625	46°51'03.80980"N	96°50'25.96025"W
17:41:02.844	46°51'08.31099"N	96°50'26.71505"W
17:41:11.563	46°51'15.12621"N	96°50'26.97325"W
17:41:20.813	46°51'22.23639"N	96°50'27.06374"W
17:41:32.781	46°51'30.85975"N	96°50'25.93653"W
17:41:53.938	46°51'40.96816"N	96°50'22.23972"W
17:43:06.688	46°51'45.08953"N	96°50'23.41067"W
18:37:43.844	46°51'55.09672"N	96°50'27.68561"W
18:38:28.844	46°52'33.39513"N	96°50'25.28135"W
18:38:37.313	46°52'40.60222"N	96°50'24.35225"W
18:39:00.313	46°53'00.01524"N	96°50'22.32281"W
18:39:31.531	46°53'24.19472"N	96°50'19.92375"W
18:40:02.469	46°53'47.70479"N	96°50'18.69649"W
18:40:21.594	46°54'02.51518"N	96°50'18.21045"W
18:40:45.156	46°54'17.26958"N	96°50'11.04181"W
18:41:03.375	46°54'18.45068"N	96°50'16.65996"W
19:07:06.375	46°52'05.34285"N	96°51'17.56236"W