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ESTIMATING LINK TRAVEL TIME ON I-70 CORRIDOR: A REAL-TIME DEMONSTRATION PROTOTYPE

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16. Abstract This report represents the findings of a study that demonstrates the feasibility of estimating link travel time and speed in real-time for rural, mountainous sections of interstate freeway in Colorado using vehicles instrumented with global positioning system receivers, serving as probes in traffic streams. The system configuration developed includes a cost-effective, portable GPS deployment unit, communication links to a server PC and an integrated prototype system for vehicle tracking and estimating link travel time statistics. This study was carried out in two phases. The objective of the first phase was to identify a cost-effective means of monitoring traffic within a rural, mountainous stretch of the I-70 freeway. An algorithm was developed to estimate average link speed, travel time and the standard error of estimates to provide user information on the reliability of the estimates based on the probe data. The algorithm was tested for different traffic conditions and geometric characteristics of links. In the second phase of the project, a real-time demonstrational prototype was developed to receive, process and estimate link travel time and speed statistics in real-time. The system was tested off-line and on-line based on field data received from the I-70 corridor. In addition, GPS receivers were deployed using a commercial vanpool service and the system was evaluated further. Implementation					
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Estimating Link Travel Time on I-70 Corridor: A Real-Time Demonstration Prototype

by

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EXECUTIVE SUMMARY

This study demonstrates the feasibility of estimating link travel time and speeds in real-time for a rural, mountainous section of an interstate freeway in Colorado using vehicles instrumented with global positioning system receivers, that serve as probes in traffic streams. The system configuration proposed and developed includes a cost-effective, portable GPS deployment unit, communication links to a PC server, and an integrated prototype system for vehicle tracking and estimating statistics on link travel time. The system also includes a user interface.

The section of the I-70 corridor in Colorado selected to evaluate the system is located in a mountainous terrain just east of the Eisenhower Tunnel, gateway to the ski resorts, including Winter Park, Vail, and Aspen, from the Denver International Airport. It carries a high traffic volume during the ski season and during the summer months. Currently there is very limited surveillance infrastructure to monitor traffic conditions on this critical corridor.

This study, funded by the Colorado Department of Transportation and carried out in two phases, explores the feasibility of monitoring this corridor using mobile surveillance technology. The objective of the first phase was to identify a cost-effective means of monitoring traffic within a rural, mountainous stretch of the I-70 corridor. In addition, an algorithm was developed to estimate average link speed, travel time, and the standard error of estimates that provides the user with information on the reliability of the estimates. The algorithm was tested based on simulated data for different traffic conditions and geometric characteristics of links.

In the second phase of the project, a real-time demonstrational prototype was developed to receive, process and estimate link travel time and speed statistics in real-time based on the algorithm proposed in the first phase. The system was tested off-line and on-line based on field data received from the I-70 corridor. In addition, GPS receivers were deployed using a commercial van pool service. This report presents an overview of the demonstration prototype developed, the surveillance technology selected, an evaluation of the system based on simulated and field data, procedures to install and maintain the system, and recommendations for larger scale implementation.

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OVERVIEW OF THE REPORT

The first chapter of this report presents an overview of the specifications of the GPS receivers and the modem selected. It also includes a description of the form of communication selected to transmit the GPS data from the field to a fixed-end central server.

The second chapter of the report presents details of the components of the real-time demonstration prototype system developed to track probe vehicles in the traffic stream, methods to estimate link travel time and speed based on probe data and the graphical interface of the system.

The third chapter presents an overview of the network selected to conduct both on-line and off-line tests based on simulated and field data to evaluate the demonstration prototype and the findings.

The fourth chapter presents conclusions and recommendations of the study.

The appendices include instructions on how to install, run and maintain the prototype system, the source code for the programs written, sample GPS data, sample output of the program, and the study proposal.

CHAPTER 1:

SELECTION OF SURVEILLANCE TECHNOLOGY

1.1 GLOBAL POSITIONING SYSTEM (GPS)

Global Positioning Systems (GPS) allow instantaneous position and velocity of a moving vehicle to be determined. To provide continuous global positioning capability, 21 evenly spaced satellites placed in a circular, 12-hr orbit inclined at 55° to the equatorial plane provide the desired coverage. This constellation provides a minimum of four satellites in good geometric position, 24 hours a day, anywhere on the earth. Depending on the selected elevation angle, more than the minimum number of satellites are often available for use.

GPS satellites provide the capability of determining location in terms of longitude, latitude and elevation by the simple resection process using the distances measured to satellites. The space coordinates relative to the center of the earth of each satellite can be computed from the ephemerides broadcast by the satellite using an algorithm. The ground receiver, defined by its geocentric position vector, employs a clock that is precisely set to GPS time. The true distance range to each satellite may be accurately measured by recording the time required for the satellite signal to reach the receiver. Each range defines a sphere with its center at the satellite. Therefore, using this technique, ranges to three satellites are needed since the intersection of three spheres yields three unknowns (longitude, latitude, and height). GPS receivers use an inexpensive quartz clock set approximately to GPS time. The clock timing error or clock bias is overcome by measuring the distances to four satellites. Other errors include satellite position error (ephemeris error), ionospheric and tropospheric refraction, receiver noise, multi-path and selective availability, collectively referred to as the UERE, or User Equivalent Range Error. The cumulative UERE totals are multiplied by a factor of 1 to 6, a factor that represents the Dilution of Precision, or DOP. DOP is a measure of the geometry of the visible satellite

constellation. The ideal orientation of the constellation would require all satellites to be equally spaced around the receiver, and one directly above. This would result in a low DOP. Selective availability is the highest source of error, an intentional error, imposed to limit accuracy to 95% probability of 328 ft. (100 m.) or less.

Instantaneous velocity of a moving vehicle is determined using the Doppler principle of radio signals. Due to the relative motion of the GPS satellites with respect to a moving vehicle, the frequency of a signal broadcast by the satellite is shifted when received at the vehicle. This measurable shift is proportional to the relative radial velocity. The radial velocity of the satellite is known, therefore the radial velocity of the moving vehicle can be deduced from the Doppler observable. The accuracy of velocity is ± 0.16 km/hr (0.1 mph) for receivers with location accuracy of 100 m. (328 feet), and with selective availability turned on. Since May, 2000 selective availability has been turned off and the accuracy has been reported to increase tenfold. The instantaneous GPS velocity reporting is independent of position fixes. Prices for GPS receivers range from \$100-\$50,000, depending on the additional features available and the reporting accuracy of the receivers. The GPS receiver selected for this study are capable of reporting location within a 100m accuracy, providing data in a non-proprietary format and is compatible with a Cellular Digital Packet Data (CDPD) modem (Trimble Navigation Limited 1996).



Figure 1. Placer 450 and Magnetic Antenna.

1.2 MODEM

The Cellular Digital Packet Data (CDPD) is a wireless, public access, packet data standard designed to operate over existing analog cellular phone systems. The Uniden Data 1000, a CDPD modem, was selected for this study. The selection of a modem is based on:

- Cost
- Reliability
- Compatibility with the GPS receivers selected.



Figure 2. Uniden Data 1000, CDPD Modem.

1.3 COMMUNICATION

CDPD is a connectionless network service that overlays the cellular voice network to wirelessly transmit data to mobile and fixed-end computing devices. The CDPD network operates as an extension of the TCP/IP data communication network. TCP/IP is the method by which data on the network is divided into packets of bytes. Then the CDPD network transmits the GPS data from the corridor to a PC server in an end-to-end system.

Key components of the end-to-end system used are the mobile system and the fixed-end host system. The mobile equipment, installed in the vehicle, comprises of a GPS receiver and a CDPD modem. The fixed-end host system, a PC, runs FleetVision (Trimble Navigation Limited 1998b). The PC server is connected to the internet and therefore the PC connects to

the CDPD network through the internet. Messages received by the cellular from the GPS are processed and routed to an IP address. Additionally, the cellular carrier providing CDPD services accepts TCP/IP transmissions for IP addresses for units that are registered and operate in its CDPD network and passes those messages on to the units. The GPS receivers come with a SLIP interface driver to communicate with the CDPD modem and a TCP/IP stack to enable it to exchange messages over the CDPD network. The CDPD modem is registered with a CDPD service provider and configured with the IP address. The modem comes with software to allow easy setup. Figure 3 below shows the configuration of the communication network.

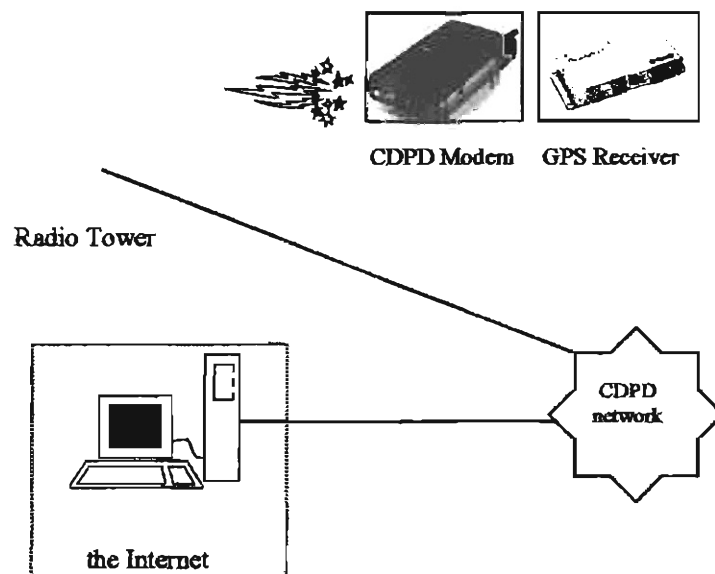


Figure 3. Communication Network.

1.4 PORTABILITY

The GPS receiver, CDPD modem, and their antennas assembled in a box provide a portable unit as shown in Figure 4. This unit is easy to install in a vehicle by slipping the adapter into a lighter/power source and mounting the magnetic antenna on the rooftop of a vehicle.

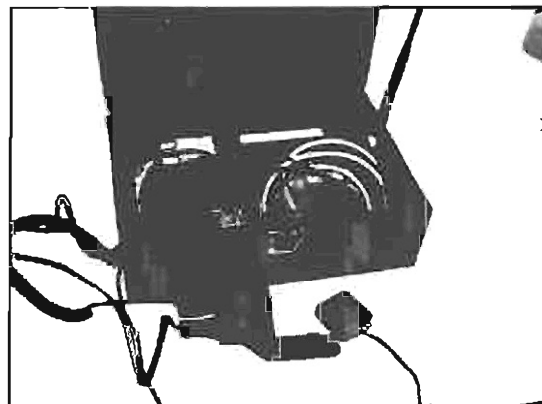
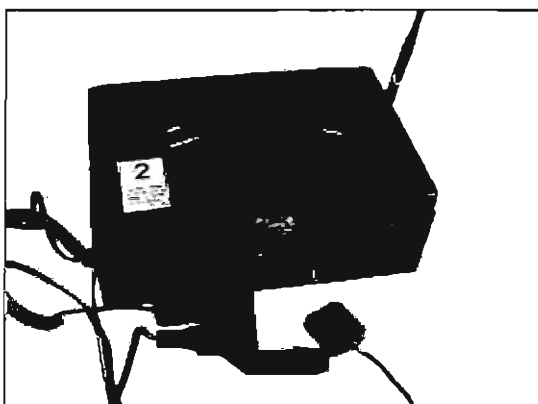


Figure 4. Assembled GPS Unit.

1.5 COST

The cost of the portable GPS receiver unit shown in Figure 4 was less than \$1500 per unit during the study. Currently, the same unit could be assembled for less. The breakdown of costs per unit is presented in Table 1.

Table 1. Cost Breakdown Per Portable GPS Unit.

	<i>Cost for Study</i>	<i>Current Costs</i>
GPS Receivers	\$800	\$599
CDPD Modem	\$350	\$350
Antenna Kit	\$180	\$45
Cables	\$60	\$50
Antenna for Modem	\$50	\$50
Cigarette Lighter Adapter	\$45	\$45
Cash Box	\$10	\$10
TOTAL	\$1,495	\$1149

CHAPTER 2:

DESCRIPTION OF THE DEMONSTRATION PROTOTYPE

2.1 COMPONENTS OF THE PROTOTYPE

The real-time demonstration prototype system developed to receive GPS data from probe vehicles in real-time, process the data and estimate link travel time and speed consists of three integrated modules. They are:

- 1) Probe Vehicle Tracking Module
- 2) Link Travel Time/Speed Algorithm
- 3) Graphical Interface

Figure 5 shows a schematic of the components. A brief description of each module is provided below:

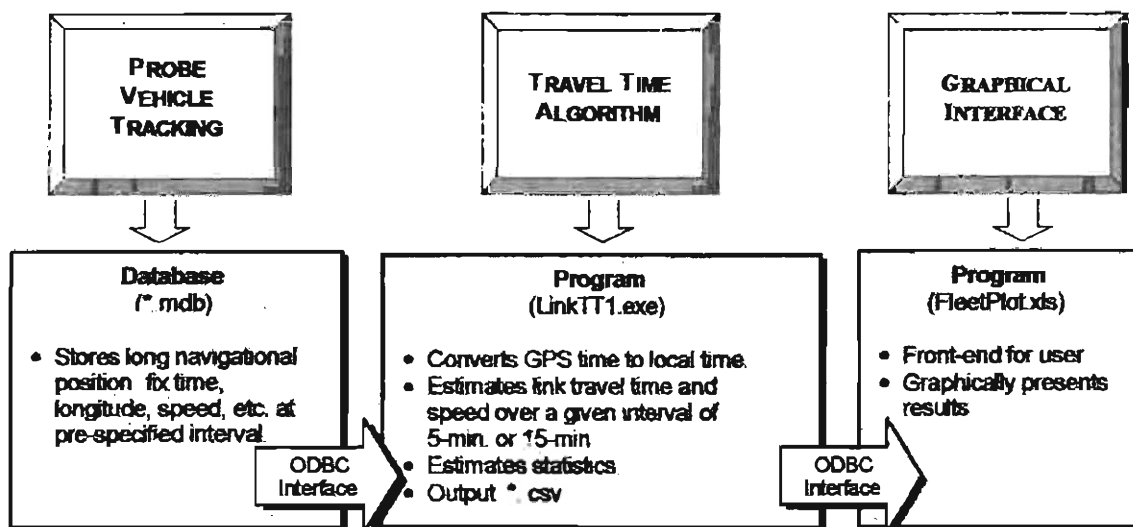


Figure 5. Components of the Real-Time Demonstrational Prototype System.

2.2 PROBE VEHICLE TRACKING SYSTEM

The Probe Vehicle Tracking Module receives GPS data in real-time from all vehicles instrumented with GPS receivers or probe vehicles operating within the test corridor using the communication network described in the previous section. This information is received as a data string at pre-specified time intervals and includes: Report Time and Position Fix Time in GPS time, latitude, longitude, altitude, horizontal and vertical speed, number of satellite vehicles used, and satellite vehicle ID. The navigational message may be received every second. For the prototype, the reporting interval is set to 5 seconds. This data is stored in a database file (*.mdb) and is passed to the Travel Time Estimation Module. Probe vehicles may be tracked and displayed on a map of the network using FleetVision (Trimble Navigation Limited 1998a).

2.2.1 Fleet Vision

FleetVision (Trimble Navigation Limited 1998b) tracks a fleet of vehicles equipped with GPS receivers in real-time. It also reports and stores the data, such as vehicle location and time, to a base computer via the CDPD modem. The reported GPS data contain vehicle ID, longitude, latitude, altitude, and speed for each vehicle every pre-specified interval. The reporting interval can be set to as frequent as 1 second. For this test network, the reporting interval was set to 5 seconds.

2.3 TRAVEL TIME AND SPEED ESTIMATION ALGORITHM

The link travel time and link speed are calculated by using a program written in Fortran language.

2.3.1 Fortran Program

The Fortran program has been developed to :

- Extract the GPS data for a selected network.
- Convert GPS time to Denver local time. The daylight saving time change and leap year are also taken into account. GPS time is the number of seconds elapsed after 00:00:00 AM January 6, 1980.
- Estimate the link travel time and link speed based on data received from probe vehicles that complete their journey through a link. The link travel time and link speed can be determined as follows:

$$LTT_{ij} = T_{out,ij} - T_{in,ij} \quad (1)$$

where,

LTT_{ij} = Travel time for probe vehicle i for link j

$T_{in,ij}$ = Time probe vehicle i enters the link j

$T_{out,ij}$ = Time probe vehicle i exits the link j

L_j = Length of link j

$$LSPD_{ij} = \frac{L_j}{LTT_{ij}} \quad (2)$$

where,

$LSPD_{ij}$ = Travel speed for probe vehicle i for link j

The probe vehicles completing their journey on a link within a given interval are used to estimate average link travel time and average link speed. For example, to estimate 15-minute average link travel time, all probe vehicles that complete their journey through the link are included. Probe vehicles are checked every 2.5 minutes, that is, the update interval is 2.5 minutes.

$$\overline{LTT}_j = \frac{\sum_{i=1}^n LTT_{ij}}{n} \quad (3)$$

$$\overline{LSPD}_j = \frac{L_j}{\overline{LTT}} \quad (4)$$

where,

$\overline{LTT}_j$ = Average travel time for link j

$\overline{LSPD}_j$ = Average travel speed for link j

n = number of probe vehicles for link j

For any given interval, the exact time a probe vehicle enters and exits a link is estimated by first converting the longitude, latitude, and altitude at any time to Earth Centered Earth-Fixed (ECEF) coordinates and estimating the distance traveled. This procedure is described in the next few sections.

2.3.2 Transformation from Geodetic Coordinates to Earth Centered, Earth-fixed (ECEF) Coordinates

The GPS reports data in longitude and latitude. To calculate the linear distance of the vehicles between two report locations, the longitude (ϕ), latitude (λ), and altitude (h) are converted to Earth Centered Earth-fixed (ECEF) Coordinates ((x,y,z) coordinates) (Figure 6).

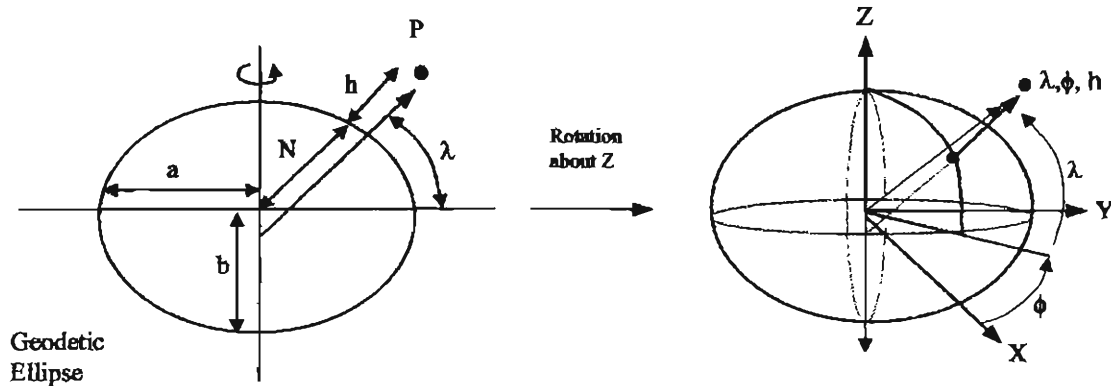


Figure 6. Geodetic Coordinates Transformation.

The flatness of the geodetic ellipsoid is defined as:

$$f = \frac{a-b}{a} = 0.0034 \quad (5)$$

where,

a = Semi-major axis length = 6378137.0 m

b = Semi-minor axis length = 6356752.3142 m

The eccentricity of the ellipsoid is defined as:

$$e = \sqrt{f(2-f)} = 0.0818 \quad (6)$$

The length of the normal to the ellipsoid, from the surface of the ellipsoid to its intersection

$$N(\lambda_i) = \frac{a}{\sqrt{1-e^2 \sin^2(\lambda_i)}} \quad (7)$$

The linear position in (x,y,z) coordinates is calculated as:

$$x_i = (N + h_i) \cos(\lambda_i) \cos(\phi_i) \quad (8)$$

$$y_i = (N + h_i) \cos(\lambda_i) \sin(\phi_i) \quad (9)$$

$$z_i = [N(1-e^2) + h_i] \sin(\lambda_i) \quad (10)$$

where,

λ_i = Latitude at time t

ϕ_i = Longitude at time t

h_i = Altitude at time t

2.3.3 Estimating the Entry and Exit Time For Probe Vehicles

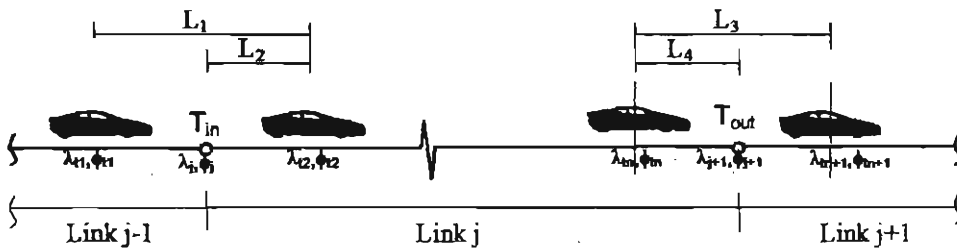


Figure 7. Probe Vehicle Entering and Exiting a Link.

The locations of vehicles in longitude (ϕ), latitude (λ), and altitude (h) are converted to (x,y,z) coordinates based on equation (8) , (9) , and (10). The time a probe vehicle enters and exits a link is estimated based on linearly interpolating between two consecutive 5-second reporting of location as follows:

$$L_1 = \left[(x_{t_1} - x_{t_2})^2 + (y_{t_1} - y_{t_2})^2 + (z_{t_1} - z_{t_2})^2 \right]^{\frac{1}{2}} \quad (11)$$

$$L_2 = \left[(x_k - x_{t_2})^2 + (y_k - y_{t_2})^2 + (z_k - z_{t_2})^2 \right]^{\frac{1}{2}} \quad (12)$$

$$L_3 = \left[(x_{t_n} - x_{t_{n+1}})^2 + (y_{t_n} - y_{t_{n+1}})^2 + (z_{t_n} - z_{t_{n+1}})^2 \right]^{\frac{1}{2}} \quad (13)$$

$$L_4 = \left[(x_{t_n} - x_{t_{n+1}})^2 + (y_{t_n} - y_{t_{n+1}})^2 + (z_{t_n} - z_{t_{n+1}})^2 \right]^{\frac{1}{2}} \quad (14)$$

where,

- L_1 = Distance a probe vehicle travels between time t_1 and t_2
- L_2 = Distance from upstream node for link j to the location of a probe vehicle at time t_2
- L_3 = Distance a probe vehicle travels between time t_n and t_{n+1}
- L_4 = Distance from the location of a probe vehicle at time t_n to node $j+1$
- t_1 = Last reporting time before entering link j
- t_2 = First reporting time after entering link j
- t_n = Last reporting time before exiting link j
- t_{n+1} = First reporting time after exiting link j
- $\lambda_{t_1}, \lambda_{t_2}, \lambda_{t_n}, \lambda_{t_{n+1}}$ = Latitude at time t_1, t_2, t_n , and t_{n+1} , respectively
- $\phi_{t_1}, \phi_{t_2}, \phi_{t_n}, \phi_{t_{n+1}}$ = Longitude at time t_1, t_2, t_n , and t_{n+1} , respectively
- λ_j, λ_{j+1} = Latitude for node j and $j+1$, respectively
- ϕ_j, ϕ_{j+1} = Longitude for node j and $j+1$, respectively

Therefore, the time a probe vehicle i enters and exits the link j are as estimated follows:

$$T_{in,ij} = t_1 + (t_2 - t_1) \frac{L_2}{L_1} \quad (15)$$

$$T_{out,ij} = t_n + (t_{n+1} - t_n) \frac{L_4}{L_3} \quad (16)$$

Based on equation (3), (4), (15) and (16) the average link travel time and speed are estimated. In addition, the standard error of the average link travel time estimates are estimated based on the average variance and covariance of the probe vehicle estimates as follows:

$$\sigma_{\overline{LTT}_j}^2(t_n) = \nu_j(t_n) + \frac{1}{n(t_n)} [\eta_j(t_n) - \nu_j(t_n)] \quad (17)$$

where,

$\sigma_{\overline{LTT}_j}^2(t_n)$ = standard error of average travel time estimate for link j , for a given analysis

period (e.g. 5-min or 15-min)

$\nu_j(t_n)$ = average variance of average travel time for link j , , for a given analysis

period

$\eta_j(t_n)$ = average covariance of average travel time for link j , , for a given analysis

period

$n(t_n)$ = number of probe vehicles that travel link j , for a given analysis period

Similarly, the standard error for average travel speed estimate is also calculated. All estimates for every link in the network are stored in a file (*.csv) and passed to Graphical Interface Module.

2.4 GRAPHICAL INTERFACE

To display the average link travel time and speed estimates, their statistics and individual probe vehicle data in a user-friendly environment, a graphical interface was developed. The routines of this module use the Open Database Connectivity (ODBC) interface to receive data from the Travel Time Estimation Module.

2.4.1 FleetPlot

FleetPlot has been developed as an Excel application. The FleetPlot is used to plot vehicle link travel time, vehicle link speed, vehicle instantaneous speed, average link travel time and average link speed. The plots show the data for the test network. The plots are automatically updated every 2.5 minutes. This update can be stopped or restarted. The plots only show the time of the last update and the number of probe vehicles in a given analysis period. The plots or data display are delayed approximately by a maximum of 2.5 minutes. Figure 8 shows a snapshot of the Graphical Interface.

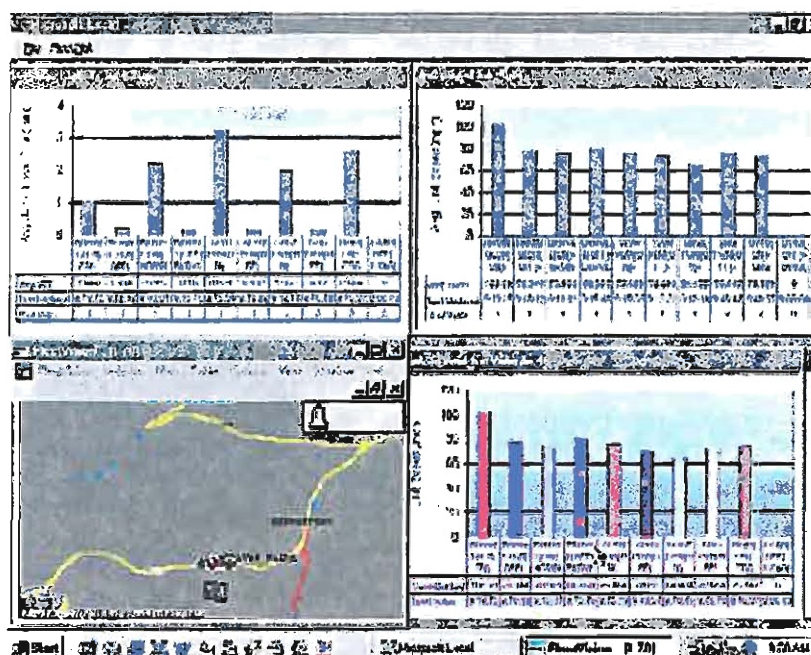


Figure 8. Sample Interface Showing the Integration of the Three Modules.

2.5 PROTOTYPE INTERFACE

The prototype consists of three modules: Probe Vehicle Tracking, Travel Time Algorithm, and Graphical Interface. The three modules are connected using Open Database Connectivity (ODBC) interface. The Travel Time Algorithm module receives data from the Probe Vehicle Tracking system. The Graphical Interface module receives data from the Travel Time

Algorithm as shown in Figure 5. The external program performs all the calculations such as time conversion, link travel time, link speed, etc. (Figure 9).

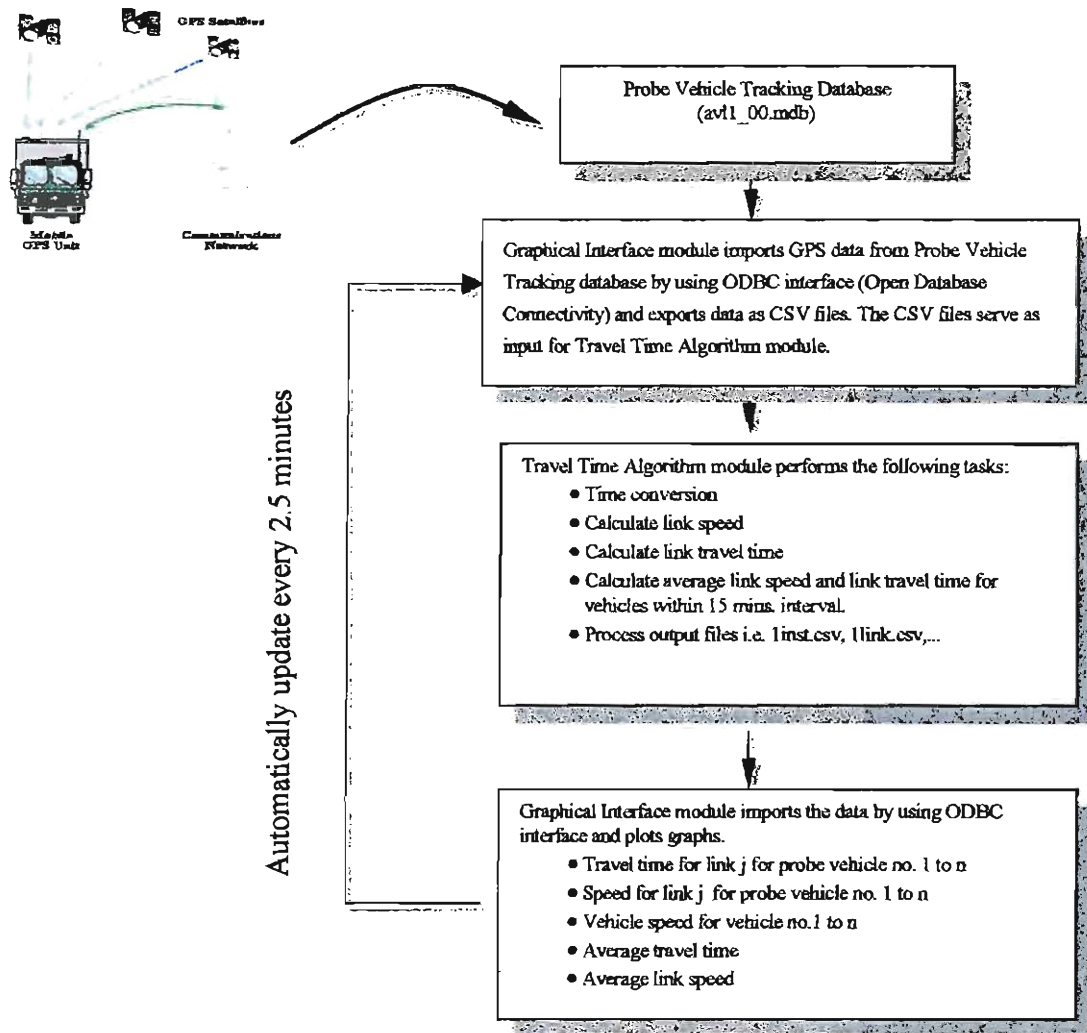


Figure 9. Flowchart.

CHAPTER 3:

EVALUATION OF THE DEMONSTRATION

PROTOTYPE

To perform a comprehensive evaluation of the demonstration prototype, a section of the I-70 corridor between the Denver International Airport and the ski resorts was selected. The next few sections present details of the test section selected, a simulated representation of the test network, off-line tests conducted, on-line real-time field data collection procedures, and findings of these tests.

3.1 TEST NETWORK

Interstate 70 westbound between US 40 Exit (Winter Park) and US 6 Exit was selected as the test section. The length of the 2-lane test network is approximately 15.8 miles. The average grade is about 3% upgrade, with a maximum of 6%. The on-ramps and off-ramps within the test network include US 40, Georgetown, Silver Plume, Bakerville, Herman Gulch, and US 6. Figure 10 shows the test network. Figure 11 shows the elevation of the network.

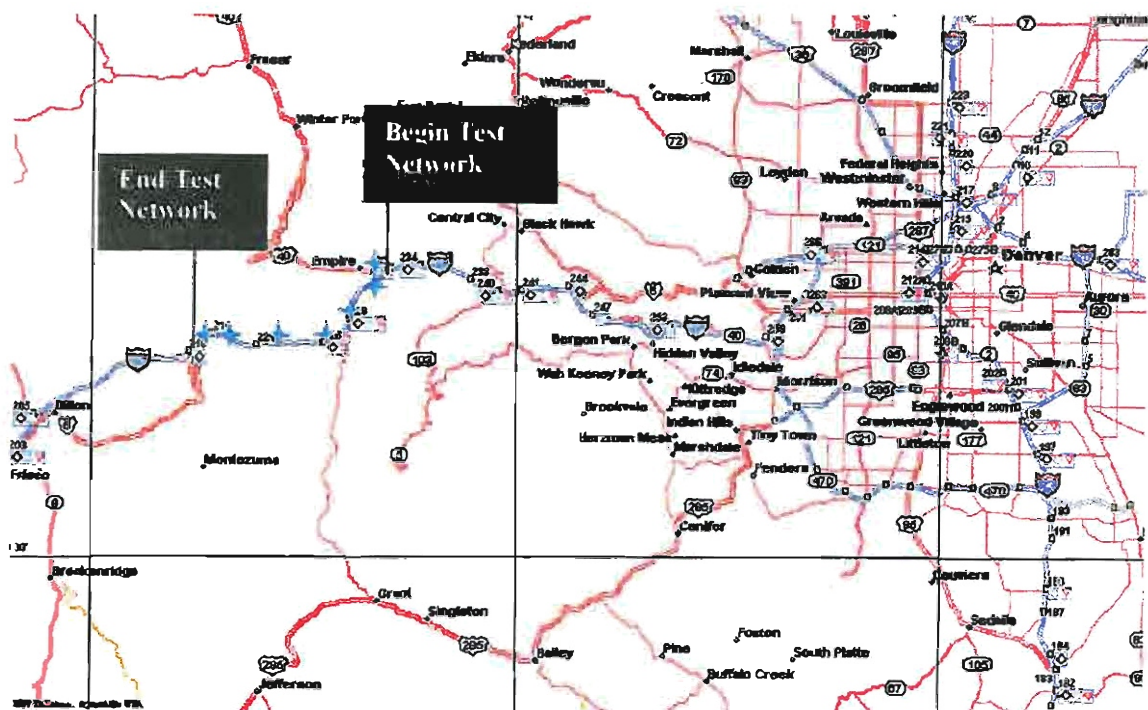


Figure 10. Test Network.

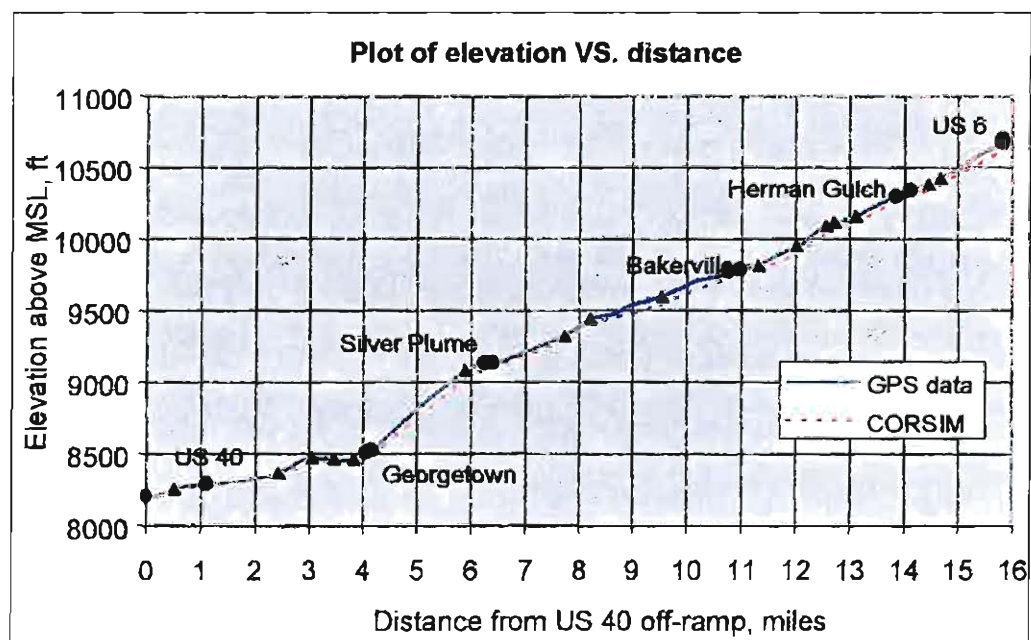


Figure 11. Elevation Profile.

3.2 NETWORK REPRESENTED IN SIMULATION

To develop and test the algorithms under different flow conditions, probe vehicle deployment, and probe report interval, the test network was simulated using CORSIM, a microsimulation model. Field data collected may often be limited. Therefore, a simulation provides extensive data for testing under a variety of operating conditions. The simulation model was calibrated based on field data to ensure that the network was well represented by the simulation model.

3.2.1 CORSIM

CORSIM (CORidor SIMulation) (Federal Highway Administration 1996), a microsimulation, developed by the Federal Highway Administration (FHWA) consists of NETSIM and FRESIM and is used to simulate a surface street and freeway network, respectively.

The traffic environment of the network is represented to include the topology of the roadway system, roadway geometry, lane channelization, driver behavior, traffic control, traffic volumes entering the roadway system, turn movements, and fleet characteristics. A schematic of the representation is shown in Figure 12.

3.2.2 Calibrating CORSIM

To calibrate CORSIM, traffic flow was recorded at US 40 and Bakerville using video cameras as shown in Figure 13. A video image processing system was used to estimate traffic flow rate and speed at these locations. In addition, volunteer drivers with GPS receivers were deployed to collect travel time data along the same section as flow data was recorded.

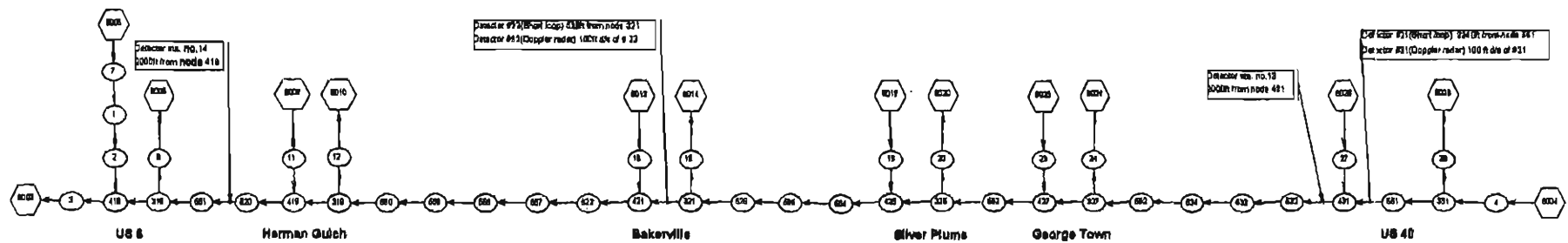


Figure 12. Nodes and Links Represented in CORSIM.

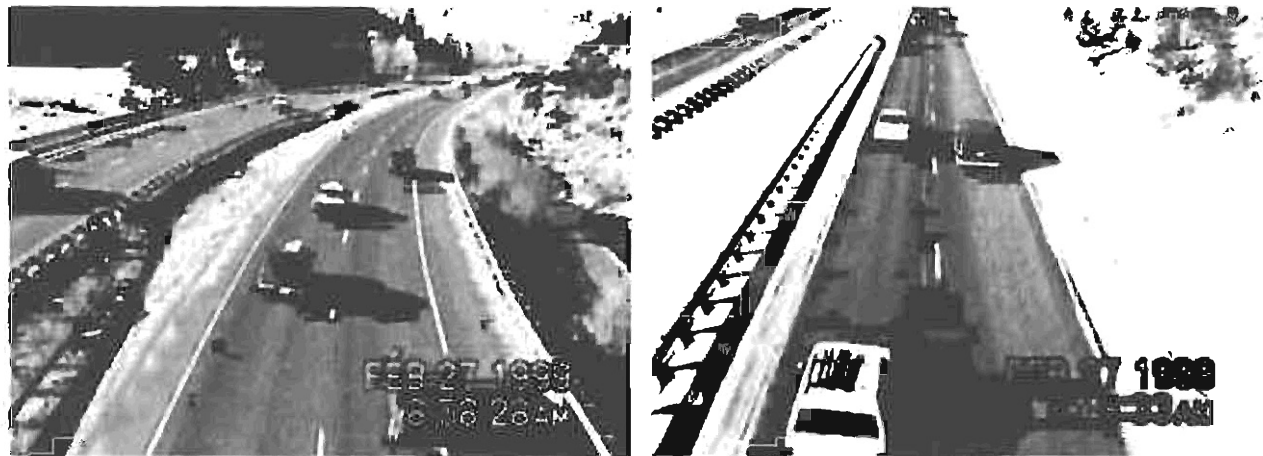


Figure 13. Cameras at US 40 and Bakerville to Monitor Traffic Flow on the I-70 Corridor to Calibrate CORSIM.

3.2.3 Results of Calibration

Details of the calibration results are presented in several papers. ((Khan (in preparation)), (Khan 1998), (Khan 2000b), and (Khan 2000a)).

3.3 OFF-LINE TESTING OF THE AVERAGE LINK TRAVEL TIME ESTIMATION ALGORITHM

Analysis of the standard error of the estimates of average link travel time based on Eq. (17) and probe vehicle data shows that increasing the number of probes beyond a certain level does not improve the accuracy of the estimates as shown in Figure 14. Here the curve flattens as the number of probes traveling a link increases, with very little marginal improvement in accuracy. In addition, the marginal improvement in the estimate of average link travel time also varies based on flow conditions and link characteristics. Details of these findings are reported separately (Khan 2000b). Figure 14 shows the standard error for a 833.63 m. (2,735 ft) link with a 3% grade between Bakerville and Herman Gulch for two flow conditions. Figure 15 shows the standard error for a short weaving section between an on and off-ramp. Figure 14 and Figure 15 show that the marginal improvement in error is higher for the weaving section for less than 5 probes, compared to a longer section.

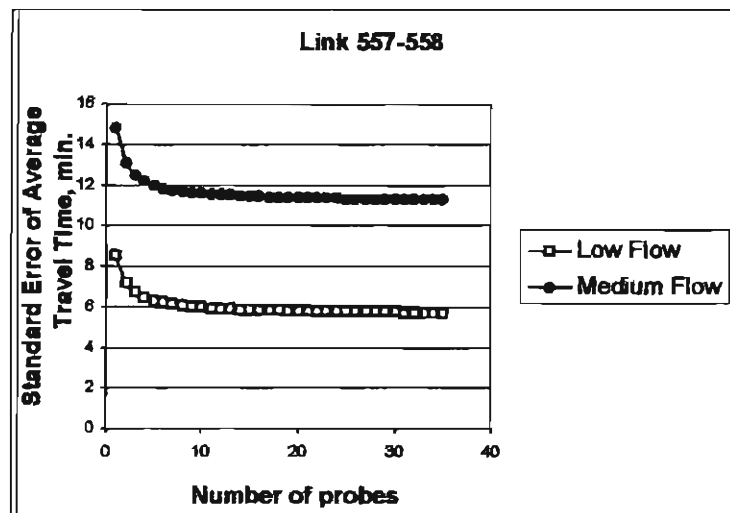


Figure 14. Standard Error of Average Link Travel Time Estimate for Link between Bakerville and Herman Gulch.

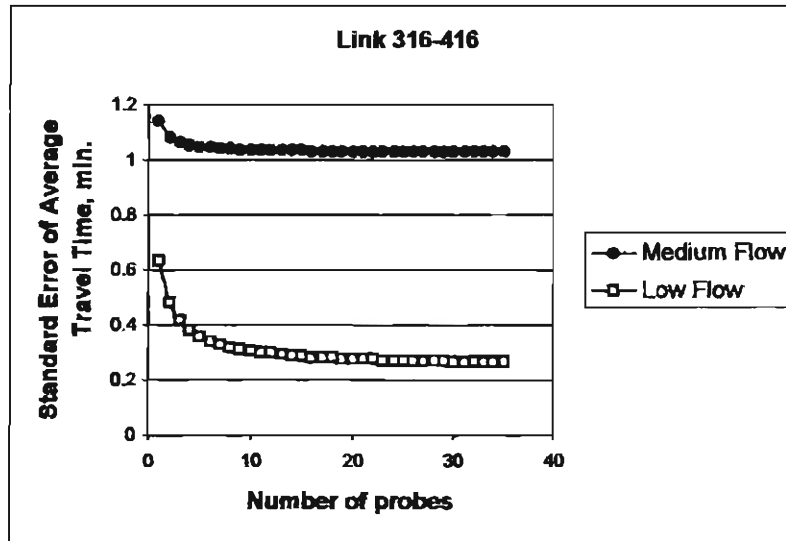


Figure 15. Standard Error of Average Link Travel Time Estimate for Link between US 6 On and Off-Ramp.

Therefore, using link travel time functions, average link travel time estimates based on probe data for an analysis period, and the number of probes used for the estimate, the standard error of the average travel time estimate may be reported. For example, for probe data collected within a 15-minute analysis period and using Eqs. (1) to (16), the average travel time for Link # 316-416 may be estimated. Based on the link travel time function as shown in Figure 16, the flow level may be identified as "Medium". Using standard error curves such as Figure 15 and the number of probes within the analysis period, the standard error of the link travel time may be estimated.

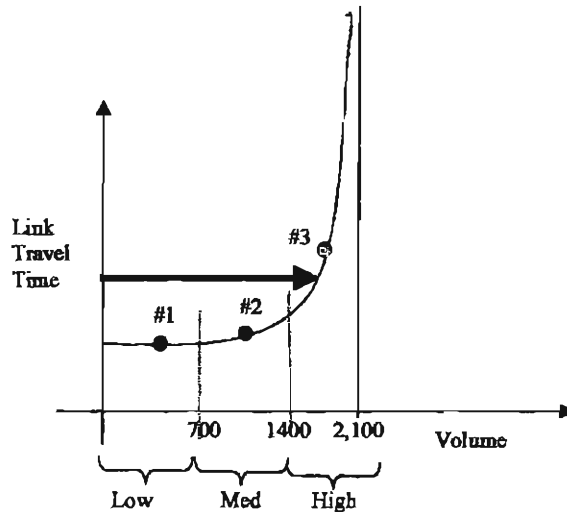


Figure 16. A Link Travel Time Function.

3.4 OFF-LINE AND ON-LINE TESTING OF THE DEMONSTRATION PROTOTYPE SYSTEM BASED ON CONTROLLED EXPERIMENTS

Several vehicles were equipped with the assembled GPS unit (Figure 4) and volunteer drivers were deployed for several weekends: March 25, April 1, and April 15, 2000. The data collection was performed during 7:00AM to 10:00AM. During this period traffic volume varied from 700 to 2200 vph westbound for the test network.

For the field study, the test network was divided into 10 links based upon the location of on-ramps and off-ramps. The length of links varies from 0.12 to 4.12 miles. The upstream and downstream locations and lengths are as follows:

1. US 40 off-ramp to US 40 on-ramp, 1.11 miles.
2. US 40 on-ramp to Georgetown off-ramp, 3.16 miles.
3. Georgetown off-ramp to Georgetown on-ramp, 0.22 miles.
4. Georgetown on-ramp to Silver Plume off-ramp, 2.11 miles.
5. Silver Plume off-ramp to Silver Plume on-ramp, 0.16 miles.
6. Silver Plume on-ramp to Bakerville off-ramp, 4.12 miles.

7. Bakerville off-ramp to Bakerville on-ramp, 0.21 miles.
8. Bakerville on-ramp to Herman Gulch off-ramp, 2.73 miles.
9. Herman Gulch off-ramp to Herman Gulch on-ramp, 0.24 miles.
10. Herman Gulch on-ramp to US 6 off-ramp, 1.73 miles.

3.4.1 GPS and Modem Coverage

Extensive testing of the prototype system has shown that the GPS coverage varies on the test network on I-70 depending on the season, with better coverage during the summer months. Based on a 5-second reporting interval, the GPS coverage statistics are summarized in Table 2. As shown in this table, the average consecutive seconds either the GPS signal or modem coverage is lost due to inadequate satellite coverage, mountainous terrain, or any obstructions is less than one minute during winter and approximately half a minute during summer. The average total duration signal is lost for a one-way, 16-mile trip is a little over two minutes during winter and less than two minutes during summer.

Table 2. Statistics on Loss of Probe Vehicle Data for the Test Network.

Winter		Summer	
<i>Average consecutive seconds GPS or modem coverage is unavailable (seconds)</i>	<i>Average total duration signal or modem connection for a one-way trip for test network is lost (seconds)</i>	<i>Average consecutive seconds GPS or modem coverage is unavailable (seconds)</i>	<i>Average total duration signal or modem connection for a one-way trip for test network is lost (seconds)</i>
53.5	134	34.5	104

3.5 ON-LINE, REAL-TIME TESTING BASED ON COMMERCIAL VANPOOL SERVICE AS PROBES

There are several van pool services from Denver International Airport (DIA) to ski resorts such as Colorado Mountain Express (CME) (Figure 17). For this study, Colorado Mountain Express was contacted to explore the feasibility of deploying several assembled GPS units from DIA to Vail to test the demonstration prototype in real-time. CME has 150 vans in their fleet operating on this route with an average headway varying from 20-30 minutes to an hour for winter and summer season respectively. CME agreed to participate in this study and 5 units were deployed between June 27, 2000 to July 17, 2000.



Figure 17. CME Vanpool Service.

Extensive on-line testing revealed a few software problems that were later resolved as part of this process. The demonstration prototype is now debugged and is fully operational and running in the Colorado TransLab.

CHAPTER 4:

CONCLUSIONS AND RECOMMENDATIONS

The study demonstrates the feasibility of estimating link travel time and speeds in real-time for a rural, mountainous section of an interstate freeway in Colorado using vehicles instrumented with global positioning system receivers, serving as probes in traffic streams. The system configuration proposed includes a cost-effective, portable GPS deployment unit, communication links to a PC server and an integrated prototype system for vehicle tracking, estimating statistics on link travel time and displaying the information in a user friendly environment.

Extensive testing of the prototype system has shown that the GPS coverage varies on the test network on I-70 depending on the season, with better coverage during the summer months. Based on a 5-second reporting interval, the GPS coverage statistics show that the average consecutive seconds either the GPS signal or modem coverage is lost due to inadequate satellite coverage, mountainous terrain, or any obstructions is less than one minute during winter and approximately half a minute during summer. The average total duration signal is lost for a one-way, 16-mile trip is a little over two minutes during winter and less than two minutes during summer.

The study also shows that average link speed, a measure independent of link length, is a better estimate to display and for an operator of the system to quickly draw inferences about traffic congestion. Link travel time estimates are also required for targeted traveler information for a given origin and destination pair. The design of the most efficient and user-friendly front-end to the prototype was not part of the scope of the study. This study may be further extended to address these issues.

A final project presentation was made on July 20, 2000 to the Project Manager, traffic engineers from the Mobility Group, DTD, ITS Group, Headquarters, Region 1 and Region 6, CDOT, and the Denver Regional Council of Governments (DRCOG). The prototype system presented was very well received by the attendees. Interest was expressed by several groups within CDOT to further extend this study for other applications. The groups that expressed an interest included: GIS, Mobility, ITS, Region 6 and Region 1. Several follow-up presentations were scheduled. One of the meetings arranged by the Mobility Analysis Group on August 23rd, 2000 included 20 attendees from the GIS, Mobility Analysis, ITS, and Region 6, CDOT. A separate meeting was scheduled by Region 1 to be held in October, 2000.

4.2 EXTENSION OF THIS STUDY

A proposal was submitted in December, 1999 to CDOT as part of the 2001 Problem Statements to extend this study to use the Regional Transit District (RTD) bus fleet already equipped with Automatic Vehicle Location System (AVL) to estimate freeway traffic speed. The proposal was very well received and has been recommended for funding. This new study is titled "Using RTD's Transit Vehicles as Probes to Develop Speed Maps for Colorado Freeways". Bruce Coltharp from the ITS Office, CDOT will serve as project manager.

APPENDIX A:

INSTALLING AND RUNNING THE PROTOTYPE SYSTEM

B.1 SYSTEM REQUIREMENTS

- Pentium 200 MHz class or higher with CD-ROM drive
- 96 MB of memory
- 2.0 GB hard disk drive
- Microsoft Windows 98
- Microsoft Excel 97
- A fixed-end host server with a static IP address

B.2 INSTALLING FLEETVISION

- Insert the FleetVision installation CD in the computer's CD-ROM drive.
- Click on Start and select Setting/Control Panel.
- Click Add/Remove Programs.
- In the Add/Remove Programs Properties dialog box click on Install and follow the on-screen instructions.

B.2.1 Communication Channel Setup

1. In FleetVision Taskbar, Click **Tools** and then **Channel Setup**.
2. Data layer should be set to **TAIP** as shown in Figure A-1.

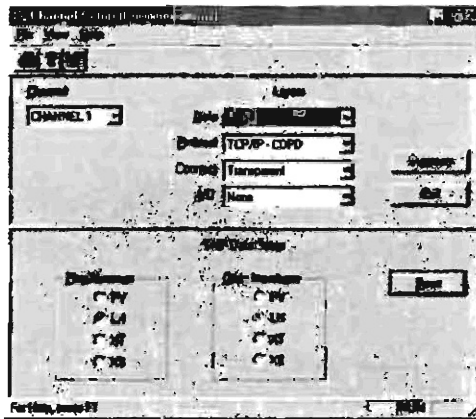


Figure A-1. Channel Setup Dialog-Data.

3. Protocol layer should be set to **TCP/IP CDPD** and the IP address is for the fixed-end host that will receive the GPS data.



Figure A-2. Channel Setup Dialog-Protocol.

B.2.2 Vehicle Configuration

1. In FleetVision taskbar, Click **Fleet, Vehicle Configuration**, and then **Create a new vehicle or edit an existing vehicle**.
2. Click **Continue...**

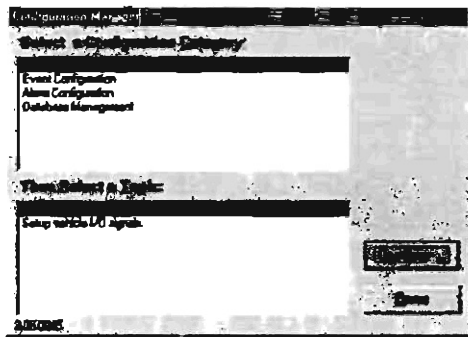


Figure A-3. Configuration Manager Dialog.

3. Enter Physical ID (a number to represent the vehicle), Name and select icon by clicking **Icon**.

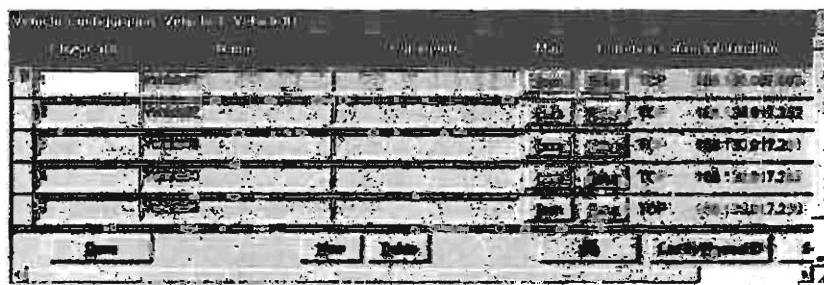


Figure A-4. Vehicle Configuration Dialog.

4. Enter communication information by clicking **Setup** to access to Vehicle Communication Configuration Dialog.

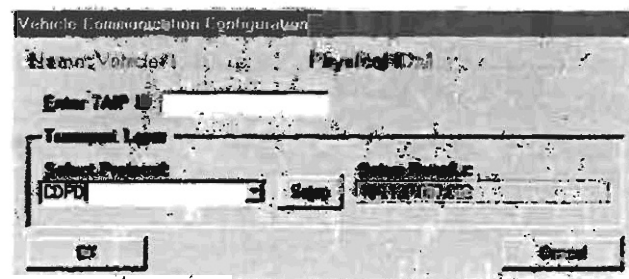


Figure A-5. Vehicle Communication Configuration Dialog.

5. Select **CDPD** in **Select Protocol** and then click **Setup** to enter the CDPD modem IP address.

B.2.3 Installing FleetPlot and Fortran Program

1. Insert the FleetPlot&Fortran program installation CD in the computer's CD-ROM drive.
2. Click on **Start** and select **Setting/Control Panel**.
3. Click **Add/Remove Programs**
4. In the **Add/Remove Programs Properties** dialog box click on **Install** and follow the on-screen instructions.

B.2.3.1 MS-Dos Prompt

MS-Dos prompt must be set to minimized as follows:

1. Click **Start, Programs**, and then **MS-DOS prompt**
2. Click  **MS-DOS Prompt Properties** dialog.
3. Set **Run** to **Minimized**.

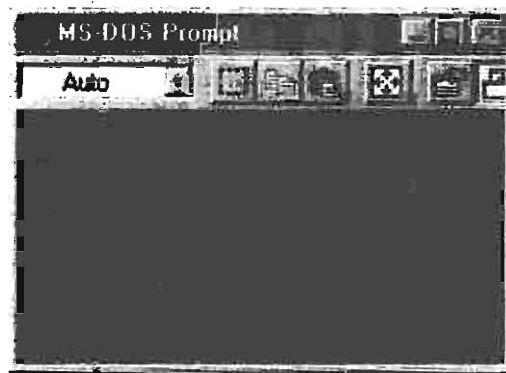


Figure A-6. MS-DOS Dialog.

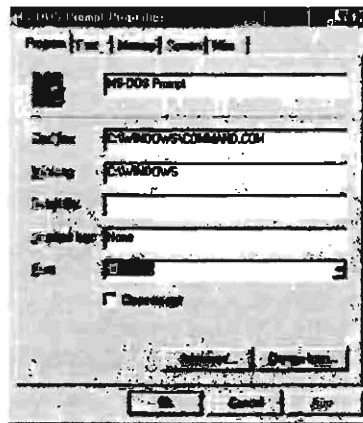


Figure A-7. MS-DOS Prompt Properties.

B.2.4 Installing GPS Receivers

B.2.4.1 Installing GPS in a Probe Vehicle:

1. Place GPS assembled unit (Figure 4) the GPS box in your car close to the cigarette lighter socket. The GPS unit may be placed on the front seat. The data modem's antenna should be in an upright position.

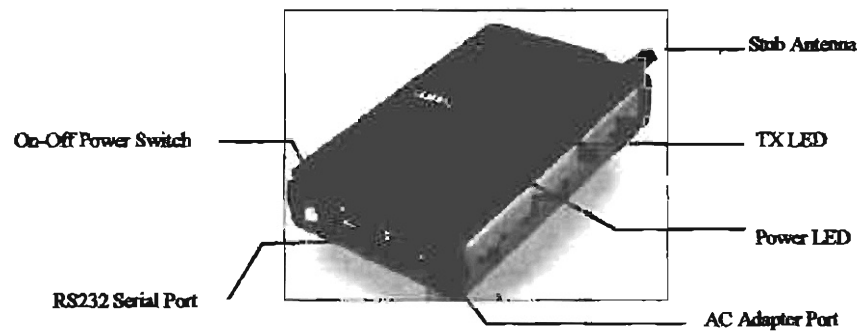


Figure A-8. Data Modem.

2. Attach the magnetic GPS antenna on probe vehicle's roof.



Figure A-9. GPS Unit (Placer 450) and GPS Antenna.

3. Plug the power cable to probe vehicle's cigarette lighter socket.
4. Turn the modem power switch on.
5. Check the data modem by following these steps:
 - Power LED- Solid red indicates power on and no light indicates power off.
 - TX LED indicates modem operational status.
 - Solid Orange indicates trying to acquire a CDPD channel.
 - Blinking Orange indicates trying to register on an acquired CDPD channel.
 - Solid Green indicates registered.
 - Flashing Green indicates transmitting while registered.

While operating, check the CDPD modem to make sure:

Power LED - is red all the time.

TX LED - is green most of the time.

B.3 SETTING UP THE MODEM

The fixed-end host computer receiving the probe vehicle data must be on the internet service with a static IP address. The power of the modem should be on. In order to set up the modem to report GPS data to the computer, the following steps should be performed:

1. Click **Start**, and then click **Run**.
2. Type **Telnet** and then click **OK**.
3. Click **Connect** and then click **Remote system**.
4. Enter the modem IP address. e.g. 166.130.7.3
5. Enter port **59100** and Terminal type **vt100**.
6. Click **Connect**
7. Type **> sda0c0xxx.xxx.xxx.xxx<**, replacing xxx.xxx.xxx.xxx with the fixed - end host computer's IP address i.e. **> sda0c0132.194.014.007 <**
8. Type **>qda<** and then press Enter. A message should be displayed similar to the following. **>RDA0C0132.194.014.007;ID=0003<**
9. Close telnet dialog box.

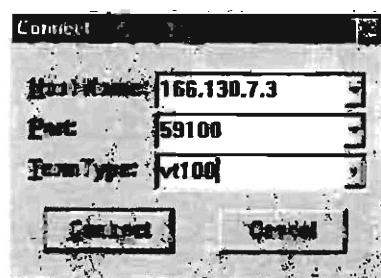


Figure A-10. Telnet Dialog Box.

B.4 RUNNING THE PROTOTYPE

To run the prototype, the FleetVision and FleetPlot program should be open while the external program is called by FleetPlot. The windows of two programs: FleetVision and FleetPlot will be displayed. The FleetVision tracks the vehicles. The FleetPlot displays the plots.

B.4.1 FleetPlot

In order to start FleetPlot, the macros should be allowed to run by clicking **Enable Macros**.

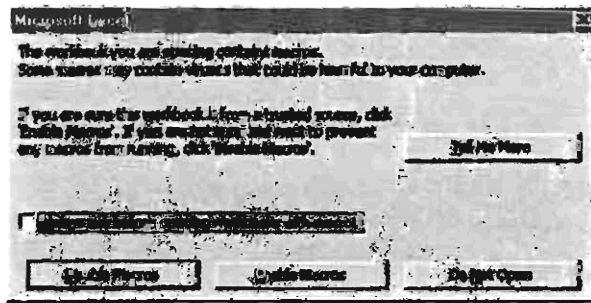


Figure A-11. Excel's Macros Protection Dialog.

B.4.1.1 FleetPlot menu

The charts show the vehicles traveling on I-70 from exit 232 (Winter Park exit) to US 6 off-ramp for a test network. The number of probe vehicles is currently set to 5 vehicles. Additional probe vehicles may be added as needed.



Figure A-12. Fleetplot Menu.

Link Travel Time and Link Speed

Under the FleetPlot menu, this selection allows a user to view the bar charts of link travel time (minutes) and link speed (mile per hour) for probe vehicles 1 to 5. The link travel time and

link speed charts show data for the last westbound run. For any link if the data from the last run is not available, the data from previous run will be shown instead. The charts also show the last updated time for each link or the last reported time before the vehicles move across the link to the next link. The link travel time and link speed for each link is represented in different color.

Vehicle speed

Under the FleetPlot menu, this selection allows a user to show a plot of speed of the probe vehicles every 5 seconds. Each color will represent the data for each link. There are currently 10 links on the test network. The charts show the GPS speed data for the last run on WB I-70. The upstream links are on the right of the chart and downstream links are on the left of the chart.

Average Last 15 min.

Under the FleetPlot menu, this selection allows a user to show the average speed and average travel time of the vehicles for each link within a 15-minute analysis period. The number of vehicles on the link within a 15-minute period is also shown on the table below the chart.

StopAutoUpdate

Once the FleetPlot starts, the data is automatically updated every 2.5 minutes. This function may be disabled by clicking "StopAutoUpdate".

RestartAutoUpdate

Under the FleetPlot menu, this selection allows a user to enable the auto update function. The data may be automatically updated every 2.5 minutes.

Update Now

Under the FleetPlot menu, this selection allows a user to start update function immediately. The updated plots are displayed after 2.5 minutes. The automatic update function is disabled. To automatically update the charts, click "RestartAutoUpdate".

Network Map

Under the FleetPlot menu, this selection allows a user to show a map of the test network on I-70 from US 40 off-ramp to US 6 off-ramp.

Help

Under the FleetPlot menu, this selection allows a user to show information about the FleetPlot.

APPENDIX B:

MAINTAINING THE PROTOTYPE SYSTEM

C.1 FLEETVISION AND FLEETPLOT MAINTENANCE

The Probe Vehicle Tracking module runs FleetVision (Trimble Navigation Limited 1998a) and its database. The Graphical Interface module runs a program FleetPlot. Depending on the frequency of probe data collection, the database may require regular maintenance. The maintenance routine requires the probe data to be exported as text files and saved. The schedule for maintenance depends on the number of probe vehicles in the fleet. The following steps are recommended:

- Click **Fleet** on FleetVision taskbar (Figure B-1).
- Select Database Management and Export or Delete data from the database and then click Continue button in the Configuration Manager dialog box (Figure B-2).



Figure B-1. FleetVision Taskbar.

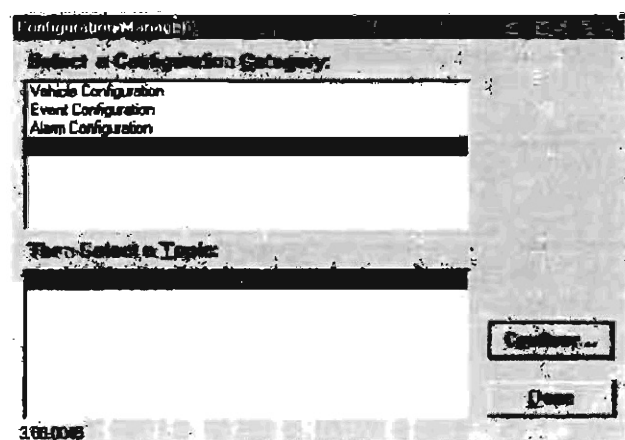


Figure B-2. Configuration Manager Dialog Box.

C.1.1 Export Data

- To export data, click  button (**Export Data to Text Files**) in the **Database Administrator** dialog box (Figure B-3).
- Enter the export date for one day of data in the **Export Date** (Figure B-4) and then click **OK**.

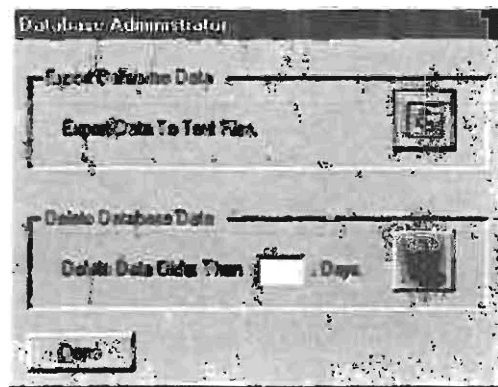


Figure B-3. Database Administrator Dialog Box.

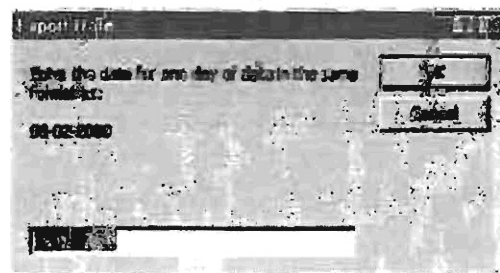


Figure B-4. Export Date Dialog.

C.1.2 Delete Data

- To delete data, on the **Database Administrator** dialog box, enter number of days i.e. enter 0 days to delete all the previous data from database.
- Click  button on **Database Administrator** dialog box to delete data.

- When finished, Click **Done** on **Database administrator** dialog box.

C.1.3 Compact AVL Database

- Click **Start**, and then click **Programs**.
- Click **FleetVision**, and then click **Compact AVL database**.

To maintain the database, perform the following on a regular schedule:

- Export data from database to text files.
- Delete data from database.
- Compact AVL database

APPENDIX C:

EXTERNAL PROGRAM

```

! Last change: T 13 Dec 1999 1:44 pm
C Last change: T 6 Sep 2000 11:25 am
PROGRAM LINK TRAVEL TIME
C This program is used to perform the following tasks:
c - Extract WB data on the test network
c - Convert GPS time to local time. Daylight saving has also
c been taken into account.
c - Calculate Link travel time, link speed, their average, and instantaneous
c speed.
CHARACTER IMOID,IREPTIME,ILAT,ILONG,IALT,JSPEED
I,INFILE(5)*12,OUTFILE1(5)*9,OUTFILE2(5)*9,OUTFILE3(5)*9
I,TEMP1(5)*11,TEMP2(5)*11,TEMP3(5)*10
CHARACTER*25 REALTIME(9999),L1RTIME(9999),L2RTIME(9999)
I,L3RTIME(9999),L4RTIME(9999),L5RTIME(9999),L6RTIME(9999)
I,L7RTIME(9999),L8RTIME(9999),L9RTIME(9999),L10RTIME(9999)
I,Z21,Z22,Z23,Z24,Z25,Z26,Z27,Z28,Z29,Z30
REAL*8 MOI(20000),REP(20000),LA(20000),LO(20000),ALT(20000)
I,SPE(20000),rep1(20000)
I,TMOI(18000),TREP(18000),TLA(18000),TLO(18000),TALT(18000)
I,TSPE(18000),MOID1(9999),REPTIME1(9999),LAT1(9999)
I,LONG1(9999),ALTITUDE1(9999),SPEED1(9999),RLONG(11),RLAT(11)
I,TD(11),PD(11),TTN(11),T(11)
I,LTT1,LSP1,LTT2,LSP2,LTT3,LSP3,LTT4,LSP4,LTT5,LSP5,LTT6,LSP6
I,LTT7,LSP7,LTT8,LSP8,LTT9,LSP9,LTT10,LSP10
I,A,B,X1,Y1,C1,P1,P2,P3,PP1,PP2,PP3,dlo(20000),dlo1(20000)
I,DLO2(20000)
I,L1SPD(10800),L2SPD(10800),L3SPD(10800)
I,L4SPD(10800),L5SPD(10800),L6SPD(10800)
I,L7SPD(10800),L8SPD(10800),L9SPD(10800),L10SPD(10800)
I,DIFTIME,diftime
I,Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,Z10
I,Z11,Z12,Z13,Z14,Z15,Z16,Z17,Z18,Z19,Z20
I,Z31,Z32,Z33,Z34,Z35,Z36,Z37,Z38,Z39,Z40
I,HDEN(10800),HDEN2(10800),HDEN3(10800)
I,GPShour(10800),GPSTIME(10800),DENH(10800)
I,RX(11),RY(11),RZ(11),X(10800),Y(10800),Z(10800)
I,DLAT1(10800),DLONG1(10800),DHEIGHT(10800),TN(10800)
INTEGER DENYEAR(10800),DENMONTH(10800),DENDATE(10800)
I,DENHOUR(10800),DENMINUTE(10800),DENSECOND(10800)
I,MOTH(13),I,NN(10)

```

```

C
C PART I EXTRACTING WEST BOUND LAST RUN DATA
C
C DO LOOP 5 TIMES DUE TO THERE ARE 5 INPUT FILES(5 VEHICLES)
DO NNNN=1,5
C FILE 1 = INPUT FILE
C FILE 10 AND 11 ARE OUTPUT FILES, THE REST ARE TEMP. FILES
INFILE(1)= "VEHICLE1.CSV"
INFILE(2)= "VEHICLE2.CSV"
INFILE(3)= "VEHICLE3.CSV"
INFILE(4)= "VEHICLE4.CSV"
INFILE(5)= "VEHICLE5.CSV"
OUTFILE1(1)= "1INST.CSV"
OUTFILE1(2)= "2INST.CSV"
OUTFILE1(3)= "3INST.CSV"

```

```

OUTFILE1(4)= "4INST.CSV"
OUTFILE1(5)= "5INST.CSV"
OUTFILE2(1)= "1LINK.CSV"
OUTFILE2(2)= "2LINK.CSV"
OUTFILE2(3)= "3LINK.CSV"
OUTFILE2(4)= "4LINK.CSV"
OUTFILE2(5)= "5LINK.CSV"
C OUTFILE3S ARE THE FILES THAT CONTAIN LINK SPEED, LINK TRAVEL
TIME,AND
C CLOCK TIME FROM PREVIOUS UPDATE. THE DATA FROM PREVIOUS
UPDATE WILL BE USED IF
C THE LINKS CONTAIN PARTIAL DATA.(FOR PRESENT RUN, LINK
TRAVEL TIME AND
C LINK SPEED WILL BE CALCULATED FOR ONLY FULL DATA LINKS.
OUTFILE3(1)= "P1LINK.txt"
OUTFILE3(2)= "P2LINK.txt"
OUTFILE3(3)= "P3LINK.txt"
OUTFILE3(4)= "P4LINK.txt"
OUTFILE3(5)= "P5LINK.txt"
TEMP1(1)= "1WBLAST.CSV"
TEMP1(2)= "2WBLAST.CSV"
TEMP1(3)= "3WBLAST.CSV"
TEMP1(4)= "4WBLAST.CSV"
TEMP1(5)= "5WBLAST.CSV"
TEMP2(1)= "1WBALLR.CSV"
TEMP2(2)= "2WBALLR.CSV"
TEMP2(3)= "3WBALLR.CSV"
TEMP2(4)= "4WBALLR.CSV"
TEMP2(5)= "5WBALLR.CSV"
TEMP3(1)= "1WBLRT.TXT"
TEMP3(2)= "2WBLRT.TXT"
TEMP3(3)= "3WBLRT.TXT"
TEMP3(4)= "4WBLRT.TXT"
TEMP3(5)= "5WBLRT.TXT"
OPEN(1,FILE = INFILE(NNNN))
OPEN(2,FILE = TEMP1(NNNN))
OPEN(3,FILE = TEMP2(NNNN))
OPEN(5,FILE = TEMP3(NNNN))
OPEN(10,FILE= OUTFILE1(NNNN))
OPEN(11,FILE= OUTFILE2(NNNN))
OPEN(12,FILE= OUTFILE3(NNNN))
C BELOW ARE LONG/LAT OF EACH NODE 1 = US40OFFRAMP,10 =
US60FFRAMP
RLONG(1)= -105647973
RLONG(2)= -105663047
RLONG(3)= -105696491
RLONG(4)= -105696940
RLONG(5)= -105724720
RLONG(6)= -105727350
RLONG(7)= -105803200
RLONG(8)= -105806990
RLONG(9)= -105855212
RLONG(10)= -105859695
RLONG(11)= -105885278
RLAT(1)= 39761.985
RLAT(2)= 39751.714

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RLAT(3) = 39717166
RLAT(4) = 39714134
RLAT(5) = 39695444
RLAT(6) = 39694400
RLAT(7) = 39693106
RLAT(8) = 39692285
RLAT(9) = 39701951
RLAT(10) = 39701809
RLAT(11) = 39685833
C (X,Y,Z)EARTH CENTERED EARTH-FIXED(ECEF) COORDINATES FOR
NODE I TO 11
RX(1)=-1324786.37064104;RY(1)=-4729559.25316836
RZ(1)=-4059279.00397136
RX(2)=-1326224.23709527;RY(2)=-4729901.04239826
RZ(2)=-4058449.37683902
RX(3)=-1329662.11125545;RY(3)=-4731535.96098373
RZ(3)=-4055540.11206678
RX(4)=-1329756.46763308;RY(4)=-4731729.35424924
RZ(4)=-4055278.15985105
RX(5)=-1332452.45330786;RY(5)=-4732511.69251608
RZ(5)=-4053811.28702252
RX(6)=-1332688.85773879;RY(6)=-4732518.60449557
RZ(6)=-4053719.28519985
RX(7)=-1339019.84667679;RY(7)=-4730987.26987959
RZ(7)=-4053736.98968364
RX(8)=-1339349.52256452;RY(8)=-4730957.79373987
RZ(8)=-4053669.45909586
RX(9)=-1343175.84205272;RY(9)=-4729283.3867963
RZ(9)=-4054594.17085953
RX(10)=-1343550.26335670;RY(10)=-4729199.70795796
RZ(10)=-4054587.01094864
RX(11)=-1345993.14559220;RY(11)=-4729757.83927683
RZ(11)=-4053285.58720716
C END OF REFERENCES LONG/LAT
C RESET ALL THE VALUES TO ZERO
DO I=1,9999
MOI(I)=0;REP(I)=0;LAT(I)=0;LO(I)=0;ALT(I)=0;SPE(I)=0
TMO(I)=0;TREP(I)=0;TLA(I)=0;TLO(I)=0;TALT(I)=0;TSPE(I)=0
MOI(I)=0;REP(I)=0;LAT(I)=0;LO(I)=0;ALT(I)=0;SPE(I)=0
L1SPD(I)=0.0;L2SPD(I)=0.0;L3SPD(I)=0.0;L4SPD(I)=0.0;L5SPD(I)=0.0
L6SPD(I)=0.0;L7SPD(I)=0.0;L8SPD(I)=0.0;L9SPD(I)=0.0;L10SPD(I)=0.0
L1R TIME(I)="" ;L2R TIME(I)="" ;L3R TIME(I)="" ;L4R TIME(I)=""
L5R TIME(I)="" ;L6R TIME(I)="" ;L7R TIME(I)="" ;L8R TIME(I)=""
L9R TIME(I)="" ;L10R TIME(I)="" ;MOI(I)=0.0; repone1(I)=0
END DO

READ(1,*)JMOID,IREP TIME,ILAT,ILONG,IALT,ISPEED
C PART II
C INPUT DATA WERE FILTERED TO OBTAIN
C LONG/LAT IN STUDY AREA, AND TO DISTINGUISH WB FROM
C WB,EB
M=0
k=0
DO I=1,20000
READ(1,*,END=24)MOI(I),REP(I),LAT(I),LO(I),ALT(I),SPE(I)
c Line below will be used if PosFixTime is constant (Vehicle is
c not moving), the number of seconds equal to report interval will
c be added to PosFixTime. If report interval change, this need to
c be changed as well. Currently, set to 5 seconds.
if (rep(I).eq. rep(I-1)) then
rep1(I)=rep1(I-1)+5.0
else
rep1(I)=rep(I)-rep(I-1)
end if
diff1(I)=rep1(I)-rep1(I-1)
if ((diff1(I).LT.0.0).AND. diff1(I).LT.0.0 .AND. DLO2(I).LT.0) THEN
WRITE(3,25)MOI(I),REP1(I),LAT(I),LO(I),ALT(I),SPE(I)
M=M+1
20 END IF
ENDIF
END IF
24 END DO
25 FORMAT(6(F14.3,","))
C FILE 3 CONTAINS WB DATA FOR ALL RUN
C BELOW IS TO OBTAIN TMO-WB ONLY LAST TRIP
NEWRUN=1
REWIND(3)
DO I=1,M
READ(3,*,END=27)TMO(I),TREP(I),TLA(I),TLO(I),TALT(I),TSPE(I)
TREP(I)=0
DIFTIME=TREP(I)-TREP(I-1)
c diffime below is the time between runs IN ORDER TO GET ONLY LAST RUN
C
IF (DIFTIME .GT. 1500 .AND. TLO(I) .LE. TLO(I-1)) THEN
NEWRUN=1
END IF
IF (TLO(I) .GE. TLO(I-1)) THEN
NEWRUN=1
END IF
MOI(I)=TMO(I)
REPTIME(I)=TREP(I)
LAT(I)=TLA(I)
LONG(I)=TLO(I)
ALTITUDE(I)=TALT(I)
SPEED(I)=TSPE(I)
27 ENDDO
REWIND(3)
C
N1=0;N2=0;N3=0;N4=0;N5=0;N6=0;N7=0;N8=0;N9=0;N10=0
NN(1)=0;NN(2)=0;NN(3)=0;NN(4)=0;NN(5)=0;NN(6)=0
NN(7)=0;NN(8)=0;NN(9)=0;NN(10)=0
DO J=NEWRUN,M
c GROUPING THE DATA TO EACH LINK (WITHIN THE BLOCK)
C LINK 1 US40 OFF-RAMP AND US40 ON-RAMP
IF ((LONG1(I)-RLONG(2)).GE. 0) .AND. (LONG1(I)-RLONG(1) .LE. 0)) then
WRITE(2,25)MOI1(I),REPTIME1(I),LAT1(I),LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N1=N1+1
END IF
C LINK 2 US40 ON-RAMP AND GEORGETOWN OFF-RAMP
IF ((LONG1(I) .LE. RLONG(2)) .AND. (LAT1(I) .GE. RLAT(3))) THEN
WRITE(2,25)MOI1(I),REPTIME1(I),LAT1(I),LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N2=N2+1
END IF
C LINK 3 GEORGETOWN OFF-RAMP AND ON-RAMP

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IF ((LAT1(I) LE RLAT(3)) AND (LAT1(I) GE RLAT(4))) THEN
WRITE(2,25)MOD1(I), REPTIME1(I), LAT1(I), LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N3=N3+1
END IF
C LINK 4 GEORGETOWN ON-RAMP AND SILVER PLUME OFF-RAMP
IF ((LAT1(I) LE RLAT(4)) AND (LONG1(I) GE RLONG(5))) THEN
WRITE(2,25)MOD1(I), REPTIME1(I), LAT1(I), LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N4=N4+1
END IF
C LINK 5 SILVER PLUME OFF-RAMP AND ON-RAMP
IF ((LONG1(I) LE RLONG(5)) AND (LONG1(I) GE RLONG(6))) THEN
WRITE(2,25)MOD1(I), REPTIME1(I), LAT1(I), LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N5=N5+1
END IF
C LINK 6 SILVER PLUME ON-RAMP AND BAKERVILLE OFF-RAMP
IF ((LONG1(I) LE RLONG(6)) AND (LONG1(I) GE RLONG(7))) THEN
WRITE(2,25)MOD1(I), REPTIME1(I), LAT1(I), LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N6=N6+1
END IF
C LINK 7 BAKERVILLE OFF-RAMP AND ON-RAMP
IF ((LONG1(I) LE RLONG(7)) AND (LONG1(I) GE RLONG(8))) THEN
WRITE(2,25)MOD1(I), REPTIME1(I), LAT1(I), LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N7=N7+1
END IF
C LINK 8 BAKERVILLE ON-RAMP AND HERMAN GLUCH OFF-RAMP
IF ((LONG1(I) LE RLONG(8)) AND (LONG1(I) GE RLONG(9))) THEN
WRITE(2,25)MOD1(I), REPTIME1(I), LAT1(I), LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N8=N8+1
END IF
C LINK 9 HERMAN GLUCH OFF-RAMP AND ON-RAMP
IF ((LONG1(I) LE RLONG(9)) AND (LONG1(I) GE RLONG(10))) THEN
WRITE(2,25)MOD1(I), REPTIME1(I), LAT1(I), LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N9=N9+1
END IF
C LINK 10 HERMAN GLUCH ON-RAMP AND US6
IF ((LONG1(I) LE RLONG(10)) AND (LONG1(I) GE RLONG(11))) THEN
WRITE(2,25)MOD1(I), REPTIME1(I), LAT1(I), LONG1(I)
1,ALTITUDE1(I),SPEED1(I)
N10=N10+1
END IF
K = MAX(N1,N2,N3,N4,N5,N6,N7,N8,N9,N10)
NN(1) = N1
NN(2) = NN(1)+N2
NN(3) = NN(2)+N3
NN(4) = NN(3)+N4
NN(5) = NN(4)+N5
NN(6) = NN(5)+N6
NN(7) = NN(6)+N7
NN(8) = NN(7)+N8
NN(9) = NN(8)+N9
NN(10) = NN(9)+N10
C NN1 = NUMBER OF POINTS AT END OF LINK 1, NN2=END OF LINK2
END DO
REWIND(2)
C ABOVE=> WB DATA FOR LAST RUN WERE SAVED IN FILE 2

```

```

C -----
C PART II CONVERT GPSTIME TO DENVER TIME
C -----
IF (NN(10) EQ 0) THEN
GOTO 200
END IF
DO I = 1, NN(10)
READ(2,*,END=30)MOD(I),REP(I),LAT(I),LONG(I),ALT(I),SPE(I)
END DO
C # OF SECONDS TO 01/01/97 12:00:00AM+7HRS. = 536137200 SEC OR
148927HRS.
c Day Light saving: between 1st sunday of April and last sunday of October
c add another 1 hour.
30 DO I = 1, NN(10)
GPSTIME(I) = REP(I)
GPSHOUR(I) = GPSTIME(I)/3600-148927
N = 0
MN = 0
M = 0
DO II = 8760,999999,8760
N = N+1
DENH(I) = II
DO III = 0.9999,4
IF (N EQ III) THEN
DENH(I) = II+24
END IF
END DO
IF (DENH(I) LT GPSHOUR(I)) THEN
MN = MN+1
ELSE
GOTO 32
END IF
DEN(I) = DENH(I)
END DO
32 DENYEAR(I) = 1997+MN
HIDEN(1) = GPSHOUR(I)-DEN(I)
C DENYEAR DEFINES YEAR
C HIDEN2 = # OF HOURS(MAX. = # OF OUR IN THAT YEAR)
DO IK = 1,MN,4
IF (IK EQ MN) THEN
M = 1
ELSE
M = 0
END IF
END DO
C IF M = 1 INDICATES LEAP YEAR(366 DAYS A YEAR)
IF (M EQ 0) THEN
MOTH(0) = 0.0
MOTH(1) = 744.0
MOTH(2) = 1416.0
MOTH(3) = 2160.0
MOTH(4) = 2880.0
MOTH(5) = 3624.0
MOTH(6) = 4344.0
MOTH(7) = 5088.0
MOTH(8) = 5832.0
MOTH(9) = 6552.0
MOTH(10) = 7296.0
MOTH(11) = 8016.0
MOTH(12) = 8760.0
ENDIF
IF (M EQ 1) THEN

```

```

MOTH(0) = 0.0
MOTH(1) = 744.0
MOTH(2) = 1440.0
MOTH(3) = 2184.0
MOTH(4) = 2904.0
MOTH(5) = 3648.0
MOTH(6) = 4368.0
MOTH(7) = 5112.0
MOTH(8) = 5856.0
MOTH(9) = 6576.0
MOTH(10) = 7320.0
MOTH(11) = 8040.0
MOTH(12) = 8784.0
END IF
DO L = 1,12
DENMONTH(I) = L
IF (HIDEN2(I) .LT. MOTH(L)) THEN
GOTO 34
END IF
END DO
C HIDEN3 = # OF HOURS IN THAT MONTH(MAX = #OF DAY IN THAT
MONTH*24)
34 N = DENMONTH(I)-1
HIDEN3(I) = HIDEN2(I)-MOTH(N)
DENDATE(I) = INT((HIDEN3(I)/24)+1)
DENTHOUR(I) = INT((HIDEN3(I)+24-DENDATE(I)*24)
DENMINUTE(I) = INT(((HIDEN3(I)-DENDATE(I)*24+24)-DENTHOUR(I))*60)
DENSECOND(I) = INT((((HIDEN3(I)-DENDATE(I)*24+24)-DENTHOUR(I))*60
-DENMINUTE(I))*60)
c Add 1 hour due to daylight saving
if (denmonth(i) .eq. 4 .and. denyyear(i) .lt. 10) then
denhour(i) = denhour(i)+1
end if
if (denyyear(i) .eq. 2000) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 2) then
denhour(i) = denhour(i)-1
end if
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 29) then
denhour(i) = denhour(i)-1
end if
end if
c
if (denyyear(i) .eq. 2001) then
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 28) then
denhour(i) = denhour(i)-1
end if
end if
c
if (denyyear(i) .eq. 2002) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 7) then
denhour(i) = denhour(i)-1
end if
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 27) then
denhour(i) = denhour(i)-1
end if
end if
.
if (denyyear(i) .eq. 2003) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 6) then
denhour(i) = denhour(i)-1
end if
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 26) then
denhour(i) = denhour(i)-1
end if
end if
if (denyyear(i) .eq. 2004) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 4) then
denhour(i) = denhour(i)-1
end if
end if
.
if (denyyear(i) .eq. 2005) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 3) then
denhour(i) = denhour(i)-1
end if
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 30) then
denhour(i) = denhour(i)-1
end if
end if
c
if (denyyear(i) .eq. 2006) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 2) then
denhour(i) = denhour(i)-1
end if
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 29) then
denhour(i) = denhour(i)-1
end if
end if
c
if (denyyear(i) .eq. 2007) then
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 28) then
denhour(i) = denhour(i)-1
end if
end if
C
if (denyyear(i) .eq. 2008) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 6) then
denhour(i) = denhour(i)-1
end if
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 26) then
denhour(i) = denhour(i)-1
end if
end if
C
if (denyyear(i) .eq. 2009) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 5) then
denhour(i) = denhour(i)-1
end if
if (denmonth(i) .eq. 10 .and. denydate(i) .gt. 25) then
denhour(i) = denhour(i)-1
end if
end if
C
if (denyyear(i) .eq. 2010) then
if (denmonth(i) .eq. 4 .and. denydate(i) .lt. 4) then
denhour(i) = denhour(i)-1
end if
end if
C
denhour(i) = denhour(i)
IF (DENMONTH(I) .LT. 10) THEN
WRITE(5,35) MON(I), REP(I), LA(I), LO(I), ALT(I), SPE(I), DENMONTH(I)
1, DENDATE(I), DENYEAR(I), DENTHOUR(I), DENMINUTE(I), DENSECOND(I)

```

```

35 FORMAT(T1,F5.0,T10,F14.3,T25,F14.3,T41,F14.3,T56,F10.2,T70,F10.3
1,T81,I1,"",T83,I2,"",T86,I4,T91,I2,"",T94,I2,"",T97,I2)
ENDIF
IF (DENMONTH(I).GE. 10) THEN
WRITE(5,36)MO(I),REP(I),LA(I),LO(I),ALT(I),SPE(I),DENMONTH(I)
1,DENDATE(I),DENYEAR(I),DENHOUR(I)
1,DENMINUTE(I),DENSECOND(I)
36 FORMAT(T1,F5.0,T10,F14.3,T25,F14.3,T41,F14.3,T56,F10.2,T70,F10.3
1,T81,I2,"",T84,I2,"",T87,I4,T92,I2,"",T95,I2,"",T98,I2)
ENDIF
ENDDO
C END OF TIME CONVERTING:WB LAST RUN DATA WITH DENVER TIME
WERE SEVED IN FILE 5

```

```

C
C =====
C PART III COMPUTE LINK TRAVEL TIME AND LINK SPEED
C =====

```

```

C NODE 1=US40 AND NODE 11=US6
REWIND(5)
DO I= 1,NN(10)
READ(5,49)END=50,MOID(1),REP TIME(1),LAT(1),LONG(1)
1,ALTITUDE(1),SPEED(1),REAL TIME(1)
49 FORMAT(T1,F5.0,T10,F14.3,T25,F14.3,T41,F14.3,T56,F10.2,T70,F10.3
1,T81,A25)
ENDDO

```

```

C CONVERTING LONG, LAT TO X, Y, Z(METERS)
DO I= 1,NN(10)
DLAT(I)= LAT(I)*3.141592654/180/1000000
DLONG(I)= LONG(I)*3.141592654/180/1000000
DHEIGHT(I)= ALTITUDE(I)/100.0
TN(I)= 6378137.0*(SQRT((1-0.0818**2)*SIN(DLAT(I))**2))
X(I)= (TN(I)+DHEIGHT(I))*COS(DLAT(I))*COS(DLONG(I))
Y(I)= (TN(I)+DHEIGHT(I))*COS(DLAT(I))*SIN(DLONG(I))
Z(I)= (TN(I)*(1-0.0818**2)+DHEIGHT(I))*SIN(DLAT(I))
ENDDO

```

```

C CONVERTING INSTANTANBOUS SPEED FROM CM/S TO MPH

```

```

IF (NN(1) .NE. 0) THEN
50 DO I= 1,NN(1)
L1SPD(I)= SPEED(1(I))*3600/160934.4
L1RTIME(I)= REAL TIME(I)
ENDDO
ENDIF
IF (NN(2) .NE. 0) THEN
DO I= NN(1)+1, NN(2)
L2SPD(I)= SPEED(1(I))*3600/160934.4
L2RTIME(I)= REAL TIME(I)

```

```

ENDDO
ENDIF
IF (NN(3) .NE. 0) THEN
DO I= NN(2)+1, NN(3)
L3SPD(I)= SPEED(1(I))*3600/160934.4
L3RTIME(I)= REAL TIME(I)

```

```

ENDDO
ENDIF
IF (NN(4) .NE. 0) THEN
DO I= NN(3)+1, NN(4)
L4SPD(I)= SPEED(1(I))*3600/160934.4
L4RTIME(I)= REAL TIME(I)

```

```

ENDDO
ENDIF
IF (NN(5) .NE. 0) THEN
DO I= NN(4)+1, NN(5)
L5SPD(I)= SPEED(1(I))*3600/160934.4

```

```

L5RTIME(I)= REAL TIME(I)
ENDDO
ENDIF
IF (NN(6) .NE. 0) THEN
DO I= NN(5)+1, NN(6)
L6SPD(I)= SPEED(1(I))*3600/160934.4
L6RTIME(I)= REAL TIME(I)

```

```

ENDDO
ENDIF
IF (NN(7) .NE. 0) THEN
DO I= NN(6)+1, NN(7)
L7SPD(I)= SPEED(1(I))*3600/160934.4
L7RTIME(I)= REAL TIME(I)

```

```

ENDDO
ENDIF
IF (NN(8) .NE. 0) THEN
DO I= NN(7)+1, NN(8)
L8SPD(I)= SPEED(1(I))*3600/160934.4
L8RTIME(I)= REAL TIME(I)

```

```

ENDDO
ENDIF
IF (NN(9) .NE. 0) THEN
DO I= NN(8)+1, NN(9)
L9SPD(I)= SPEED(1(I))*3600/160934.4
L9RTIME(I)= REAL TIME(I)

```

```

ENDDO
ENDIF
IF (NN(10) .NE. 0) THEN
DO I= NN(9)+1, NN(10)
L10SPD(I)= SPEED(1(I))*3600/160934.4
L10RTIME(I)= REAL TIME(I)

```

```

ENDDO
ENDIF

```

```

C OUTPUT INSTANTANEOUS SPEED FOR EACH LINK

```

```

WRITE(10,51)MOID,"NO.1","LINK 1 TIME","US40(OFF)-US40(ON)"
1,"NO.2","LINK2 TIME","US40(ON)-GEORGE TOWN(OFF)"
1,"NO.3","LINK3 TIME","GEORGE TOWN(OFF)-GEORGE TOWN(ON)"
1,"NO.4","LINK4 TIME","GEORGE TOWN(ON)-SILVER PLUME(OFF)"
1,"NO.5","LINK5 TIME","SILVER PLUME(OFF)-SILVER PLUME(ON)"
1,"NO.6","LINK6 TIME","SILVER PLUME(ON)-BAKERVILLE(OFF)"
1,"NO.7","LINK7 TIME","BAKERVILLE(OFF)-BAKERVILLE(ON)"
1,"NO.8","LINK8 TIME","BAKERVILLE(ON)-HERMAN GLUCH(OFF)"
1,"NO.9","LINK9 TIME","HERMAN GLUCH(OFF)-HERMAN GLUCH(ON)"
1,"NO.10","LINK 10 TIME","HERMAN GLUCH(ON)-US6(OFF)"
1,"US40(OFF)-RAMPF"

```

```

51 FORMAT(31(A,"",),A)
DO I= 1,K
I1= NN(1)+I
I2= NN(2)+I
I3= NN(3)+I
I4= NN(4)+I
I5= NN(5)+I
I6= NN(6)+I
I7= NN(7)+I
I8= NN(8)+I
I9= NN(9)+I
I10= NN(10)+I
WRITE(10,52)MOID(1),L1RTIME(I),L1SPD(I)
1,I1,L2RTIME(I),L2SPD(I)
1,I2,L3RTIME(I),L3SPD(I)
1,I3,L4RTIME(I),L4SPD(I)
1,I4,L5RTIME(I),L5SPD(I)

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1,15,L6R TIME(15),L6SPD(15)
1,16,L7R TIME(16),L7SPD(16)
1,17,L8R TIME(17),L8SPD(17)
1,18,L9R TIME(18),L9SPD(18)
1,19,L10R TIME(19),L10SPD(19)
52 FORMAT(F14.3,10(' ',J10,'A,"AMPM",',F14.3))
END DO

C CALCULATE TIME FOR EACH NODE BY INTERPOLATION
C TD2 = TOTAL DISTANCE BET. GPS LOCATION BEFORE AND AFTER
NODE1 → NODE2
C PD2 = DISTANCE BET. GPS BEFORE NODE2 AND NODE2
C TTN2 = TIME BETWEEN GPS BEFORE NODE2 AND NODE2

P1=0
P2=0
P3=0

C NODE 1 AND NODE 11 ARE CALCULATED BY EXTRAPOLATION
TD(1)=SQRT((X(2)-X(1))**2+(Y(2)-Y(1))**2+(Z(2)-Z(1))**2)
A=(X(NN(10))-X(NN(10)-1))**2
B=(Y(NN(10))-Y(NN(10)-1))**2
C=(Z(NN(10))-Z(NN(10)-1))**2
TD(11)=SQRT(A+B+C)
IF (LONG1(NN(10)) EQ. 0) THEN
  TD(11)=0
ENDIF

C PD1 = DISTANCE FROM NODE 1 (US400FRAMP) TO FIRST POINT
C TD1 = DISTANCE BETWEEN 1ST AND 2ND POINTS OF GPS DATA
PD(1)=SQRT((RX(1)-X(1))**2+(RY(1)-Y(1))**2+(RZ(1)-Z(1))**2)
PP1=(RX(1)-X(NN(10)))**2
PP2=(RY(1)-Y(NN(10)))**2
PP3=(RZ(1)-Z(NN(10)))**2
PD(11)=SQRT(PP1+PP2+PP3)
IF (LONG1(NN(10)) EQ. 0) THEN
  PD(11)=0
ENDIF

TTN(1)=(REPTIME1(2)-REPTIME1(1))*PD(1)/TD(1)
TTN(11)=(REPTIME1(NN(10))-REPTIME1(NN(10)-1))*PD(11)/TD(11)
IF (TD(11) EQ. 0) THEN
  TTN(11)=0
ENDIF

C END EXTRAPOLATION OF NODES 1 AND 11
DO I = 1,9
  IF (NN(I+1) NE. NN(I)) THEN
C *** IF THAT LINK CONTAINS FULL DATA ⇒ LINK TT AND LINK SPEED
WILL BE CALCULATED
  X1=(X(NN(I)+1)-X(NN(I)))**2
  Y1=(Y(NN(I)+1)-Y(NN(I)))**2
  C1=(Z(NN(I)+1)-Z(NN(I)))**2
  TD(I+1)=SQRT(X1+Y1+C1)
  P1=(RX(I+1)-X(NN(I)))**2
  P2=(RY(I+1)-Y(NN(I)))**2
  P3=(RZ(I+1)-Z(NN(I)))**2
  PD(I+1)=SQRT(P1+P2+P3)
  IF (LONG1(NN(I)) EQ. 0 OR LAT1(NN(I)) EQ. 0) THEN
    PD(I+1)=0
  ENDIF
  TTN(I+1)=(REPTIME1(NN(I)+1)-REPTIME1(NN(I)))*PD(I+1)/TD(I+1)
  IF (PD(I+1) EQ. 0 OR TD(I+1) EQ. 0) THEN
    TTN(I+1)=0
  ENDIF
ENDIF
C
ENDDO

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READ (12,57)Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,Z10
READ (12,57)Z11,Z12,Z13,Z14,Z15,Z16,Z17,Z18,Z19,Z20
READ (12,58)Z21,Z22,Z23,Z24,Z25,Z26,Z27,Z28,Z29,Z30
READ (12,59)Z31,Z32,Z33,Z34,Z35,Z36,Z37,Z38,Z39,Z40
57 FORMAT(10(F7.3))
58 FORMAT(10(A19))
59 FORMAT(10(F14.3))
REWIND(12)
CLOSE(12)

C ⇒ END INTERPOLATION ⇒ LINK CONTAINS PARTIAL DATA -LINKTT
AND LINK SPEED
C ⇒ WILL BE SET TO ZERO

DO J = 2,11
  T(J)=REPTIME1(NN(J-1))+TTN(J)
ENDIF

IF (PD(1) GE. 1000) THEN
  T(1)=0
ELSE
  T(1)=REPTIME1(1)-TTN(1)
ENDIF

C IF THERE IS NO DATA ON THAT LINK T(N) = T(N-1), LTT AND LSP = 0
C LTT = LINK TRAVEL TIME(MINUTES), LSP = LINK SPEED(MPH)
IF (NN(1) NE. 0) THEN
  IF (NN(1) NE. 0 AND NN(2) GT. NN(1)) THEN
    IF (T(1) NE. 0 AND T(2) NE. 0) THEN
      IF (T(1) NE. 0) THEN
        LTT1=(T(2)-T(1))/60
        LSP1=(5843.428/5280)/LTT1*60
      ENDIF
    ELSE
      LTT1 = Z1
      LSP1 = Z11
      L1R TIME(NN(1)) = Z21
      REPTIME1(NN(1)) = Z31
    ENDIF
  ENDIF

C
  IF (NN(2) NE. 0) THEN
    IF (NN(2) GT. NN(1) AND NN(3) GT. NN(2)) THEN
      IF (T(2) NE. 0 AND T(3) NE. 0) THEN
        LTT2=(T(3)-T(2))/60
        LSP2=(16725.59/5280)/LTT2*60
      ENDIF
    ELSE
      LTT2=Z2
      LSP2=Z12
      L2R TIME(NN(2)) = Z22
      REPTIME1(NN(2)) = Z32
    ENDIF
  ENDIF

C
  IF (NN(3) NE. 0) THEN
    IF (NN(3) GT. NN(2) AND NN(4) GT. NN(3)) THEN
      IF (T(3) NE. 0 AND T(4) NE. 0) THEN
        LTT3=(T(4)-T(3))/60
        LSP3=(1139.125/5280)/LTT3*60
      ENDIF
    ELSE
      LTT3=Z3
      LSP3=Z13
      L3R TIME(NN(3)) = Z23
    ENDIF
  ENDIF

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REPTIME1(NN(3)) = Z33
END IF
END IF
C
IF (NN(4) .NE. 0) THEN
IF (NN(4) .GT. NN(3) AND. NN(5) .GT. NN(4)) THEN
  if (tm(4) .ne. 0 and. tm(5) .ne. 0) then
    LTT4 = (T(5)-T(4))/60
    LSP4 = (11158.396/5280)/LTT4*60
  END if
ELSE
  LTT4 = Z4
  LSP4 = Z14
  LAR TIME(NN(4)) = Z24
REPTIME1(NN(4)) = Z34
END IF
END IF
C
IF (NN(5) .NE. 0) THEN
IF (NN(5) .GT. NN(4) AND. NN(6) .GT. NN(5)) THEN
  if (tm(5) .ne. 0 and. tm(6) .ne. 0) then
    LTT5 = (T(6)-T(5))/60
    LSP5 = (838.457/5280)/LTT5*60
  END if
ELSE
  LTT5 = Z5
  LSP5 = Z15
  LSR TIME(NN(5)) = Z25
REPTIME1(NN(5)) = Z35
END IF
END IF
C
IF (NN(6) .NE. 0) THEN
IF (NN(6) .GT. NN(5) AND. NN(7) .GT. NN(6)) THEN
  if (tm(6) .ne. 0 and. tm(7) .ne. 0) then
    LTT6 = (T(7)-T(6))/60
    LSP6 = (21776.219/5280)/LTT6*60
  END if
ELSE
  LTT6 = Z6
  LSP6 = Z16
  LGR TIME(NN(6)) = Z26
REPTIME1(NN(6)) = Z36
END IF
END IF
C
IF (NN(7) .NE. 0) THEN
IF (NN(7) .GT. NN(6) AND. NN(8) .GT. NN(7)) THEN
  if (tm(7) .ne. 0 and. tm(8) .ne. 0) then
    LTT7 = (T(8)-T(7))/60
    LSP7 = (1134.646/5280)/LTT7*60
  END if
ELSE
  LTT7 = Z7
  LSP7 = Z17
  L7R TIME(NN(7)) = Z27
REPTIME1(NN(7)) = Z37
END IF
END IF
C
IF (NN(8) .NE. 0) THEN
IF (NN(8) .GT. NN(7) AND. NN(9) .GT. NN(8)) THEN
    if (tm(8) .ne. 0 and. tm(9) .ne. 0) then
      LTT8 = (T(9)-T(8))/60
      LSP8 = (14421.616/5280)/LTT8*60
    END if
    ELSE
      LTT8 = Z8
      LSP8 = Z18
      L8R TIME(NN(8)) = Z28
      REPTIME1(NN(8)) = Z38
    END IF
    END IF
  C
  IF (NN(9) .NE. 0) THEN
  IF (NN(9) .GT. NN(8) AND. NN(10) .GT. NN(9)) THEN
    if (tm(9) .ne. 0 and. tm(10) .ne. 0) then
      LTT9 = (T(10)-T(9))/60
      LSP9 = (1267.546/5280)/LTT9*60
    END if
    ELSE
      LTT9 = Z9
      LSP9 = Z19
      L9R TIME(NN(9)) = Z29
      REPTIME1(NN(9)) = Z39
    END IF
    END IF
  C
  IF (NN(10) .NE. 0) THEN
  IF (NN(10) .GT. NN(9) AND. NN(9) .GT. NN(8)) THEN
    if (tm(10) .ne. 0 and. tm(11) .ne. 0) then
      LTT10 = (T(11)-T(10))/60
      LSP10 = (9156.001/5280)/LTT10*60
    END if
    ELSE
      LTT10 = Z10
      LSP10 = Z20
      L10R TIME(NN(10)) = Z30
      REPTIME1(NN(10)) = Z40
    END IF
    END IF
    IF LINK TRAVEL TIME FROM PREVIOUS RUN EQUALS TO ZERO THEN
  C SET IT EQUAL TO DATA FROM PREVIOUS RUN
  IF (LTT1 .EQ. 0 AND. NN(1) .NE. 0) THEN
    LTT1 = Z1
    LSP1 = Z11
    L1R TIME(NN(1)) = Z21
  END IF
  IF (LTT2 .EQ. 0 AND. NN(1) .NE. 0) THEN
    LTT2 = Z2
    LSP2 = Z12
    L2R TIME(NN(2)) = Z22
  END IF
  IF (LTT3 .EQ. 0 AND. NN(1) .NE. 0) THEN
    LTT3 = Z3
    LSP3 = Z13
    L3R TIME(NN(3)) = Z23
  END IF
  IF (LTT4 .EQ. 0 AND. NN(1) .NE. 0) THEN
    LTT4 = Z4
    LSP4 = Z14
    L4R TIME(NN(4)) = Z24
  END IF
  IF (LTT5 .EQ. 0 AND. NN(1) .NE. 0) THEN

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LTT5=Z5
LSP5=Z15
L5R TIME(NN(5)) = Z25
END IF
IF (LTT6.EQ. 0.AND. NN(1).NE. 0) THEN
LTT6=Z6
LSP6=Z16
L6R TIME(NN(6)) = Z26
END IF
IF (LTT7.EQ. 0.AND. NN(1).NE. 0) THEN
LTT7=Z7
LSP7=Z17
L7R TIME(NN(7)) = Z27
END IF
IF (LTT8.EQ. 0.AND. NN(1).NE. 0) THEN
LTT8=Z8
LSP8=Z18
L8R TIME(NN(8)) =Z28
END IF
IF (LTT9.EQ. 0.AND. NN(1).NE. 0) THEN
LTT9=Z9
LSP9=Z19
L9R TIME(NN(9))= Z29
END IF
IF (LTT10.EQ. 0.AND. NN(1).NE. 0) THEN
LTT10=Z10
LSP10=Z20
L10R TIME(NN(10))=Z30
END IF
C *****OUTPUT*****
C NODE 1=US40OFF,NODE 11=US60OFF
60 FORMAT(11,F15.3,"")
70 FORMAT(10,"",F15.3)
WRITE(11,80)"TIME US40-US6","US40(OFF)-US40(ON)"
1,"US40(ON)-GRG TWN(OFF)"
1,"GRG TWN(OFF)-GRG TWN(ON)"
1,"GRGE TWN(ON)-SLVR PLM(OFF)"
1,"SLVR PLM(OFF)-SLVR PLM(ON)"
1,"SLVR PLM(ON)-BKRVLL(OFF)"
1,"BKRVLL(OFF)-BKRVLL(ON)"
1,"BKRVLL(ON)-HRMN GLCH(OFF)"
1,"HRMN GLCH(OFF)-HRMN GLCH(ON)"
1,"HRMN GLCH(ON)-US6(OFF)"
80 FORMAT(A,10,"",A)
90 FORMAT(9(A25,"AMPM",""),A25,"AMPM")
DO I= 1,10
IF (NN(I).EQ. 0) THEN
NN(I)=1
L1R TIME(I)= '00/0000 00:00:00'
L2R TIME(I)= '00/0000 00:00:00'
L3R TIME(I)= '00/0000 00:00:00'
L4R TIME(I)= '00/0000 00:00:00'
L5R TIME(I)= '00/0000 00:00:00'
L6R TIME(I)= '00/0000 00:00:00'
L7R TIME(I)= '00/0000 00:00:00'
L8R TIME(I)= '00/0000 00:00:00'
L9R TIME(I)= '00/0000 00:00:00'
L10R TIME(I)= '00/0000 00:00:00'
REPTIME1(I)=0
END IF
END DO
WRITE(11,70)LTT1,LTT2,LTT3,LTT4,LTT5,LTT6,LTT7,LTT8,LTT9,LTT10
WRITE(11,70)LSP1,LSP2,LSP3,LSP4,LSP5,LSP6,LSP7,LSP8,LSP9,LSP10
WRITE(11,(A,"AMPM"))L1R TIME(NN(1))
WRITE(11,(A,"AMPM"))L2R TIME(NN(2))
WRITE(11,(A,"AMPM"))L3R TIME(NN(3))
WRITE(11,(A,"AMPM"))L4R TIME(NN(4))
WRITE(11,(A,"AMPM"))L5R TIME(NN(5))
WRITE(11,(A,"AMPM"))L6R TIME(NN(6))
WRITE(11,(A,"AMPM"))L7R TIME(NN(7))
WRITE(11,(A,"AMPM"))L8R TIME(NN(8))
WRITE(11,(A,"AMPM"))L9R TIME(NN(9))
WRITE(11,(A,"AMPM"))L10R TIME(NN(10))
open (12, file=outfile3(unnn))
WRITE(12,57)LTT1,LTT2,LTT3,LTT4,LTT5,LTT6,LTT7,LTT8,LTT9,LTT10
WRITE(12,57)LSP1,LSP2,LSP3,LSP4,LSP5,LSP6,LSP7,LSP8,LSP9,LSP10
WRITE(12,58)L1R TIME(NN(1)),L2R TIME(NN(2))
1,L3R TIME(NN(3)),L4R TIME(NN(4)),L5R TIME(NN(5))
1,L6R TIME(NN(6)),L7R TIME(NN(7)),L8R TIME(NN(8))
1,L9R TIME(NN(9)),L10R TIME(NN(10))
WRITE(12,59)REPTIME1(NN(1)),REPTIME1(NN(2))
1,REPTIME1(NN(3)),REPTIME1(NN(4)),REPTIME1(NN(5))
1,REPTIME1(NN(6)),REPTIME1(NN(7)),REPTIME1(NN(8))
1,REPTIME1(NN(9)),REPTIME1(NN(10))
95 FORMAT(9(F7.3,""),F7.3)
96 FORMAT(9(A19,""),A19)
97 FORMAT(9(F14.3,""),F14.3)
100 FORMAT(9(A18),A18)
CLOSE(2,STATUS='delete')
CLOSE(3,STATUS='delete')
CLOSE(5,STATUS='delete')
REWIND(1)
REWIND(10)
REWIND(11)
REWIND(12)
CLOSE(1)
CLOSE(10)
CLOSE(11)
close(12)
c close(15)
200 end do
CALL SMS()
C ABOVE END DO IS FOR THE LOOP TO READ 5 INPUT FILES VEHICLE1-5.CSV
END PROGRAM
c SUBROUTINE SMS BELOW IS TO CALCULATE SPACE MEAN SPEED IN CASE MORE THAN 1 VEHICLE EXIST
C ON THAT LINK WITHIN 15 MINUTES
SUBROUTINE SMS()
DOUBLE PRECISION TIME(5,10),SPD(5,10),GTIME(5,10),DD(10)
1,ATTIME(10),ASPEED(10),LASTRUN(10),TTIME(10),N(10),spd(10)
CHARACTER RTIME(5,10)*19,IRTIME(10)*19
OPEN (20, FILE = "PILNK.txt")
READ (20,110)TIME(1,1),TIME(1,2),TIME(1,3),TIME(1,4)
1,TIME(1,5),TIME(1,6),TIME(1,7),TIME(1,8),TIME(1,9)
1,TIME(1,10)
READ (20,110)SPD(1,1),SPD(1,2),SPD(1,3),SPD(1,4),SPD(1,5)
1,SPD(1,6),SPD(1,7),SPD(1,8),SPD(1,9),SPD(1,10)
READ (20,120)RTIME(1,1),RTIME(1,2),RTIME(1,3),RTIME(1,4)
1,RTIME(1,5),RTIME(1,6),RTIME(1,7),RTIME(1,8),RTIME(1,9)
1,RTIME(1,10)
READ (20,130)GTIME(1,1),GTIME(1,2),GTIME(1,3),GTIME(1,4)
1,GTIME(1,5),GTIME(1,6),GTIME(1,7),GTIME(1,8),GTIME(1,9)
1,GTIME(1,10)

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C
OPEN (21, FILE = "P2LNK.txt")
READ (21,110)TIME(2,1),TIME(2,2),TIME(2,3),TIME(2,4)
1,TIME(2,5),TIME(2,6),TIME(2,7),TIME(2,8),TIME(2,9)
1,TIME(2,10)
READ (21,110)SPD(2,1),SPD(2,2),SPD(2,3),SPD(2,4),SPD(2,5)
1,SPD(2,6),SPD(2,7),SPD(2,8),SPD(2,9),SPD(2,10)
READ (21,120)R.TIME(2,1),R.TIME(2,2),R.TIME(2,3),R.TIME(2,4)
1,R.TIME(2,5),R.TIME(2,6),R.TIME(2,7),R.TIME(2,8),R.TIME(2,9)
1,R.TIME(2,10)
READ (21,130)G.TIME(2,1),G.TIME(2,2),G.TIME(2,3),G.TIME(2,4)
1,G.TIME(2,5),G.TIME(2,6),G.TIME(2,7),G.TIME(2,8),G.TIME(2,9)
1,G.TIME(2,10)

C
OPEN (22, FILE = "P3LNK.txt")
READ (22,110)TIME(3,1),TIME(3,2),TIME(3,3),TIME(3,4)
1,TIME(3,5),TIME(3,6),TIME(3,7),TIME(3,8),TIME(3,9)
1,TIME(3,10)
READ (22,110)SPD(3,1),SPD(3,2),SPD(3,3),SPD(3,4),SPD(3,5)
1,SPD(3,6),SPD(3,7),SPD(3,8),SPD(3,9),SPD(3,10)
READ (22,120)R.TIME(3,1),R.TIME(3,2),R.TIME(3,3),R.TIME(3,4)
1,R.TIME(3,5),R.TIME(3,6),R.TIME(3,7),R.TIME(3,8),R.TIME(3,9)
1,R.TIME(3,10)
READ (22,130)G.TIME(3,1),G.TIME(3,2),G.TIME(3,3),G.TIME(3,4)
1,G.TIME(3,5),G.TIME(3,6),G.TIME(3,7),G.TIME(3,8),G.TIME(3,9)
1,G.TIME(3,10)

C
OPEN (23, FILE = "P4LNK.txt")
READ (23,110)TIME(4,1),TIME(4,2),TIME(4,3),TIME(4,4)
1,TIME(4,5),TIME(4,6),TIME(4,7),TIME(4,8),TIME(4,9)
1,TIME(4,10)
READ (23,110)SPD(4,1),SPD(4,2),SPD(4,3),SPD(4,4),SPD(4,5)
1,SPD(4,6),SPD(4,7),SPD(4,8),SPD(4,9),SPD(4,10)
READ (23,120)R.TIME(4,1),R.TIME(4,2),R.TIME(4,3),R.TIME(4,4)
1,R.TIME(4,5),R.TIME(4,6),R.TIME(4,7),R.TIME(4,8),R.TIME(4,9)
1,R.TIME(4,10)
READ (23,130)G.TIME(4,1),G.TIME(4,2),G.TIME(4,3),G.TIME(4,4)
1,G.TIME(4,5),G.TIME(4,6),G.TIME(4,7),G.TIME(4,8),G.TIME(4,9)
1,G.TIME(4,10)

C
OPEN (24, FILE = "P5LNK.txt")
READ (24,110)TIME(5,1),TIME(5,2),TIME(5,3),TIME(5,4)
1,TIME(5,5),TIME(5,6),TIME(5,7),TIME(5,8),TIME(5,9)
1,TIME(5,10)
READ (24,110)SPD(5,1),SPD(5,2),SPD(5,3),SPD(5,4),SPD(5,5)
1,SPD(5,6),SPD(5,7),SPD(5,8),SPD(5,9),SPD(5,10)
READ (24,120)R.TIME(5,1),R.TIME(5,2),R.TIME(5,3),R.TIME(5,4)
1,R.TIME(5,5),R.TIME(5,6),R.TIME(5,7),R.TIME(5,8),R.TIME(5,9)
1,R.TIME(5,10)
READ (24,130)G.TIME(5,1),G.TIME(5,2),G.TIME(5,3),G.TIME(5,4)
1,G.TIME(5,5),G.TIME(5,6),G.TIME(5,7),G.TIME(5,8),G.TIME(5,9)
1,G.TIME(5,10)
110 FORMAT (10(F7.3))
120 FORMAT (10(A19))
130 FORMAT (10(F14.3))

C SORT GPS TIME FROM LATEST TO EARLIEST
OPEN (30, FILE = "AVGLT.T.CSV")
DD(1) = (5843.428/5280)
DD(2) = (16725.39/5280)
DD(3) = (1139.125/5280)
DD(4) = (11158.396/5280)
DD(5) = (838.457/5280)

DD(6) = (21776.219/5280)
DD(7) = (1134.646/5280)
DD(8) = (14421.616/5280)
DD(9) = (1267.546/5280)
DD(10) = (9407.86/5280)
DO I = 1,10
  TTIME(I) = 0.0
  N(I) = 0.0
  LASTRUN(I) = MAX(GTIME(1,I),GTIME(2,I),GTIME(3,I),GTIME(4,I),
1,GTIME(5,I))
  DOI = 1,5
c WITHIN 15 MINUTES(900 SECONDS) AFTER LASTRUN
IF ((LASTRUN(I)-GTIME(I)) LE 900 and. time(i) ne 0) THEN
  TTIME(I) = TTIME(I) + TIME(I)
  Tspd(I) = spd(I) + spd(I)
  N(I) = N(I) + 1.0
else
  time(i) = time(i)
  Tspd(I) = Tspd(I)
  n(i) = n(i)
END IF
IF ((LASTRUN(I)-GTIME(I)) EQ 0) THEN
  TRTIME(I) = R.TIME(I)
END IF
END DO

C CALCULATE AVG. TIME MEAN SPEED OF VEHICLE WITHIN 15MINS.
RANGE
ATTIME(I) = TTIME(I)/N(I)
ASPEED(I) = (DD(I))*60/ATTIME(I)
if (attime(i) .eq. 0.0) then
  aspeed(i) = 0.0
end if
if (n(i) .eq. 0.0) then
  aspeed(i) = 0.0
  attime(i) = 0.0
end if
if (n(i)-1.0 EQ 0) then
  ASPEED(I) = Tspd(I)
end if
END DO

C
WRITE(30,40) (A,10(" ",A)) "TIME(US40-US6)", "US40(OFF)-US40(ON)"
1, "US40(ON)-GRG TWN(OFF)"
1, "GRG TWN(OFF)-GRG TWN(ON)"
1, "GRG TWN(ON)-SLVR PLM(OFF)"
1, "SLVR PLM(OFF)-SLVR PLM(ON)"
1, "SLVR PLM(ON)-BKR VLL(OFF)"
1, "BKR VLL(OFF)-BKR VLL(ON)"
1, "BKR VLL(ON)-HRMN GLCH(OFF)"
1, "HRMN GLCH(OFF)-HRMN GLCH(ON)"
1, "HRMN GLCH(ON)-US4(OFF)"
WRITE(30,200) ATTIME(1),ATTIME(2),ATTIME(3),ATTIME(4),ATTIME(5)
1,ATTIME(6),ATTIME(7),ATTIME(8),ATTIME(9),ATTIME(10)
WRITE(30,200) ASPEED(1),ASPEED(2),ASPEED(3),ASPEED(4)
1,ASPEED(5),ASPEED(6),ASPEED(7),ASPEED(8),ASPEED(9),ASPEED(10)
WRITE(30,200)N(1),N(2),N(3),N(4),N(5),N(6),N(7),N(8),N(9),N(10)
WRITE(30,201)TRTIME(1)
WRITE(30,201)TRTIME(2)
WRITE(30,201)TRTIME(3)
WRITE(30,201)TRTIME(4)
WRITE(30,201)TRTIME(5)
WRITE(30,201)TRTIME(6)

```

```
WRITE(30,201)IRTIME(7)
WRITE(30,201)IRTIME(8)
WRITE(30,201)IRTIME(9)
WRITE(30,201)IRTIME(10)
200 FORMAT(10,"",F7.3)
201 FORMAT(A,"AMPM")
END SUBROUTINE
```

APPENDIX D: SAMPLE GPS DATA

```

"MobileKey", "MobileID", "ReportTime", "PosFixTime", "PTTsec", "Latitude", "Longitude", "Altitude", "Speed", "
Course", "PosageFlag", "GpsFixSrc", "Status1", "Status2", "StatusTime", "RunOnOff", "OnOff1", "OnOff2", "OnOff3",
"OnOff4", "OnOff5", "OnOff6", "OnOff7", "OnOff8", "RunReading", "Reading1", "Reading2", "Reading3", "Reading4",
"LenExtended", "Extended", "EventID", "Flags"
376750,3,646151515,646151320,0,39754378,-105142979,160119,2679,3593,1,2,-1,0,,,,,0,,,0,0,0
376759,2,646151515,646151320,0,39504039,-105195921,309917,3290,929,1,2,-1,0,,,,,0,,,0,0,0
376760,3,646151515,646151325,0,39765568,-105142977,167870,2652,3595,1,2,-1,0,,,,,0,,,0,0,0
376761,2,646151515,646151325,0,39504037,-105193407,309900,3241,992,1,2,-1,0,,,,,0,,,0,0,0
376762,3,646151515,646151330,0,39765944,-105143090,167221,2934,3595,1,2,-1,0,,,,,0,,,0,0,0
376763,2,646151515,646151330,0,39504030,-105191564,309004,3120,992,1,2,-1,0,,,,,0,,,0,0,0
376764,3,646151520,646151340,0,39765804,-105143037,165327,2643,3590,1,2,-1,0,,,,,0,,,0,0,0
376765,2,646151530,646151340,0,39504051,-105187955,309030,3131,982,1,2,-1,0,,,,,0,,,0,0,0
376766,3,646151530,646151345,0,39770771,-105143054,165912,2920,3590,1,2,-1,0,,,,,0,,,0,0,0
376767,2,646151530,646151345,0,39504030,-105195152,307917,3142,1022,1,2,-1,0,,,,,0,,,0,0,0
376768,2,646151530,646151350,0,39504035,-105184303,308279,3000,1047,1,2,-1,0,,,,,0,,,0,0,0
376769,3,646151530,646151350,0,39772047,-105143063,165710,2670,3595,1,2,-1,0,,,,,0,,,0,0,0
376770,3,646151540,646151355,0,39773343,-105142005,165568,2678,3597,1,2,-1,0,,,,,0,,,0,0,0
376771,2,646151540,646151355,0,39503732,-105182556,307690,3000,1051,1,2,-1,0,,,,,0,,,0,0,0
376772,3,646151540,646151360,0,39774535,-105143095,165559,2670,3599,1,2,-1,0,,,,,0,,,0,0,0
376773,2,646151540,646151360,0,39503230,-105180943,306565,3155,1099,1,2,-1,0,,,,,0,,,0,0,0
376774,3,646151550,646151365,0,39773949,-105142980,165775,2954,223,1,2,-1,0,,,,,0,,,0,0,0
376775,2,646151550,646151365,0,39502010,-105179176,306332,3227,1104,1,2,-1,0,,,,,0,,,0,0,0
376776,2,646151550,646151370,0,39502321,-105177422,305447,3107,1079,1,2,-1,0,,,,,0,,,0,0,0
376777,3,646151552,646151370,0,39777150,-105142299,163864,2656,307,1,2,-1,0,,,,,0,,,0,0,0
376778,2,646151559,646151375,0,39501975,-105175644,304412,3150,1029,1,2,-1,0,,,,,0,,,0,0,0
376779,3,646151560,646151375,0,39770152,-105141260,166104,2642,472,1,2,-1,0,,,,,0,,,0,0,0
376780,3,646151560,646151380,0,39778077,-105139875,166051,2807,525,1,2,-1,0,,,,,0,,,0,0,0
376781,2,646151560,646151380,0,39501637,-105173864,303190,3150,963,1,2,-1,0,,,,,0,,,0,0,0
376782,2,646151570,646151385,0,39501388,-105172003,302709,3170,926,1,2,-1,0,,,,,0,,,0,0,0
376783,3,646151570,646151385,0,39779444,-105139386,165860,2653,643,1,2,-1,0,,,,,0,,,0,0,0

```

APPENDIX E: **SAMPLE OUTPUT**

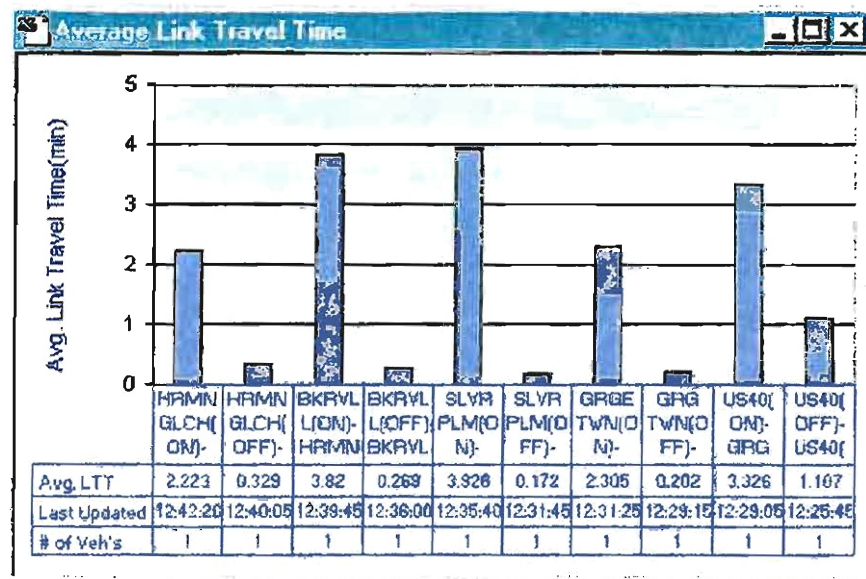


Figure E-1. Average Link Travel Time.

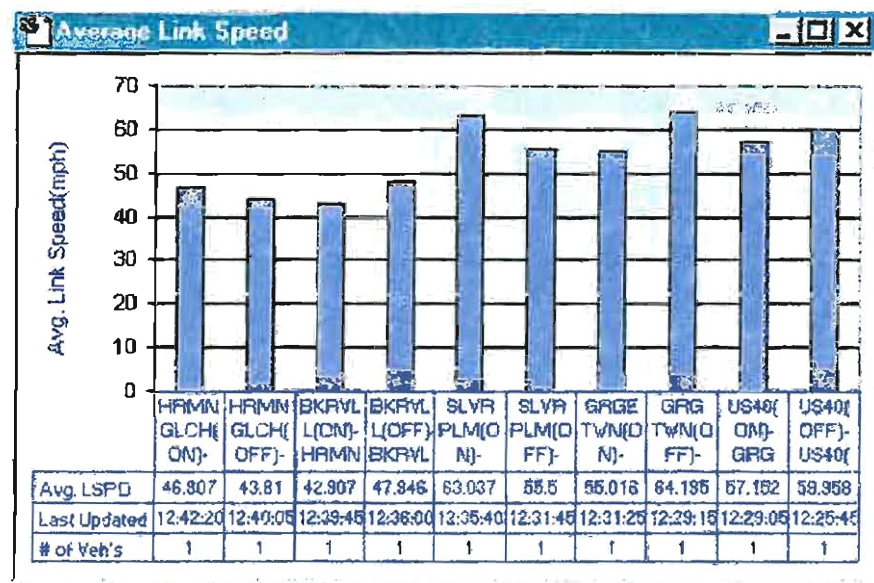


Figure E-2. Average Link Speed.

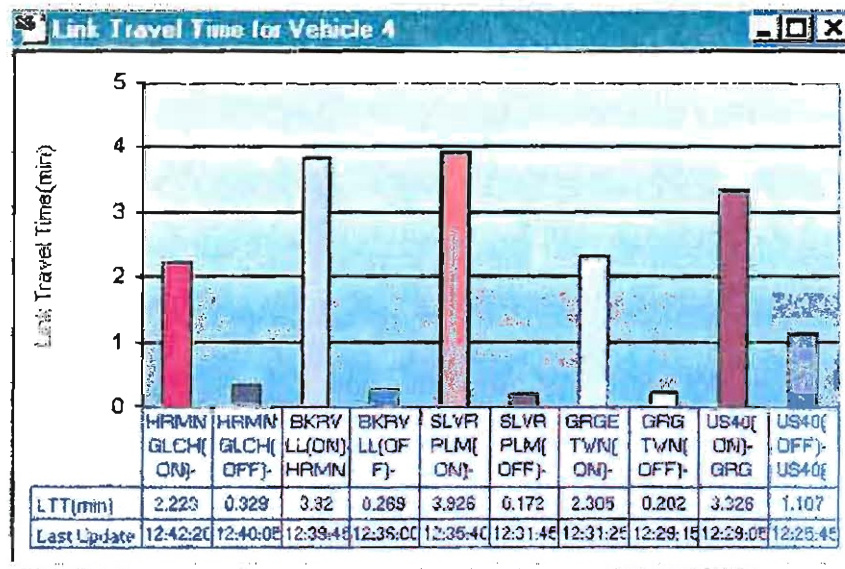


Figure E-3. Link Travel Time for Vehicle No. 4.

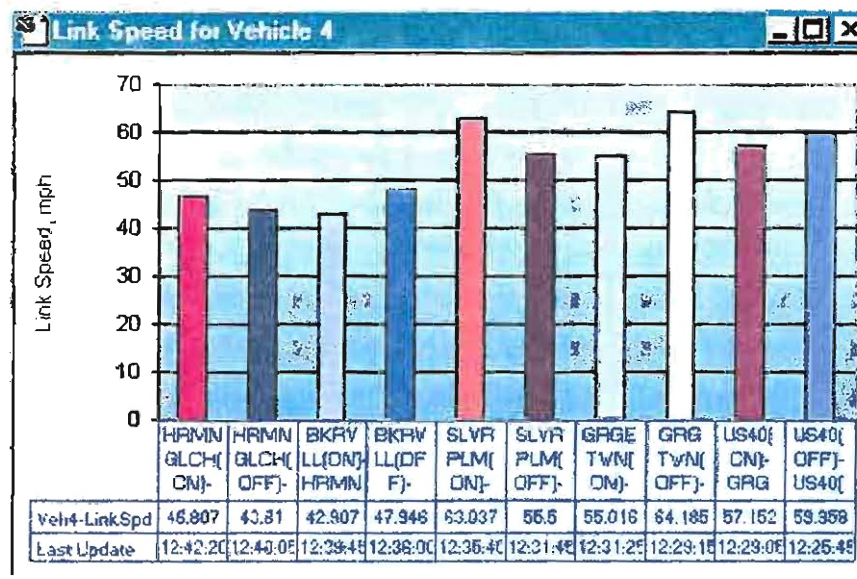


Figure E-4. Link Speed for Vehicle No. 4.

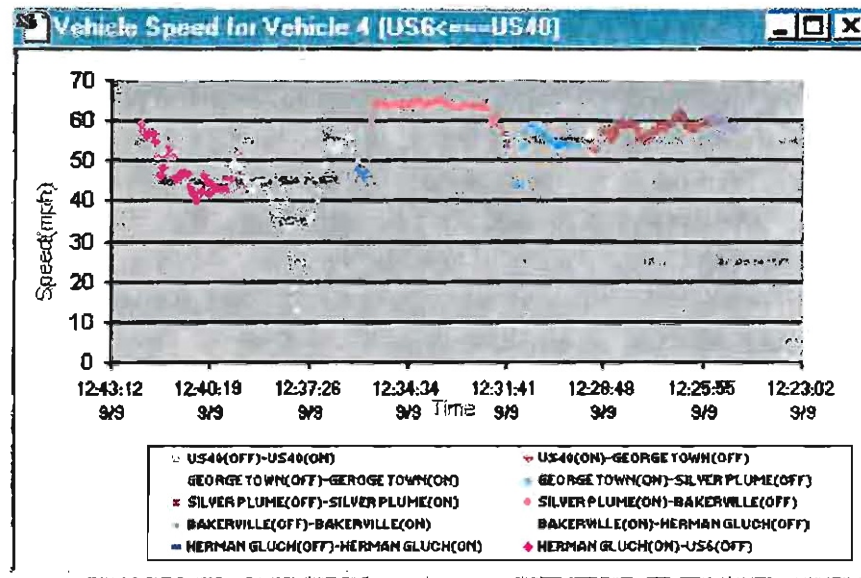


Figure E-5. Instantaneous Vehicle Speed for Vehicle No. 4.

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