CONCURRENT SESSION 2A - TRAVEL TIME DATA COLLECTION

USING GPS

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EMERGING ISSUES IN THE USE OF GPS FOR TRAVEL TIME DATA COLLECTION

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Introduction

The implementation of effective congestion mitigation and mobility enhancement projects is an important concern to federal, State, and local transportation officials. This is increasingly the case as the Federal Highway Administration (FHWA) fosters the use of performance based considerations in the planning process. A key underlying factor in the success of this effort will be the practical selection and application of appropriate performance measures to support planning and decision making.

Of the numerous performance measures now under consideration and use, travel time-based measures (e.g., travel speed, person hours of delay, speed variations, etc.) are of particular importance. They benefit from being a) understood easily by the traveling public, b) applicable across modes, c) readily translated into other measures (such as user costs), d) used in other non-congestion management planning activities (such as travel demand modeling and air quality planning), and e) capable of tracking system reliability more effectively than volume-based measures.

High costs and limited accuracy have historically hindered the collection and use of travel time data. Recent advances in global positioning system (GPS) technologies have largely overcome these barriers, making travel tune relatively simple to collect and analyze. In response to these advances, a few organizations have begun to use GPS as the backbone of a travel time data program. Most have cited considerable success in its use, but their collective experiences suggest that many issues must be resolved in order for this technique to gain widespread acceptance. This session will identify these issues, discuss their implications, and suggest steps that can be taken to ensure that time-based travel information becomes a common, basic resource for transportation planning.

Time-based measure applications

Travel tune-based measures serve the entire range of typical transportation planning activities. For strategic planning, they provide policy analysts and decision makers with credible estimates of system performance and reliability. Such knowledge compliments the traditional examination of how many vehicles can be moved through the system by permitting a more thorough consideration of the quality of transportation system performance.

Time-based measures have numerous applications at the system level too. They can be used directly to validate other system planning tools (such as travel demand forecasting models). In addition, they provide an analytic basis to make more thorough and informed comparisons of performance characteristics throughout a region. Such measures can reveal systemwide evidence of transportation deficiencies, particularly in areas that routinely experience oversaturated flow. If carried out with GPS technology, they can be collected in conjunction with other data collection activities. For example, FHWA is currently investigating the collection of travel time data as part of travel diary survey. Travel in this survey is being collected and maintained through the use of personal digital assistants (PDAs) connected to GPS receivers. The devices log trips, pinpoint origins and destinations, and simultaneously collecting detailed speed data associated with each trip.

When used to carry out corridor or subarea planning and operations studies, GPS travel time data has the potential to provide speed and delay information that generally equals or exceeds the accuracy of manually collected data. Moreover, the system provides far more detail (generally, speeds are collected at one second intervals) at a considerably lower cost, since data processing and evaluation are largely automated. In addition, the data can be aggregated to support systemwide evaluations, thus creating a direct link between operations and systems planning. They also present a simple and direct basis for before and after comparisons of traffic operations improvements and travel demand management programs.

Issues

Although the promise offered by GPS is significant, the relative newness of the technology raises many issues for potential users. These issues tend to revolve around the following areas: hardware, application software and data processing, user interface and preferences, and the application and display of results.

A. Hardware

GPS hardware is evolving rapidly, and receivers are tailored to such a large number of applications that potential users are faced with a wide array of choices, many of which are not appropriate for travel time data collection. While the number and type of GPS receivers are growing rapidly, their cost and size seem to be dropping at an inverse rate. Most receivers appropriate for travel speed studies are currently available for around five hundred dollars. If past trends hold true, costs should continue to fall into the future, making this technology affordable to even small agencies with limited funding resources. Similarly, the receivers themselves are becoming quite small. Most units are highly compact and lightweight. Many are contained within a PCMCIA card,

Drops in power requirements have generally not kept pace with drops in size. For example, PCMCIA receivers cannot be run in a PDA unless they are powered by an external source. Manufacturers are working on this problem and hope to develop low voltage receivers within the near future.

Receiver protocols are another issue that must be addressed by the potential user. National Marine Equipment Standard A (NMEA-0183) was developed for marine equipment, but it is not used by all manufacturers since it does not track altitude and is limited to speeds under 250 miles per hour. Receivers therefore generally use protocols that are specific to each manufacturer. These are not compatible, so the use of receivers with NMEA protocols may be of advantage to an agency, since NMEA limitations do not constrain the collection of travel speed data. This would provide an agency with the greatest flexibility in choosing receivers from different manufacturers without modifying their GPS software.

Another key characteristic of GPS receivers is the number of satellites tracked. Receivers are generally capable of tracking a signal from either one, three, more than three satellites at a time. The GPS receiver's cost is generally related to this capability. Research to-date suggests that, for travel time applications, users should consider receivers capable of simultaneously tracking five or more satellites in order to maintain an acceptable level of accuracy. Such receivers have the side benefit of providing direct measurements of speed. This is an important consideration, since the receiver's velocity outputs are not influenced by select availability (SA) to the degree that position outputs are.

SA is an intentional degradation of the GPS signal used by the Department of Defense (DoD) for purposes of national security. The general effect of SA is to introduce an positional error of up to 70 meters from the receiver's actual location. The impacts of SA can be largely overcome by providing a correction signal to the receiver. Known as differential correction (DGPS), locational accuracy can be restored by receiving a correction signal. Correction signals are transmitted on FM radio sidebands. DGPS adds to the price of a receiver but such costs are expected to be minimized if current trends continue. In addition to the hardware, the user must subscribe to a correction signal. Private providers of correction signals currently charge about $150 per year. Public signals (such as those provided by the U.S. Coast Guard) are available to public agencies free of charge. To-date, the collective experience of those using GPS for travel time suggests that DGPS is not necessary, although it may improve the ability to match output to a base map, particularly on dense street grids.

B. Software

While a range of GPS receivers is now generally available to make travel time data collection practical for most agencies, all of the software needed to process the data is not. Specifically, software is required to a) format and store raw data generated by the GPS receiver, b) process the data and generate user outputs, or reformat the raw data for input into other analysis software c) provide visual displays of the data or link the data to a GIS, d) match location data to a base map, and e) compress the data for storage and retrieval.

These steps may be carried out ad hoc using a wide array of preexisting software, but this process quickly becomes cumbersome and time consuming, negating many of the potential benefits offered by GPS. Unfortunately, no standard software packages are available that support the processing of GPS data for travel time studies. Currently, agencies must have the staff expertise to develop their own software or they must rely on a limited pool of consultants with the experience and expertise to develop software for them.

Another issue is the level of user interface required by the software. So far, practitioners have developed methods that range from the near replication of traditional floating car studies that require a relatively high level of user interaction during travel time runs, to largely automated methods that enable runs to be made by almost anyone by simply turning on the unit.

In addition to user interaction during travel runs themselves, a certain degree of post processing or manipulation is also needed. This revolves around filtering outlying data points and matching positional data to the correct facility. Careful forethought to software design is required to minimize the overall level of effort to process travel time runs and maximize the automation of data processing. Software should allow users to concentrate on the examination of travel performance, not on the manipulation of data. This is particularly important since GPS offers the potential for making a large, statistically valid number of runs (generating a significant amount of data) with relatively little effort. This potential will be of little use if post processing becomes too burdensome.

A final consideration during the development of processing software is the manner in which the data will ultimately be used. It is helpful to consider the potential performance measures that might be generated by travel time data and to consider methods to streamline the production and use of these measures.

C. Data collection

Most agencies collecting travel time data do so with paid drivers, often technicians or interns. The portability and relative transparency of GPS to the user makes it possible to extend the range of potential drivers to nearly anyone. This could include agency staff, who could collect data during their regular commute with little or no effort, or to volunteers from the general public. For example, the Central Transportation Planning Staff in Boston conducted a before and after study of the impacts from new HOV lanes on the southeast expressway by having an agency secretary use the GPS unit immediately prior to and after the HOV lane opening.

As GPS travel time units (receivers and data storage devices) become smaller and less power hungry, their portability will increase so that virtually anyone can collect travel information. This could provide for the development of a comprehensive empiric database of performance information that would facilitate the comparison of modal alternatives within a metropolitan area.

D. User Preferences
While there has not been a large body of practice with GPS for travel time data collection, limited experiences to-date suggest that users have fairly strong preferences. First, they want the GPS units to be inexpensive and readily available. While this was an issue for many who began the use of this technique over the last two years, enough options exist today to overcome this concern. Users also want to minimize the overall level of interface needed to set up travel runs, collect the data while driving, and process the data back in the office. Further work is needed in this area. Users also have expressed the need for accurate and reliable information. This is particularly important if the methodology is to gain credibility and widespread acceptance in the near future. Finally, a strong preference has been expressed to maintain the level of flexibility offered by GPS data collection so that agencies may tailor data collection, processing, and, most importantly, analysis and application, to their unique needs. This flexibility will make it considerably more challenging to develop generic interface software to serve the wide variety of circumstances encountered throughout the US.

Today's Session

This session offers a great opportunity to review some early, practical applications of GPS for travel time studies. While all of the participants have developed GPS data collection methods, none were aware of the others' activities, and all have addressed the issues I've just discussed in unique ways. So, in addition to learning more about this application, we are also getting a first chance to discuss our experiences with each other. I find this opportunity for collaboration particularly exciting.

Dr. Art Salwin of Mitretek will discuss the GPS odograph developed by his organization last year under the aegis of FHWA's Office of Traffic Management and Intelligent Transportation Systems Applications. The application does a remarkable job of replicating stopwatch and clipboard studies, while proving many of the numerous automated processing and display advantages offered by GPS. The method has been tested by the Washington DC MPO.

Dr. Darcy Bullock of Louisiana State University will present his experiences from developing travel time collection programs in Baton Rouge and New Orleans. Among many factors, his work is distinguished by the use of network segmentation to reduce GPS data storage burdens.

Jim Gallagher of the Central Transportation Planning Staff in Boston will present some of the findings of their work, which uses a GIS platform for map matching and data processing.

Finally, we will close the session with David Roden of JHK and Associates. JHK, in collaboration with Battelle, is currently under contract with FHWA to address many of the issues we will be discussing at this session. He has carried out numerous studies using the technology, not only for travel time information, but also for an NCHRP panel examining acceleration/deceleration characteristics at intersections for air quality modeling.

EXPERIENCE WITH A PORTABLE GPS-BASED ODOGRAPH

Arthur E. Salwin
Mitretek Corporation

Presented at
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EXPERIENCES WITH A PORTABLE GPS-BASED ODOGRAPH

ARTHUR E. SALWIN

MITRETEK SYSTEMS

A prototype GPS odograph was built for conducting travel time surveys ("speed runs"). The prototype is portable and was configured with an off-the-shelf laptop computer and a GPS receiver (non-differential mode). Field testing compared the use of this device with the traditional manual data collection methods. The talk will describe the techniques used, results from operational use of the prototype by an MPO, and some advantages that a continuous GPS data stream could offer in characterizing traffic data.

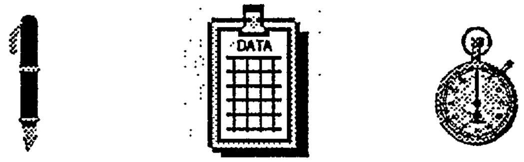
Experiences With a Portable GPS-based Odograph

Dr. Arthur E. Salwin

May 6, 1996

MITRETEK SYSTEMS

Current State-of-the-Practice



- Labor intensive
- Error prone
- No formal files or data bases

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GPS Concept

- Use GPS to overcome the shortcomings inherent in the manual data collection methods
- Build a prototype to test the concept, using open architecture and off-the-shelf equipment
  - Commercial GPS receiver
  - Commercial PC-compatible laptop computer to collect, process, real-time display and playback, and store data
  - Use ASCII files with published format
- Try two different computation methods:
  - SΔt
  - Δ(lat,lon)

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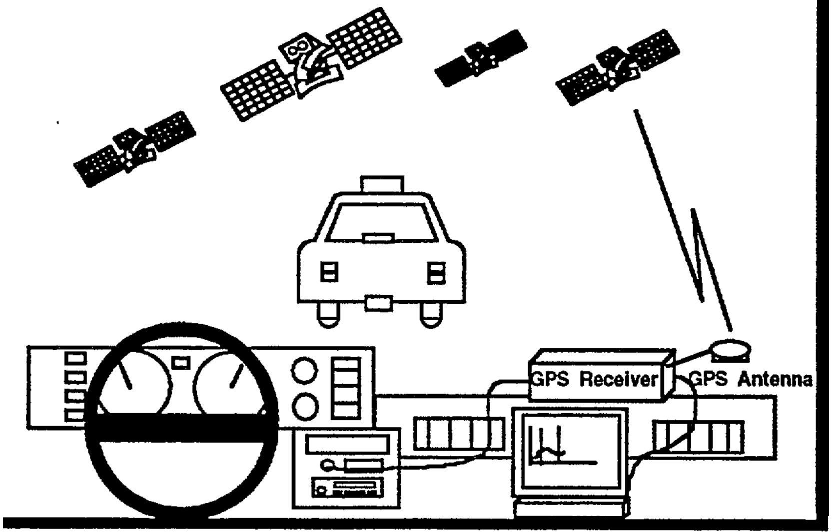
System Configuration



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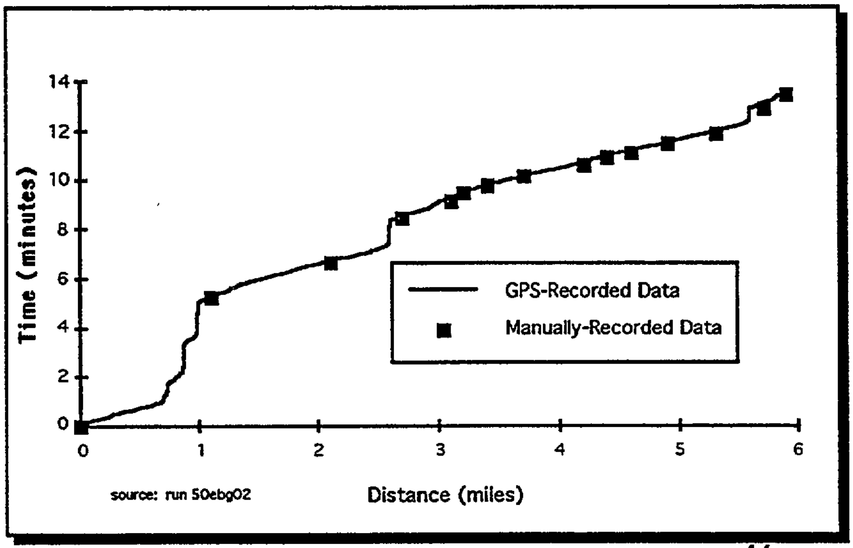
Agreement With Manual Results



source: run 50ebg02

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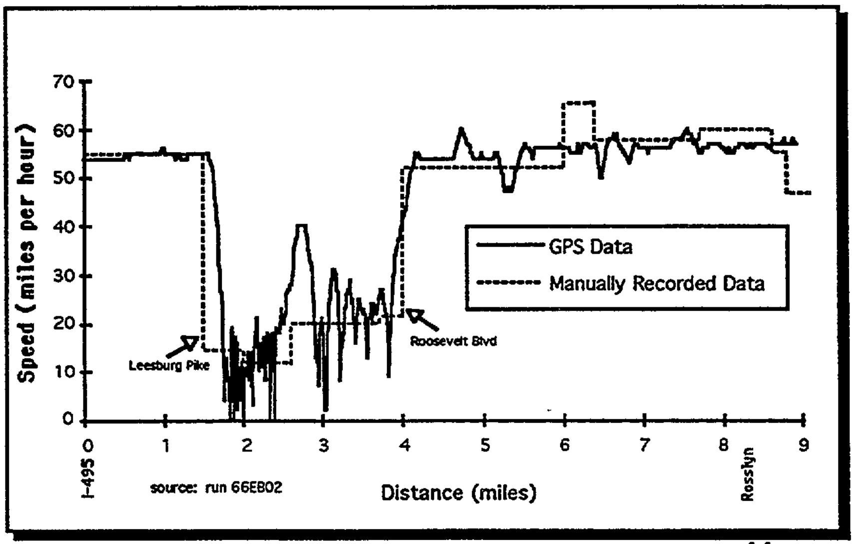
Comparison of GPS and Manual Data



source: run 66EB02

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Comparison With State-of-the-Art Hard-Wired (non-GE's) Commercial Technology

- Results virtually identical
  - Difference in computed speeds = 0.5 mph
  - Difference in measured distances < 0.01 miles per link
  - Both produce continuous data streams
- Advantages of using GPS
  - Portability and ease of installation
  - Open architecture and fife format, amenable to user analyses
  - Includes location information
  - Produces real-time plots as data are collected
  - User can input annotations

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Comparison With State-of-the--Art Hard-Wired (non-GE's) Commercial Technology

- Advantages of using the commercial technology
  - Commercial quality, with wide range of post-processing software and hardware options
  - Well human-factored hand-held hardware
  - Options for other types of traffic engineering studies available today

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Summary of Field Test Results

- GPS data collection is a viable concept
- Data accuracy compares favorably with manual data collection methods; DGPS not necessary
- Easy to interface to different GPS receivers. However, results varied across vendor products
  - spec sheets do not provide all the necessary parameters to make a choice
- The $s\Delta t$ approach is preferred to the Δ(lat,lon) approach
  - finding agrees with published literature
- The altitude data was not meaningful

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Summary of Field Test Results (continued)

- "Continuous" GPS data provides a number of additional benefits over manual "point" data:
  - Provides a more detailed picture of the traffic situation
  - Historical record of all possible links
  - Better accuracy on shorter links
  - Novel depictions and more detailed characterization on the performance of the road network are possible

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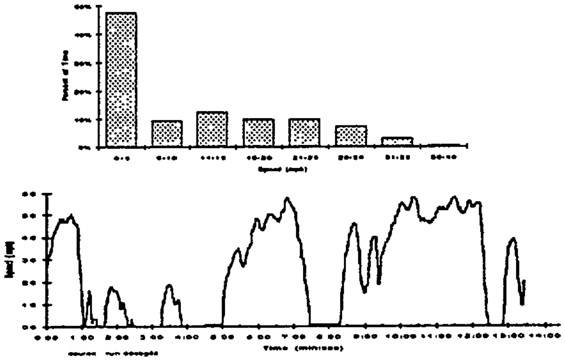
Novel Depictions of Traffic Data



	Run With Congestion (HOV Lifted)	Run With HOV Restrictions in Effect
Distance traveled (miles)	8.9	9.0
Length of trip (min:sec)	16·17	9:46
Speed (mph) mean std dev	32 21	55 1
Number of accelerations	19	2
Number of stops	4	0

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Operational Testing

- Metropolitan Washington Council of Governments used the prototype in conjunction with some of their speed runs.
- Findings:
  - Positives:
    - accuracy
    - reduced workload for post-processing
  - Neither good nor bad:
    - continuous data
    - data displays in the vehicle
  - Negatives:
    - does not reduce the number of people needed to collect the data in the car
    - cost
- COG plans to use the device for forthcoming series of runs

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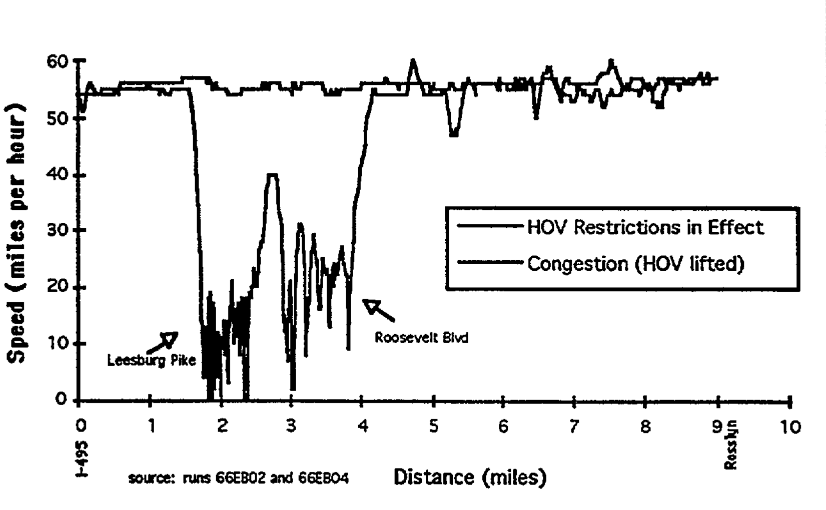
- Zito R., G. D'Este, and M.A.P. Taylor, *Global Positioning Systems in the Time Domain: How Useful a Tool for Intelligent Vehicle-Highway Systems?,* Transportation Research-C, Vol 3, pages 193-209, 1995.
- Internet: Usenet news group *sci.geo.satellite-nav*
- vendor literature and spec sheets

"Advertisement" for Car-Pooling



source: runs 66EB02 and 66EB04

DATA COLLECTION AND REPORTING FOR CONGESTION MANAGEMENT SYSTEMS

Speaker: Darcy Bullock
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May 5-9, 1996

DATA COLLECTION AND REPORTING FOR CONGESTION MANAGEMENT SYSTEMS[1]

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ABSTRACT

Travel time studies are widely used to document congestion and quantify the impact of highway improvements after construction has been finished. For safety reasons, these studies are typically performed with two people in the automobile. The driver is responsible for "floating" with the traffic stream. The passenger is responsible for recording the time the vehicle passes predetermined landmarks. Occasionally, a device that plugs into the odometer is used to log speed between landmarks. This data collection methodology works quite well provided the driver and data collector are conscientious and consistent in their data collection. However, since data collection personnel typically are not highly trained, it is difficult to maintain consistency when a vehicle passes, say, an entrance ramp or exit ramp. Odometer devices help some, but must be carefully initialized and calibrated between vehicles.

Due to production economies of scale, it is now possible to purchase a Global Positioning System (GPS) receiver and a notebook computer for $2,000 (Advanstar 1996) to record the velocity and location of a probe vehicle every one second. This has two significant benefits: 1) There is no need for a passenger to record data during travel time runs. 2) There is no need to rely on technicians accurately or consistently recording the location of landmarks since the GPS receiver provides absolute locations every 1 second. However, since a one hour travel time run would collect 3,600 position and velocity records, the data recorded from the GPS receiver is too voluminous to be directly useful. To reduce the GPS data to a meaningful tabulation, it must be overlaid on a highway map and the travel time between particular locations determined. This paper describes procedures for: importing GPS data into a Geographic Information System (GIS); obtaining travel time along segments of a highway network; and developing report templates used to document travel time on color coded maps and 11x17" report pages.

DATA COLLECTION METHODOLOGY

To use GPS and GIS technology for conducting travel time studies it was essential to construct a base vector map that could be linked to a database. One way of obtaining this base vector map is to use digitized quad maps or TIGER files. However, both these sources do not have the required accuracy. Instead, study personnel drove probe vehicles over all study routes in both directions collecting GPS data every one second. During this field work they also drove all

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entrance and exit ramps so that these discontinuities could be included on the base map (Figure la). Once this data was imported into the GIS map a procedure was developed for using the GPS data to create a directional centerline network map. This map included the location of discontinuities such as ramps, lane drops, and signalized intersections (Figure lb). By constructing this base map directly from the GPS data, we were certain the GPS data collected during future travel time studies would match the vector base map.

Traditional travel time studies record travel time and average speed between checkpoints along the study route. We sought to formalize the establishment of these checkpoints by using two simple rules for creating checkpoints. First, a checkpoint would be established at all physical discontinuities such as signalized intersections, significant unsignalized intersections, lane drops, exit ramps, entrance ramps, or other geometric discontinuities. Second, the section of road between checkpoints at physical discontinuities would be segmented so that there would be n checkpoints every mile. Figure lc illustrates how checkpoints are established at the various entrance and exit ramps at the I-10 and I-12 interchange. Figure Id illustrates how the relatively large distances between entrance and exit ramps are segmented to create intermediate checkpoints with a nominal spacing of 0.2 miles (5 checkpoints per mile). For the travel time project performed in Baton Rouge (Quiroga and Bullock, 1996a, 1996b), there were 155 miles of Interstate and Principal Arterial routes included in the study (310 miles in both directions). These routes were broken into 2,397 segments resulting in an average segment length of 0.129 miles (683 feet).

Finally, with the network broken into reasonably spaced segments a procedure was needed to link each of the discrete segments shown in Figure Id to a relational database. This was done by assigning unique integer identifier numbers to each segment. For example, segment 12444 in Figure le always represents the section of I-10 EB immediately before the I- 10 & I-12 Split. Similarly, segment 12478 in Figure le always represents the segment of I-12 EB immediately after the entrance ramp from I-10 WB. By creating these unique identifiers, each segment could have fixed data such as number of lanes and posted speed limit associated with it. Similarly, several travel time studies performed on different dates and times could also be associated with specific segments.

These travel time studies would be conducted by driving a probe vehicle equipped with a GPS receiver and traversing the study routes during the morning peak hour, afternoon peak hour, and off peak periods. The following section describes the procedure used to reduce the GPS data collected to meaningful travel time data that could be associated with each segment identifier.

DATA REDUCTION METHODOLOGY

Table 1 shows the format of the data collected by the GPS receiver in the probe vehicle. For each GPS point, `time` is expressed in seconds since midnight in Greenwich Mean Time (GMT). Latitude and Longitude are recorded with a spatial accuracy of l-5 meters spherical error probability (SEP) after differential correction (Trimble 1993). Speed is computed in the GPS receiver by using the coordinates and time associated with successive GPS points. This GPS data can be imported into a GIS and overlaid on a vector map. Figure 2 shows an enlarged diagram of Figure le with the GPS points overlaid along a section of I-12 WB that merges with I-10 WB. The table at the bottom of Figure 2 shows the GPS point data collected by the GPS receiver, but formatted in local time and expressing latitude and longitude in traditional hh:mm:ss notation. From this data we can observe that the vehicle enters segment 12447 at 8:30:01, then segment 12448 at 8:30: 11, and finally segment 12436 at 8:30:21. The table to the right of the GPS point data shows the travel time for vehicle through segments 12447, 12448, and 12436. That table also tabulates the average vehicle speed reported by the GPS receiver. It is these two values: travel time and average speed that are the important summary statistics. In order to successfully use GPS receivers to perform travel time studies, it was essential to develop efficient data reduction procedures for transforming the GPS point data (Table 1) into segment summary statistics (Figure 2, Segment aggregated data, Table 2). Notice that Table 2 contains some additional housekeeping data such as what time the segment was entered, the date of the survey, and vehicle ID performing the study.

To efficiently transform the GPS point data into segment travel times and average speeds, a data reduction application with a convenient user interface was developed (Figure 3, Figure 4). The user of this application was responsible for loading the GPS data files (Table 1) and overlaying the GPS data on the vector base map. For example, Figure 4 shows an exploded view of the I-10 EB /I-12 EB split. The travel time and average speed for segment 12444 are shown in the user interface displayed in Figure 3. The operator of this reduction application would be responsible for directing the reduction utility to I-12 or to I-10. From Figure 4, it is obvious that the GPS points closely match I-12 EB so the operator would click on the I-12 segment. The data reduction application would realize the operator was clicking on segment 1245 1, figure out the entrance and exit time, and update the user interface form (Figure 3). Successive segments would be selected by the operator in a similar fashion.

Over the past year, several undergraduate students have performed this data reduction process on over 25,000 miles in Baton Rouge, creating more than 125,000 travel time records. Operators are typically trained in one to two hours and are proficient within 10 hours. They can typically reduce data about 8 times faster than when it was collected in the probe vehicle. For example, if two hours of GPS data were collected (7,200 entries similar to Table l), this data could be reduced to a table of segment identifiers, travel time, and average speed (Table 2) in about 15 minutes.

DATA REPORTING METHODOLOGY

Once the data is reduced to segment statistics (Table 2), it becomes important to develop efficient reporting procedures. Since the Baton Rouge system has over 125,000 records, simply printing out segment statistics in a tabular layout would be confusing. Instead, two different reporting procedures were used.

The most obvious approach is to develop maps where each of the segments is color coded based upon the average or minimum observed speed during a particular time period. Figure 5 shows an example gray scale shaded map corresponding to the minimum observed speed during the evening peak hour in the Summer of 1995. Obviously, the query used to generate the map could be modified to include different time periods or show average speeds. For illustration purposes, Figure 5 shows only a very small portion of the network. However, in practice large format color plots covering a 10x10 mile area were typically plotted. These maps are very effective for explaining congestion problems at public meetings, but are a bit bulky and awkward for archiving results. Consequently, it was necessary to develop a second reporting format.

This alternative reporting format is similar to the one found in strip maps used to document highway features such as sign posts and culverts. These strip maps are produced on 11 x 17" paper and laid out in the manner shown in Figure 6. The right most part of the map contains the labels and graphics showing the location of the study route. The "Network Location" box shows where the strip map is located in the network. The "Study Area" box shows an expanded view of the geometry of the study area. The "Strip Map" box shows the study area stretched out in a linear fashion with the corresponding segment numbers above and below. The data tabulated above and below the "strip map" are travel time and average speed for both directions of travel during the a.m. peak, off peak, and p.m. peak periods

Figure 7 shows an example of the printout within the 8.5x1 1" rectangle shown in Figure 6. As an illustration, segment 118 10 is located on I-10 EB between Acadian Thruway and College Drive. Segment 11810 is 0.12 miles long and has a posted speed limit of 55mph. During the morning peak, the cumulative travel time to the entrance of the segment is 33 seconds. The cumulative travel time to reach segment 12426 is 41 seconds, Therefore, on average, it takes 8 seconds to traverse this segment. The corresponding average speed is 51 mph. Similarly, the off peak travel time through this segment is 10 seconds and the average speed is 48 mph. During the evening peak the travel time through this segment is 23 seconds and the average travel time is 27 mph. The shading next to the average segment speed provides visual indication of the ratio of observed speed to speed limit so that problem areas are readily apparent.

The procedure to produce printed report pages such as the one shown in Figure 7 has been automated using Microsoft's Access 7. A series of concatenated macros coordinated by a single master macro have been defined to execute the necessary queries on the travel time table. In a typical application, database operators would be asked to select a range of dates, say from May 16, 1995 to August 16, 1995. Then they would be asked to select the report page of interest, the printing date, and the operator's name. The application automatically formats the report page and sends the results to the 11x17" printer. Using a Pentium 133 machine, the whole process takes about 1 minute. The procedure could then be run again for producing other report pages.

CONCLUSION

In this paper, a methodology for collecting, reducing and reporting data for congestion management systems is described. This methodology is based on GPS-GIS technology. Compared to'traditional approaches such as the floating car technique which require a significant amount of manual field work and are prone to recording errors, GPS is capable of providing a very accurate depiction of vehicle location and speed.

A trade-off in the automation provided by GPS is the large amounts of data that it produces. A reduction scheme was devised to decrease the amount of data to be stored. Such a scheme was based on the aggregation of GPS data using segments of road typically 0.2 mi in length. However, the model is sufficiently general so that smaller or larger segment sizes can be easily accommodated.

The data reduction and storage system is a geographic database that uses a relational database model. The GIS-based model allows for both spatial and non-spatial queries. Examples of the type of results that the system can provide include displaying travel time and speed using color coded maps and reports in tabular form. Color coded maps are effective for explaining congestion problems at public meetings, but tend to become bulky and awkward for archiving purposes. The tabular "strip map" reports offer a very compact way of archiving travel time and speed data. The procedure to produce these tabular reports has been automated, therefore increasing the usefulness of such an approach.

The methodology described in this paper is sufficiently general as to allow its use beyond the specific case of Baton Rouge. Currently, the same approach is being followed to develop similar systems in New Orleans and Shreveport, Louisiana. In the case of New Orleans, the congestion corridor network covers approximately 300 mi. In the case of Shreveport, it covers approximately 90 mi.

ACKNOWLEDGMENTS

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Quiroga, C.A., and Bullock, D. (1996b). "Updated Procedures for Performing Travel Time Studies". Submitted to the ASCE Journal of Transportation Engineering.

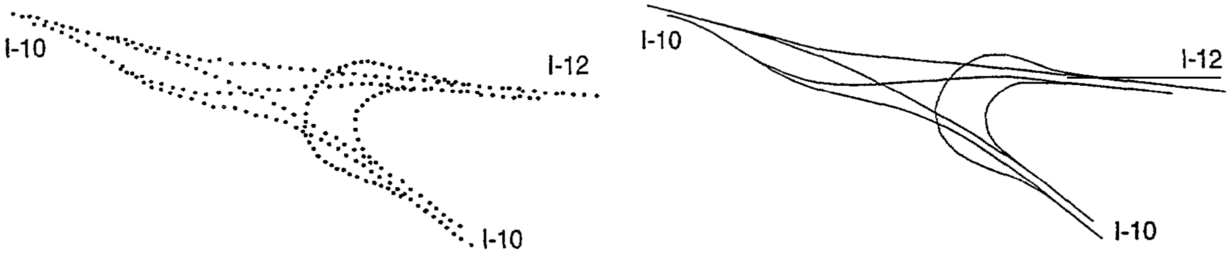
Trimble Navigation Ltd. (1993). ***Placer GPS 400 Installation and Operator's Manual.*** Sunnyvale, California.

Table 1: GPS file format used for data reduction

Time (s)	Latitude (°)	Longitude (°)	Speed (mph)
43339	30.4079608	-91.1860431	33.4
43340	30.4080936	-91.1860955	34.4
43341	30.4081597	-91.1861196	33.2
43342	30.4083609	-91.1861840	32.8
43343	30.4084293	-91.1862008	32.7

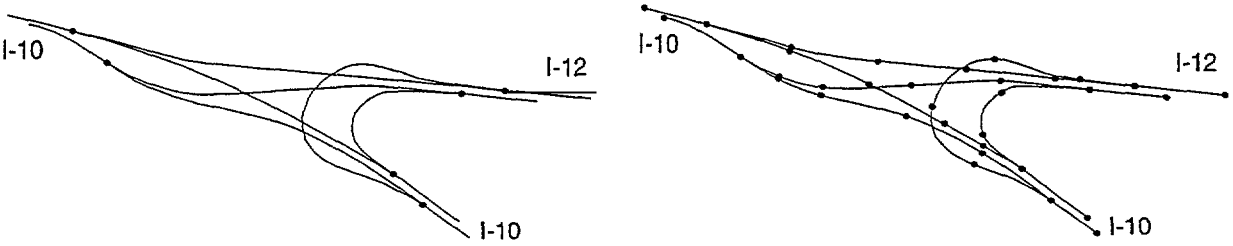
Table 2: Example travel time and speed data at the I-10 & I-12 Split

Segment Code	Date	Starting Time (seconds GMT)	Vehicle ID	Travel Time (seconds)	Segment Speed (mph)
12444	25-JUL-95	49556.75	2	11.5	56.50
12451	25-JUL-95	49568.25	2	7.0	57.30
12450	25-JUL-95	49574.75	2	7.0	57.30
12463	25-JUL-95	49581.75	2	12.5	58.78
12464	25-JUL-95	49594.25	2	12.5	59.17
12444	23-JUL-95	43546.78	1	10.97	60.86
12451	23-JUL-95	43557.75	1	7.0	58.52
12450	23-JUL-95	43564.75	1	5.5	59.08
12463	23-JUL-95	43570.25	1	12.5	60.64
12464	23-JUL-95	43582.75	1	11.5	62.21
12444	25-JUN-95	42000.25	2	12.5	52.92
12453	25-JUN-95	42012.75	2	8.0	51.25
12454	25-JUN-95	42020.75	2	10.0	51.53
12444	13-AUG-95	41211.25	1	11.5	61.27
12453	13-AUG-95	41222.75	1	6.0	59.94
12454	13-AUG-95	41228.75	1	7.0	58.38



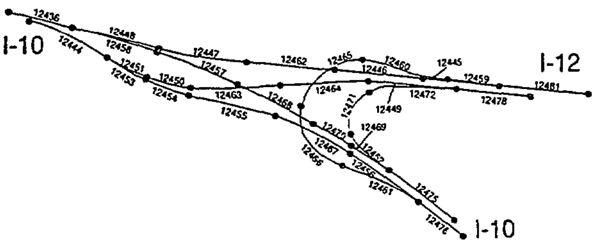
(a) Raw GPS data

(b) Vector representation of study routes



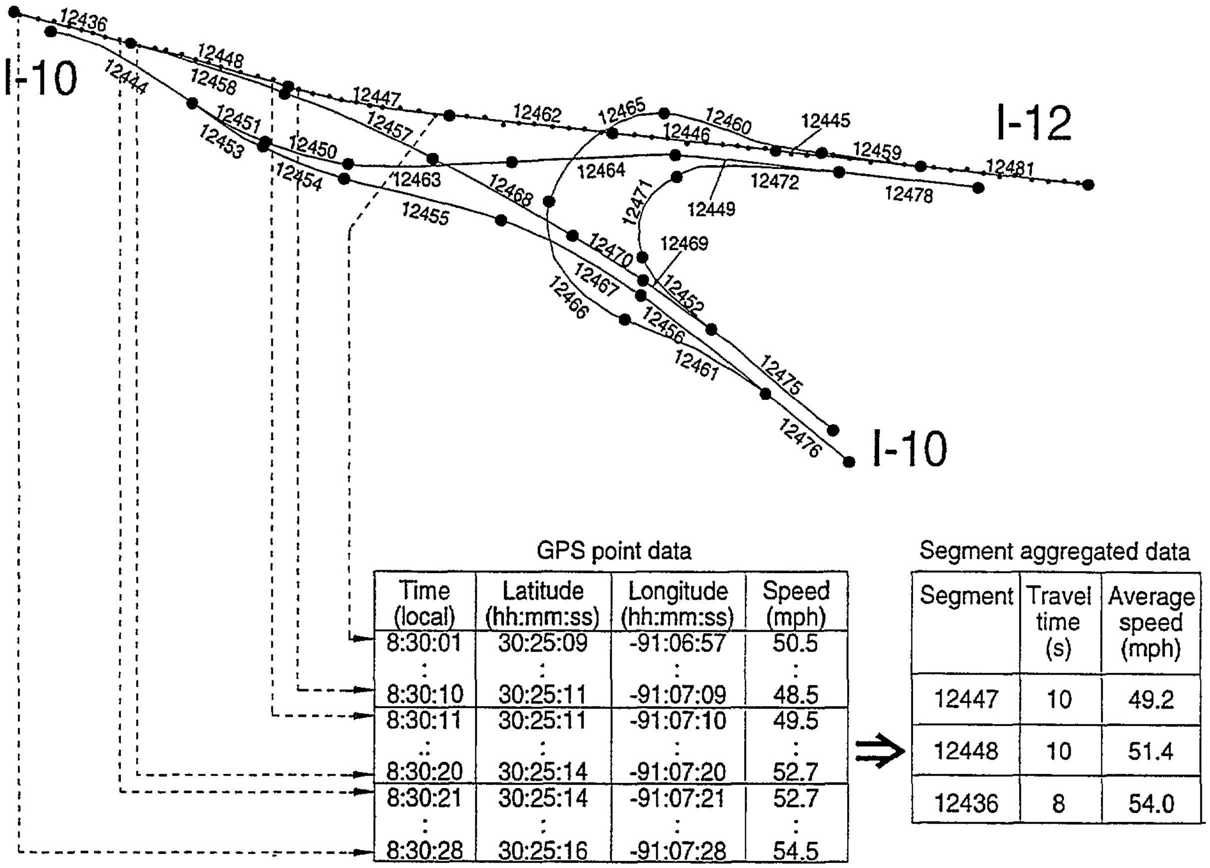
(c) Vector representation broken at discontinuities

(d) Vector representation broken into regularly spaced intervals



(e) Segments linked to database

Figure 1: Sample network map geocoding and segmentation of the I-10612 split in Baton Rouge, Louisiana



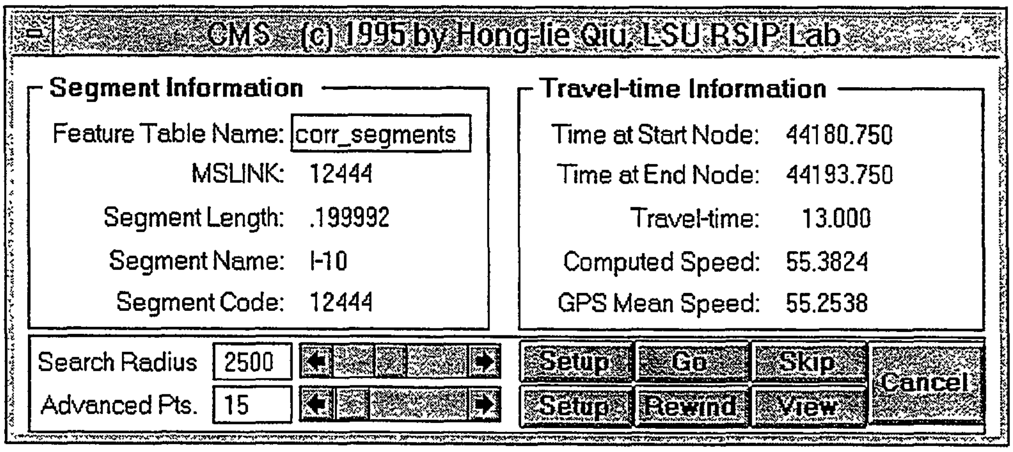
GPS point data

Time (local)	Latitude (hh:mm:ss)	Longitude (hh:mm:ss)	Speed (mph)
8:30:01	30:25:09	-91:06:57	50.5
:	:	:	:
8:30:10	30:25:11	-91:07:09	48.5
8:30:11	30:25:11	-91:07:10	49.5
:	:	:	:
8:30:20	30:25:14	-91:07:20	52.7
8:30:21	30:25:14	-91:07:21	52.7
:	:	:	:
8:30:28	30:25:16	-91:07:28	54.5

Segment aggregated data

Segment	Travel time (s)	Average speed (mph)
12447	10	49.2
12448	10	51.4
12436	8	54.0

Figure 2: GPS data mapping onto highway segments


CMS (c) 1995 by Hong-lie Qiu, LSU RSIP Lab

Segment Information

Feature Table Name: corr_segments
MSLINK: 12444
Segment Length: .199992
Segment Name: I-10
Segment Code: 12444

Travel-time Information

Time at Start Node: 44180.750
Time at End Node: 44193.750
Travel-time: 13.000
Computed Speed: 55.3824
GPS Mean Speed: 55.2538

Search Radius: 2500
Advanced Pts.: 15

Figure 3: GPS data reduction form

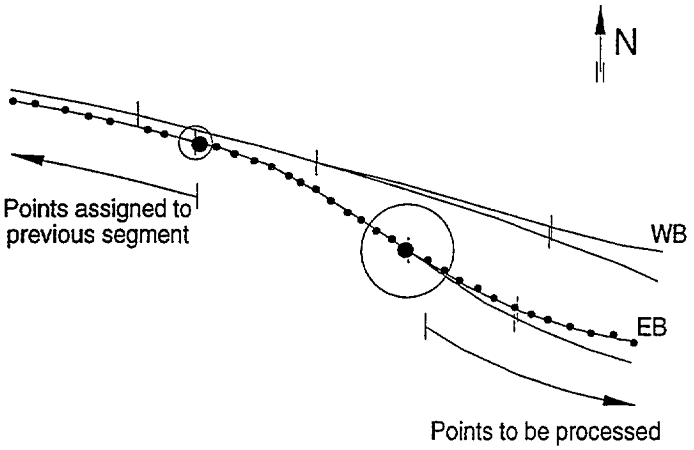


Figure 4: Assignment of GPS points to segment 12444 shown in Figure 1

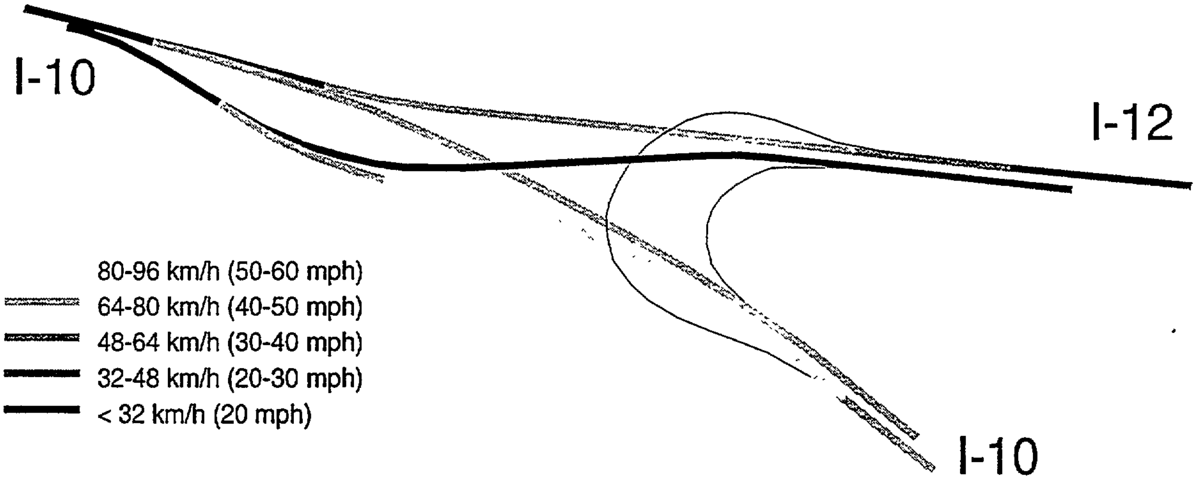


Figure 5: Minimum speed between 3:00 pm and 6:00 pm for the period May 1st-August 24th, 1995, at the I-10 & I-12 split

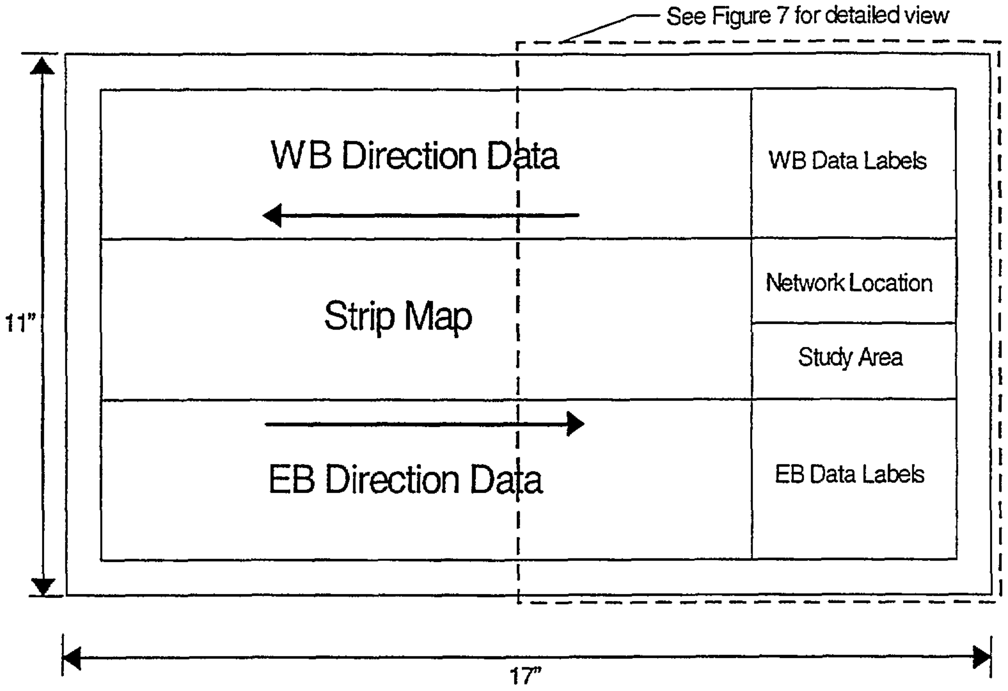
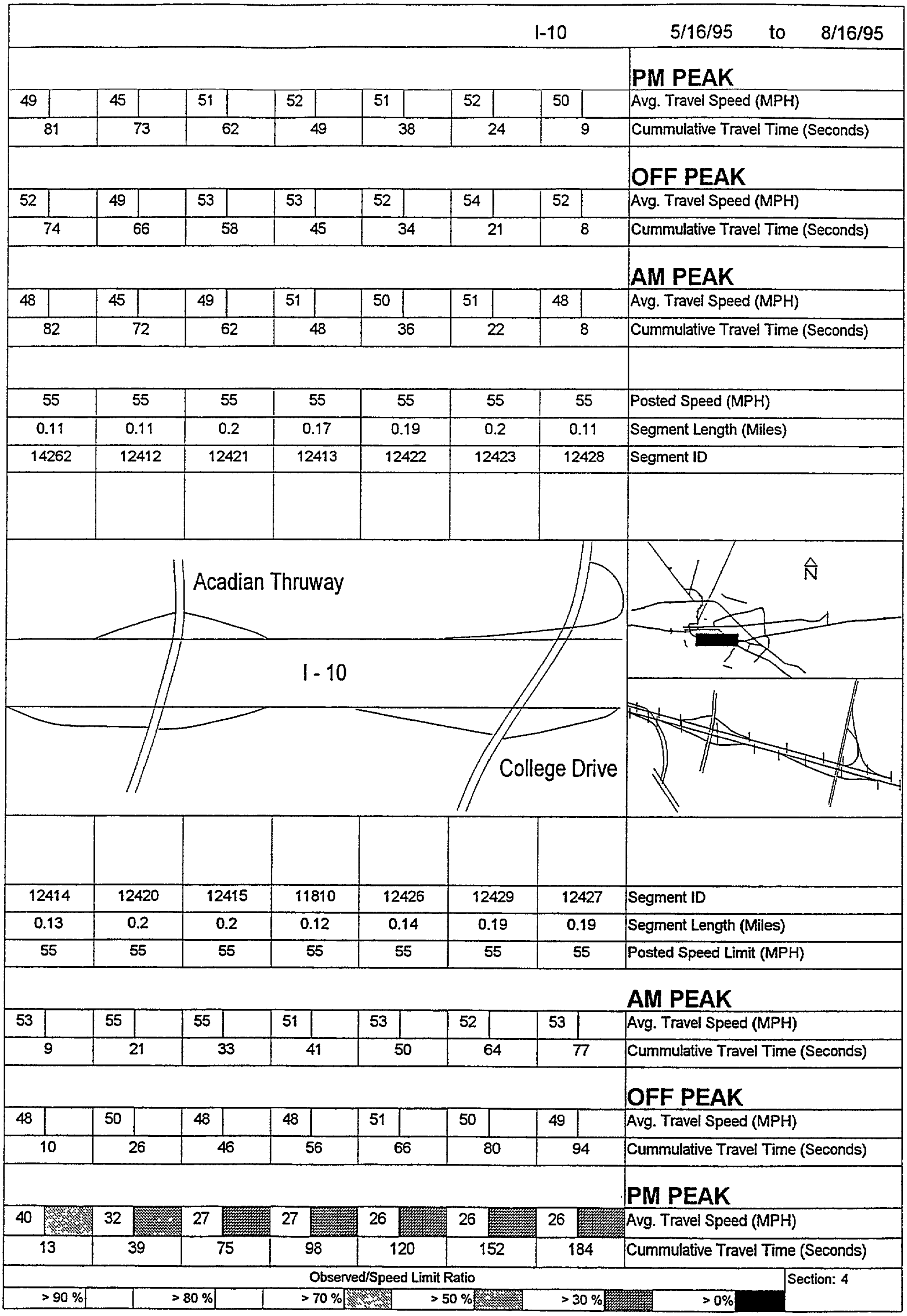


Figure 6: Standard report page structure



I-10 5/16/95 to 8/16/95

							PM PEAK
49	45	51	52	51	52	50	Avg. Travel Speed (MPH)
81	73	62	49	38	24	9	Cummulative Travel Time (Seconds)
							OFF PEAK
52	49	53	53	52	54	52	Avg. Travel Speed (MPH)
74	66	58	45	34	21	8	Cummulative Travel Time (Seconds)
							AM PEAK
48	45	49	51	50	51	48	Avg. Travel Speed (MPH)
82	72	62	48	36	22	8	Cummulative Travel Time (Seconds)
55	55	55	55	55	55	55	Posted Speed (MPH)
0.11	0.11	0.2	0.17	0.19	0.2	0.11	Segment Length (Miles)
14262	12412	12421	12413	12422	12423	12428	Segment ID

12414	12420	12415	11810	12426	12429	12427	Segment ID
0.13	0.2	0.2	0.12	0.14	0.19	0.19	Segment Length (Miles)
55	55	55	55	55	55	55	Posted Speed Limit (MPH)
							AM PEAK
53	55	55	51	53	52	53	Avg. Travel Speed (MPH)
9	21	33	41	50	64	77	Cummulative Travel Time (Seconds)
							OFF PEAK
48	50	48	48	51	50	49	Avg. Travel Speed (MPH)
10	26	46	56	66	80	94	Cummulative Travel Time (Seconds)
							PM PEAK
40 ░	32 ▒	27 ▓	27 ▓	26 ▓	26 ▓	26 ▓	Avg. Travel Speed (MPH)
13	39	75	98	120	152	184	Cummulative Travel Time (Seconds)

Observed/Speed Limit Ratio — Section: 4

> 90 %	> 80 %	> 70 % ░	> 50 % ▒	> 30 % ▓	> 0% ■

Figure 7: Example of report page

TRAVEL TIME DATA COLLECTION USING GPS

Jim Gallagher
Central Transportation Planning Staff, Boston, MA

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9,1996

ABSTRACT

With the advent of the ISTEA Management Systems, particularly the Congestion Management System, travel time has emerged as an important measure of the performance of a transportation system. In the Boston MPO, travel time has not previously been systematically collected, and most corridor studies that included evaluations of travel time or speeds relied on manual “floating car” techniques to collect this data. This technique is very labor intensive and provides many opportunities to introduce error into the results.

To reduce the opportunity for error and the data collection costs (or, to collect more data at the same cost), CTPS investigated the use of Global Positioning System (GPS) equipment to collect travel time data. Using a laptop computer, with a GPS card in the PCMCIA slot and an external antenna, travel time information was collected simultaneously with this device and using the traditional manual methods. Comparisons of the results obtained with each generally showed segment differences of less than 0.1 mile in distance and 1 mph in speed between the two methods.

Most travel time data in the Boston MPO is now being collected using GPS (some manual collection is still done because only one GPS unit is currently available). Processing the wealth of data collected in a timely fashion has been the biggest obstacle faced to date. Using our GIS, a number of subroutines have been written to convert the latitude/ longitude readings to state plane coordinates, to overlay the GPS points onto the local road network, and to calculate the travel time, distance, and speed between any two points. Currently, GPS data can be easily converted to these parameters between designated points on many of the freeways and major arterials in eastern Massachusetts. In the future, the remaining data along these routes may be used to produce speed profiles, as needed, along road segments, to better calibrate traffic microsimulation and emission models, and for other purposes not yet envisioned.

BACKGROUND

Travel time data is being used in the Boston area Congestion Management System (CMS) to identify problems, evaluate a variety of multimodal strategies, and monitor the results of implemented actions. Travel time was selected as a performance measure because it has the following advantages:

- Travel time is the most common way that users measure the quality of their trip;
- It is a variable that can be directly measured (as opposed to a calculated or assumed variable, like capacity, or delay);
- Travel time data collection can easily be designed to identify the location and extent of bottlenecks and queues;
- Travel time is a simple measure to use for traffic monitoring, such as through the construction of travel time contour maps;
- Because travel time varies inversely with speed, it can be easily related to operational restrictions and limitations, such as speed limits;
- Travel time allows for the evaluation of the statistical accuracy and reliability of results;
- Travel time can be forecast using existing regional models as well as future, improved models.

As a result, a large amount of new travel time data was expected to be needed in the Boston region.

USES OF TRAVEL TIME DATA IN THE BOSTON REGION

Traditionally, the collection of travel time in the Boston region has been limited to corridor studies, where intersection level of service calculations have been verified and supplemented with this information. However, this has changed with the coming of Congestion Management System. Travel time, expressed as a variety of performance measures, has been identified as a variable which has the ability to express many of these mobility goals of the Massachusetts CMS. Recent before-and-after studies have employed travel time to measure the effectiveness of transportation improvements. And regional model calibration to speeds is becoming a reality.

Perhaps not coincidentally, a wealth of travel time data has been collected in the Boston metropolitan area in the past few years. Beginning in the spring of 1994, over 2000 travel time runs have been carried out using floating car techniques on both freeways and arterials. As a result, identifying and adopting the best techniques for collecting travel time data has become a priority in the Boston region.

WHY GPS?

Our reasons for investigating the use of Global Positioning Systems (GPS) were simple - the potential for more accurate data at reduced cost. All the manual travel time data collection efforts in the Boston region utilize two persons, a driver and a recorder. Using GPS, the human recorder is replaced by the GPS receiver and a laptop computer. This reduction in staff requirements greatly increases our capacity and flexibility in data collection.

Manual data collection methods also have a number of potential sources of error. Recording points can be missed or incorrectly recorded. The information recorded can be incorrectly transferred to the computer database. Finally, using odometer readings or maps introduces inaccuracies in the link lengths.

Data collection using GPS removes most of these errors, but may introduce new ones. Data is collected every second, with checkpoints identified later, possibly automatically. Data transfer involves no recopying or editing.

However, the uncorrected GPS latitudes and longitudes we were using have a presumptive accuracy of +/- 300 feet from the true point. And with data collection every second, a vehicle traveling at 60 MPH, for example, could actually be 88 feet distant from the target location when information is recorded. A discussion of whether the resulting travel information is accurate enough will be presented later in the paper.

Besides accuracy, GPS increases the amount and variety of data available. Since information is collected every second, queue lengths, stopped delay, and link speed profiles can all be developed. None of this is possible using traditional manual methods.

Finally, longitudes and latitudes provide travel times with a geographic anchor. This allows easy assimilation with Geographic Information Systems (GIS), a potent force for data integration and presentation.

DATA COLLECTION

Equipment

For the initial GPS data collection in the Boston region, a Compaq laptop computer was purchased for under $1000. This is a 486-based machine running at 25 MHz, with 4Mb RAM, a 171 Mb hardrive, and black and white screen. A PCMCIA Type II slot is the only optional equipment needed to use the GPS card. Other “better” Compaq laptops have since been used as well, with no problems.

The GPS card is a Rockwell SATNAV, with NMEA output. An external antenna and magnet is provided to attach to a vehicle roof. These and similar cards are available for around $600.

The equipment weighs less than 10 pounds and is easily setup in all vehicles we have used. A cigarette lighter adapter for the computer was purchased to insure a reliable power supply. This particular laptop and card configuration will run about one-half hour on the computer’s batteries.

Software

The signals captured by the GPS receiver can be read by the computer using the Terminal program of Windows. This will display and save data exactly as received from the GPS card. Editing and analysis of the data must be done elsewhere.

Our initial GPS data collection employed this approach, as the card arrived before the software we purchased. This method is a perfectly adequate approach to basic data collection, but ultimately it lacks the flexibility to alter data collection formats.

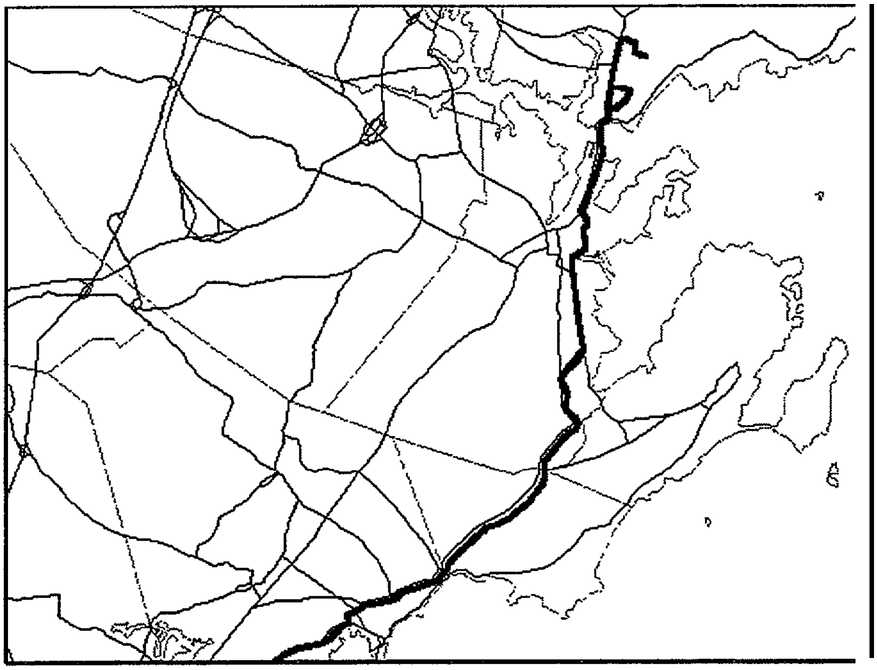
GPSLOG software is currently used to collect and save data. This allow us to collect positions every second, every N seconds, or only at selected points. Information on the satellites being tracked, course, speed, distance, and a variety of other information is also available from the program. But tracking the vehicle’s movement in real time on the laptop requires additional software. Vehicle tracking was not considered necessary for travel time data collection.

Many software packages are available for collecting GPS data. Good software will read the GPS card you are using (all software does not read all GPS output formats), allow control of the data collection rate (Windows Terminal program does not), and interface directly with your GIS software.

The Data Collection Process

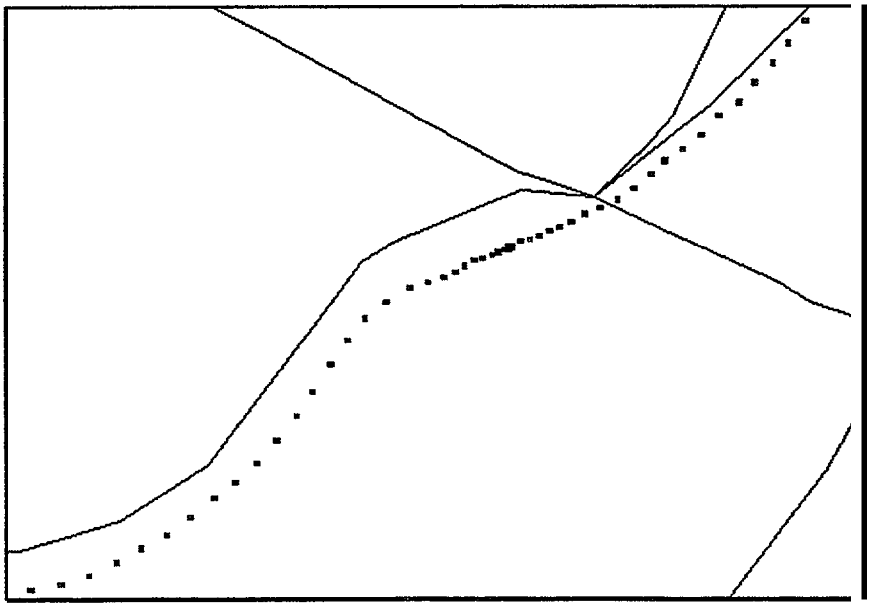
Any GPS receiver should provide data on latitude and longitude (in degrees, minutes, and seconds) and the time those readings were collected (in Universal Time Coordinated, formerly Greenwich Mean Time). Altitude is also frequently available, although sometimes with less reliability. Ground speed, course, information on the satellites in view, and an estimate of the dilution of precision attached to these readings are additional outputs provided.

Data collection is simple. A single driver is used for each travel time run, in effect moving the GPS equipment over the correct route. Unless a problem occurs, no other human intervention is necessary - once the program has been invoked, it begins collecting all the available data as soon as the required number of satellites have been located (more about problems with this later).



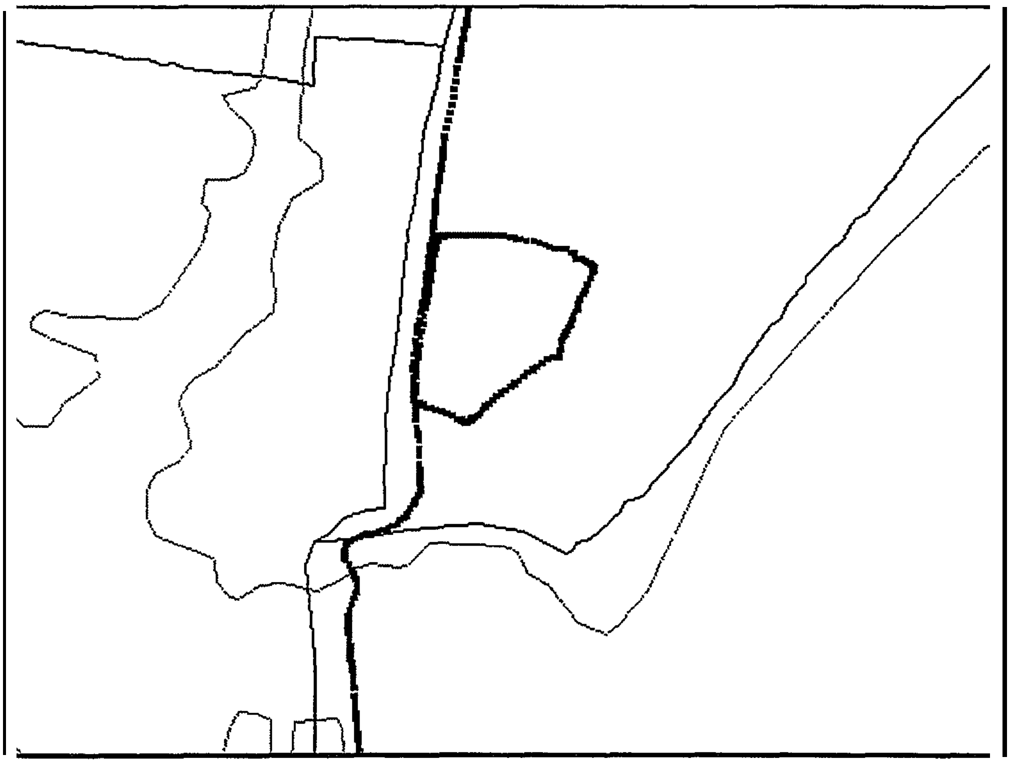
In the Boston area, GPS was initially used to collect travel time information on freeways. GPS can also be used for arterial runs, as shown to the left, and this has been the primary source of travel time data for these roadways in the Boston area.

Data can be collected every second, and this is the typical collection rate in the Boston region.



Using GPS on arterials, for example, will show queues and delays at signals. Speed profiles can be developed, and acceleration and deceleration rates can be calculated.

And GPS will even reveal errors during the data collection process (a quick detour for coffee perhaps).

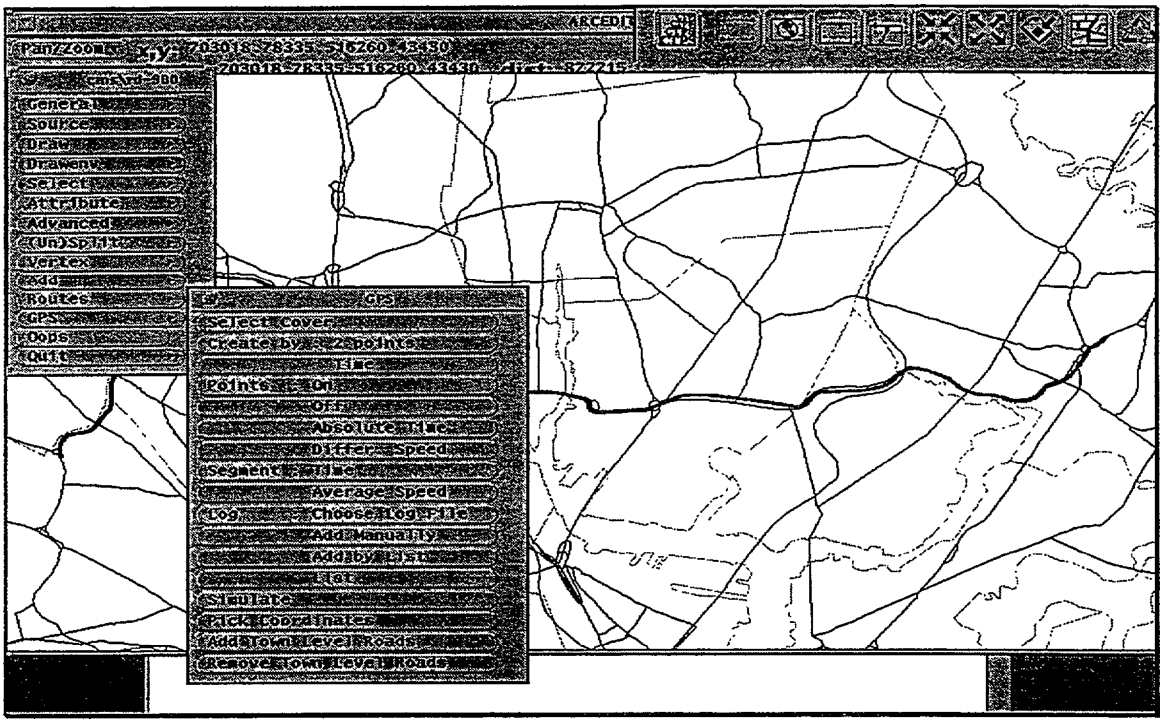


However, tunnels and trees can block satellite reception, and tall buildings can reflect signals and distort positions. This makes GPS unsuitable or unavailable for certain locations.

PROCESSING THE COLLECTED DATA

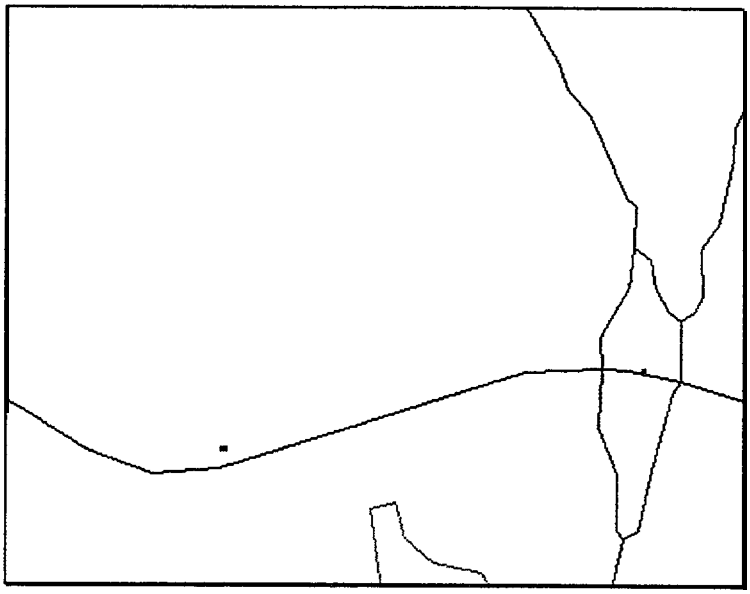
While collecting information on locations every second is easy with GPS, turning this into useful information on segment travel times or queues at traffic signals can be time consuming and tedious. Canned programs which make the necessary calculations and provide outputs in a format readable to GIS systems would be a tremendous benefit, and are likely to be developed as more areas use GPS for a variety of data collection efforts. However, we do not possess such software in Boston.

In the Boston region, the GPS data was processed in ARC/INFO, the GIS platform available. The menu system below was developed to standardize and simplify the editing process. Many months of work went into the development of this menu system.



This menu (and the programs behind it) allows us to find the coordinates and times of individual points, and to calculate the distance, travel time, and average speed of segments for any travel time run. Most importantly, it allows us to automatically calculate this information for a predetermined set of segments along any route. A file is created containing the route, date, segment name, segment start and end times, segment length (which is calculated independently for every travel time run as another error checking step), and the average speed along the segment, for each segment along a route which has been driven with a GPS.

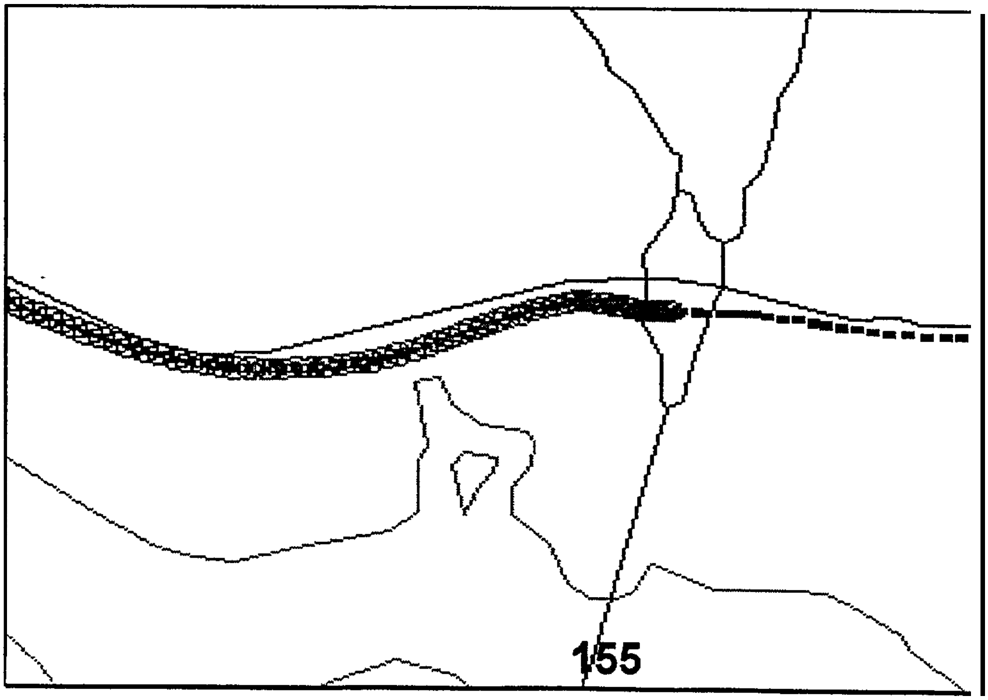
To edit the results automatically, checkpoint locations must first be marked. This is also done using GPS, using the Manual recording mode of the GPSLOG software. As with the “true” Manual method, information is only recorded at selected points. Rather than the just the time a checkpoint is passed, however, the latitude and longitude of this point is also captured.



The map to the left shows two points selected in this manner and edited into the GIS.

These results are then applied to the GPS results done every second along the same route. The GIS routine identifies the points with coordinates closest to those selected (within 500 feet) as a segment, and calculates length, travel time, and speed automatically.

The result of this automatic segment identification is shown below.



ISSUES IN USING GPS

Accuracy of GPS Versus Manual Methods

To check on the accuracy of using GPS, travel time data was collected on the southern section of Route 128 (the ring road around Boston) in October, 1995 for the PM Peak period. Three complete runs were made, both northbound and southbound, and data was collected using the standard Manual method and GPS equipment simultaneously, with the same people.

For the Manual method, two person teams are always used. The passenger uses a stopwatch to determine the time when certain predetermined checkpoints are passed. These times are recorded manually, and eventually entered into an EXCEL spreadsheet, where checkpoint locations and the distances between each have already been entered. Once the checkpoint times are entered, link travel times and speeds are calculated automatically. This process involves considerable startup costs to determine the checkpoints and the link distances, but once setup, adding the results of subsequent runs usually takes less than an hour.

The GPS data collection setup involves a small laptop computer, with GPSLOG software installed, and a GPS card inserted in the PCMCIA slot, as described previously. Two alternative methods are available for collecting GPS data with this setup.

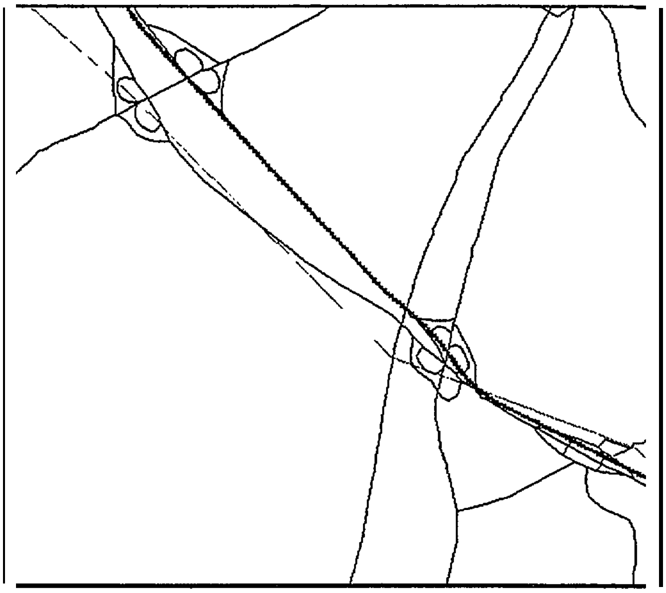
The first, the GPS Manual method, essentially mimics the Manual methods described above. The ENTER key on the laptop is struck whenever a checkpoint is passed. GPSLOG will record the time, longitude, and latitude for each checkpoint, saving the information in a file. As with the Manual method above, two persons are generally required to safely and accurately record information in this manner.

The second method is known as ASAP in GPSLOG. The GPS receiver reports longitude, latitude, time, altitude, and a variety of other information every second. GPSLOG will record this information every second when in ASAP mode (it can also be configured to record a subset of this information - every 2,5, or 10 seconds, for example). Since this information is collected automatically, a second person is not needed for data collection (for this test, the passenger’s only GPS responsibility was to monitor its continued operation).

Distances in the Manual GPS method are calculated based on the straight line distance between the two checkpoints. ASAP distances, on the other hand, are the cumulative total of the distances between every two points collected every second. We would expect the ASAP method to be more accurate for curved segments.

GPS information is received by triangulating on a least 4 of 24 satellites. GPS longitudes and latitudes collected in this manner have a claimed accuracy of ± 100 meters (times are supposed to be within a nanosecond, due to the atomic clocks on the satellites).

Corrections are possible to accuracies within 1 meter, but these are not available with the setup we use in the Boston region. Whether these inaccuracies lead to inaccurate link distances and travel times is the major question to be addressed below.



The map at left shows data collected for one of the ASAP runs. Note that the GPS and map coordinates sometimes agree closely on the location of the roadway, other times there are differences.

The initial columns in Tables 1 and 2 below compare standard Manual method results with those from GPS Manual. Since the data were collected simultaneously, any differences in results should be due either to operator errors (failure to hit the ENTER key, or to record times simultaneously), or to the inaccuracies inherent in uncorrected GPS lat/lon readings. Differences in distance and speeds between the two methods are shown for each segment, for all runs.

There were no significant differences in elapsed times (never more than 2 seconds) between the two Manual methods, with one missed GPS checkpoint and one startup problem being the only significant sources of Manual error. Differences in distances can perhaps be attributed to GPS inaccuracies, and ranged from 0 to 0.21 miles. Almost all GPS distances are smaller than the “official” Manual distances. Most Manual GPS discrepancies would seem to be attributable to the straight line method of calculating distances, or to the extra mileage added by changing altitudes. In fact, all of the differences greater than 0.1 mile occur between Exits 16 and 17, a long, curving section with rolling terrain. Since distances show much smaller errors in the ASAP results (see below) this would suggest that most of the distance errors are due to the straight line estimates.

Nevertheless, since the elapsed time and distances are generally in agreement, the speeds estimated from the two Manual methods are very similar. Only the Exit 16 to Exit 17 segment has differences in speeds over 3 MPH, and even here, since the speeds are always above 50 MPH, both methods would indicate free flow speeds.

More interesting is whether GPS data collected by one person is comparable to the standard Manual results. The last four columns in each table show these comparisons. The ASAP GPS results were developed using the coordinates identified in the Manual

TABLE 1

COMPARISON OF GPS VERSUS MANUAL DATA COLLECTION
Route 128 Northbound

	Differences - Manual minus GPS							
	GPS Manual - Run 1		GPS Manual - Run 2		GPS ASAP - Run 1		GPS ASAP - Run 2	
Segment	**Distance**	**Speed**	**Distance**	**Speed**	**Distance**	**Speed**	**Distance**	**Speed**
SE expressway On-Ramp to Exit 6	-0.01	-4	NA	NA	-0.01	-1	NA	NA
Exit 6 to Exit 5B	-0.11	-4	NA	NA	-0.05	0	NA	NA
Exit 5B to Exit 4	-0.04	-3	-0.05	-3	-0.03	-3	-0.06	-3
Exit 4 to Route 24 On-Ramp	-0.03	-1	0.02	1	-0.03	-5	0.02	-5
Route 24 On-Ramp to Exit 3	0.01	0	0.01	0	0.01	0	0.02	0
Exit 3 to Exit 2B	-0.02	-1	-0.02	-1	-0.01	0	-0.02	0
Exit 2B to I-95s 1/2 mi sign	0.02	0	0.02	1	0.01	1	0.01	1
I-95S 1/2 mi sign to Exit 1	-0.03	-1	-0.03	-2	-0.03	-3	-0.01	-3
Exit 1 to I-95 On-Ramp	0.01	1	0.02	2	0.01	2	0.01	2
I-95 On-Ramp to Exit 13	-0.02	-2	-0.02	-2	-0.02	0	-0.01	0
Exit 13 to Exit 14	-0.01	-2	-0.02	-2	0.00	-1	-0.02	-1
Exit 14 to Exit 15A	0.01	1	-0.02	1	-0.01	0	-0.02	0
Exit 15A to Exit 16A	-0.05	-2	-0.03	-1	-0.04	-1	-0.02	-1
Exit 16A to Exit 17	-0.18	-6	-0.21	-6	0.01	-1	-0.02	-1
Exit 17 to Exit 18	0.00	-3	0.02	-2	-0.01	-1	0.01	-1
Exit 18 to CRR Overpass	-0.02	0	-0.04	-3	-0.02	2	-0.04	2
CRR Overpass to Exit 19 1mi sign	-0.04	-3	-0.04	-3	-0.01	-2	-0.01	-2
Exit 19 1 mi sign to Exit 19	-0.01	-1	0.00	-1	-0.02	-1	0.00	-1
Exit 19A to Exit 20 sign	0.00	0	0.00	0	0.01	1	-0.01	1
Exit 20 sign to Exit 20A	-0.01	0	0.00	1	-0.02	2	0.00	3
Exit 20A to Exit 20B	0.01	3	-0.02	-1	0.01	0	0.36	-16

TABLE 2

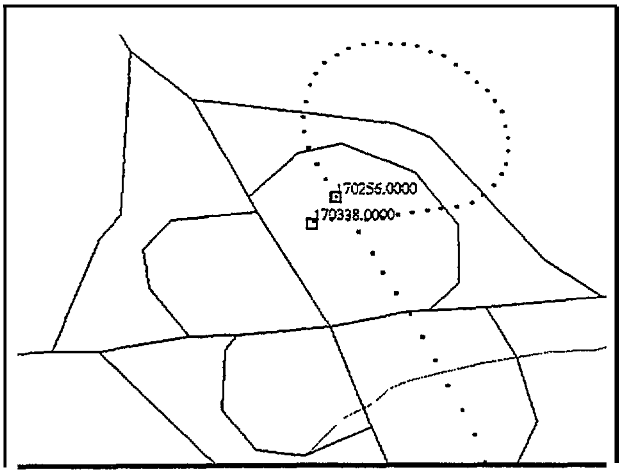
COMPARISON OF GPS VERSUS MANUAL DATA COLLECTION
Route 128 Southbound

	Differences - Manual minus GPS							
	GPS Manual - Run 1		GPS Manual - Run 2		GPS ASAP - Run 1		GPS ASAP - Run 2	
Segment	**Distance**	**Speed**	**Distance**	**Speed**	**Distance**	**Speed**	**Distance**	**Speed**
Exit 20A to Exit 19B	-0.01	0	-0.02	-1	-0.01	0	0.00	0
Exit 19B to Kendrick Overpass	-0.04	-4	-0.03	-3	0.00	1	-0.02	1
Kendrick to Exit 18 1 mi sign	-0.05	-3	-0.05	-1	-0.06	-2	-0.05	-2
Exit 18 1 mi sign to Exit 18	-0.08	-4	-0.06	-3	-0.07	-2	-0.03	-2
Exit 18 to Exit 17	-0.01	0	-0.01	0	0.00	0	-0.02	-1
Exit 17 to Exit 16B	-0.10	-4	-0.11	-5	0.02	-2	0.03	-2
Exit 16B to Exit 15B	-0.04	-2	-0.07	-2	0.02	1	-0.02	3
Exit 15B to Exit 14	-0.04	-2	-0.02	-1	-0.02	0	-0.01	-1
Exit 14 to I-95 1 mi sign	0.01	1	-0.01	0	0.03	0	0.01	0
I-95 1 mi sign to Exit 13	-0.01	0	0.02	0	0.05	1	0.07	1
Exit 13 to I-95S Off-Ramp	-0.03	-2	-0.03	-1	-0.03	-2	-0.03	-3
I-95S Off to I-95N On-Ramp	-0.02	-1	-0.01	-2	0.01	-4	-0.01	-4
I-95N On-Ramp to Exit 2A	-0.01	0	-0.01	-2	0.02	1	-0.01	0
Exit 2A to Exit 3	-0.02	0	-0.02	0	-0.01	0	-0.02	0
Exit 3 to Exit 4	NA	NA	-0.01	-2	NA	NA	-0.01	-1
Exit 4 to Route 24 On-Ramp	NA	NA	0.00	3	NA	NA	0.00	-1
Route 24 On-Ramp to Exit 5A	-0.01	-1	-0.02	-2	0.01	0	-0.02	0
Exit 5A to Exit 6 1 mi sign	-0.05	-4	-0.03	-1	-0.02	-2	0.00	-2
Exit 6 1 mi sign to Exit 6	-0.02	-1	0.01	0	-0.03	0	0.02	0
Exit 6 to SE expressway Split	-0.04	-4	-0.03	-1	-0.03	-1	-0.03	-1

GPS runs. While the ASAP data were only collected during one run, the second, the coordinates from both Manual GPS runs were used to develop separate estimates, to determine how much the particular set of coordinates used influences the outcome.

If anything, these results show even better agreement with the Manual. All differences in distances are less than 0.1 mile, all speeds agree to within 5 MPH. It is particularly significant that the low speeds found on the southbound run were accurately detected by the GPS.

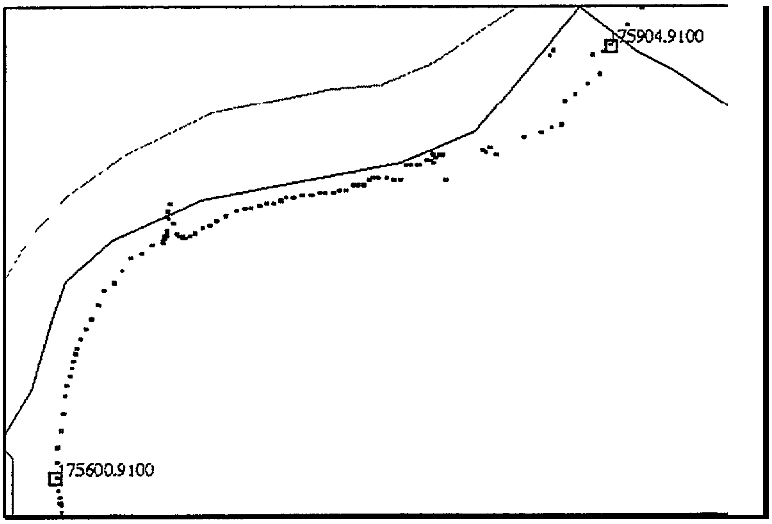
Also significant is the small difference in results using the two different sets of Manual GPS coordinates. Segment lengths never differ by more than 0.04 miles, speeds never more than 2 MPH. Travel times did differ by up to 23 seconds (southbound, Exit 16B to Exit 15B), but this was during a stretch where traffic was barely moving and had no impact on speeds.



The one exception to these close fits occurs on the last northbound segment, Exit 20A to 2OB, where the coordinates from the last Manual GPS run produce results far different from any other. The figure on the left illustrates why this happened. The points shown are the universe of ASAP points available for matching the Manual GPS coordinates. The point labeled 170256 was matched to the first run coordinate, and can reasonably be seen as the correct checkpoint. However, point 170338 was actually closer to the last run coordinates, and its selection added 0.35 miles and 42 seconds to the estimated link results. This problem can be eliminated by removing any obviously spurious points from the file before segment identification begins, but it does illustrate the need for careful editing to insure accurate results.

It seems clear that GPS data, particularly ASAP data, can produce travel time information as accurately as our standard Manual methods. It also seems clear that ASAP should be preferred over the Manual GPS method, since it will require only one person to collect data and produce more accurate distance estimates. Inaccuracies from the GPS receiver would appear to have minor impacts on travel time results.

Distorted Coordinates



Since GPS distortion is typically the same amount from point to point, most distances are highly accurate, as demonstrated above. However, a few GPS distances on arterials have differed from the Manually-measured figures by almost 20%. This is due to distorted coordinates, shown at the left, which typically occurs when the receiver switches satellites between two points, or when reflections off buildings or other surfaces occur. In this case, since the distance between the individual points increases, the segment distance also increases. This problem can be recognized and corrected in post-processing.

Picking Up Satellites

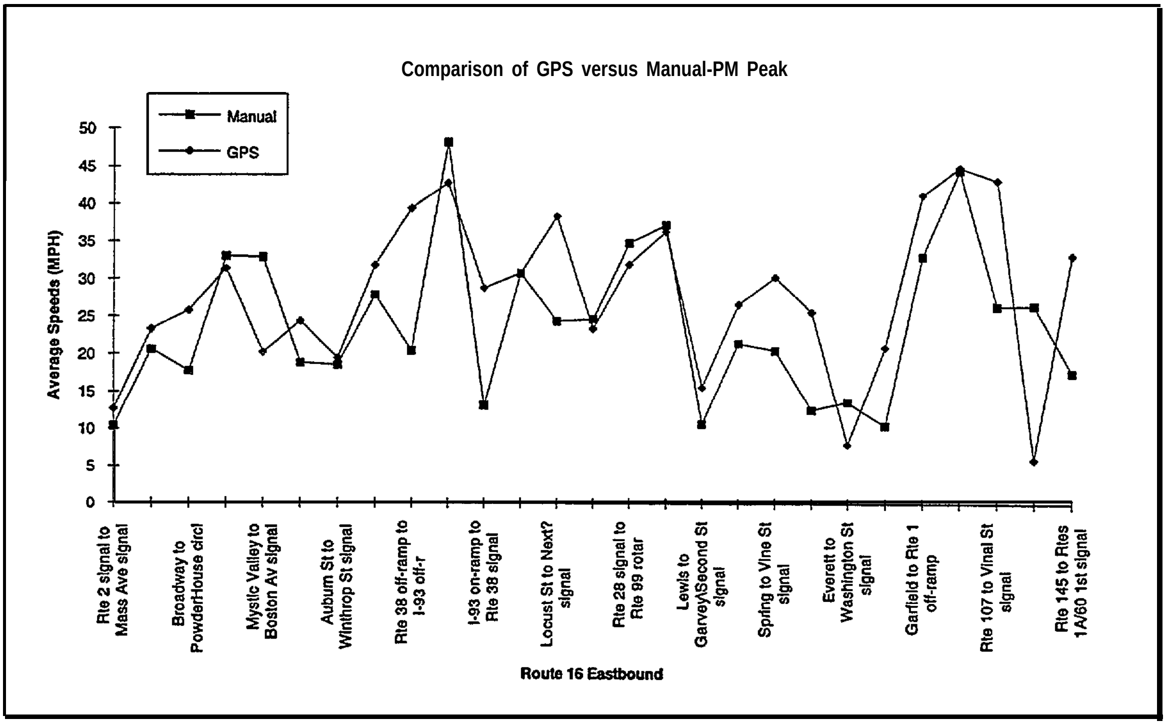
A particular problem in the Boston area has been the initial location of satellites by the GPS receiver. This has ranged from a reasonable l-2 minute time frame up to an hour or more. Until 4 satellites can be located, no position data can be collected. Problems are typically more pronounced in the CBD, but we have had problems making the initial contact in suburban areas as well. After repeated consultations with both the hardware and software manufacturers, the reasons for this problem remain unclear. The problem itself is infrequent enough that data can still be collected without too much wasted time on those days. However, it is troubling that this occurs, and is the biggest single disappointment we have encountered to date in the Boston region with GPS.

Future Extensions

We in Boston have just begun to explore the possibilities for using the wealth of data collected with GPS receivers. Having accurate information on vehicle locations along a road every second provides the opportunity to develop link speed profiles. Queues and delays at a signal or at any point can be readily detected and counted from the collected information. Rates of acceleration and deceleration, and time spent idling can be calculated. Programs for our GIS are currently being written to allow all this information to be easily extracted. Calibration of traffic engineering and air quality models to previously unavailable data will follow. Surely other applications will emerge as well.

IN CONCLUSION

The graph below shows speeds collected along one arterial in 1995 using both Manual and GPS methods. Both lines show the expected variation from point to point along a route, and the differences in the averages are probably due more to sampling issues than to any differences in techniques. The point is, GPS is no longer an experimental technique for collecting travel time, it's ready for widespread use.



The following conclusions should help other areas decide whether GPS is appropriate:

- **Startup will be time-consuming, but GPS will eventually save money;**
- **With care, GPS can be more accurate;**
- **Differential GPS is not needed for travel times;**
- **Satellite reception can be a problem;**
- **GPS is a flexible, robust data collection method.**

Many new ways of collecting transportation data are emerging. GPS is certainly one that can be successfully used in many areas.

TRAVEL TIME DATA COLLECTION USING GPS TECHNOLOGIES

David Roden
JHK and Associates

Presented at
National Traffic Data Acquisition Conference
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Roden, David

Travel Time Data Collection using GPS Technologies

Introduction

The Clean Air Act Amendments (CAAA) of 1990, the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, and public involvement in transportation investments have changed the orientation of transportation planning and traffic engineering. In the past, the primary concern was to determine travel demand, enabling the engineers and planners to design a transportation system to adequately accommodate the demand estimates. Now that CAAA and ISTEA regulate the decision making process for transportation investments, quantifying air quality and demand management impacts are significantly more important. For air quality analysis, detailed profiles of travel speed are needed in order to calculate the vehicle emissions by time of day and, if possible, by categories of a driving cycle. In the ISTEA arena, multi-model performance comparisons are needed for Major Investment Studies (MIS), Congestion Management Systems (CMS) and Inter-modal Management Systems (IMS). These systems compare the performance of a wide variety of travel options that can not be quantified with traditional level of service measures based on highway traffic volumes. Since most people seem to agree that the primary objective of a transportation system is to move people and goods from one place to another in the least amount of time and at a reasonable cost, the public tends to think more in terms of travel time (rather than volume) in evaluating the quality of the transportation system. As a result of CAAA, ISTEA and public involvement, travel time and speed are becoming critical performance measures in most transportation studies.

In the current general practice, the high costs and limited accuracy of travel time and speed data collection have hindered planner and engineer use of these data for transportation studies. Travel speed data are typically collected using vehicle probes to approximate the average behavior of drivers in the traffic stream. In addition to the driver, a passenger is usually employed to record events using stop watches and tally sheets. Alternatively, the driver records events on an audio tape for transcription later in the office. Either method is costly and time consuming, and requires manual data processing to evaluate the results.

There are a number of opportunities, given advances in technology, to devise much more cost-effective, comprehensive travel time data collection systems than have been possible in the past. Research in Intelligent Transportation Systems (ITS) technologies is identifying a number of these opportunities for application in the planning arena. There are several possible techniques that could yield travel time data of the quality necessary to support air quality and congestion management activities:

- Spot speed measurement technologies. This approach employs a range of detector technologies to measure speeds at spot location. Approaches range from traditional inductive loop detectors to video image detection.
- Vehicle matching or identification approaches. These techniques include traditional license plate matching, automated matching through video image processing, and various forms of automatic vehicle identification (AVI) with AVI readers placed at strategic points within the network.
- Vehicle tracking approaches. These include a range of technologies from dead reckoning systems to global positioning systems (GPS).
- Trip tracking through the recording of origin/destination location and trip start and stop time, either manually or through automated means.

This report focuses on the potential of GPS technologies for travel time and speed studies. Of all the techniques listed above, GPS technologies may be the most useful and cost-effective method of collecting a significant quantity of travel time and speed data in the near term. It is by far the most flexible, and has the potential to revolutionize transportation data collection in a variety of areas. It has been suggested, for example, that GPS technologies could simplify data collection to the point where volunteers from the general public could collect trip and travel time data as part of their daily activities with minimal inconvenience. Even for simple corridor studies, GPS methods would have several advantages. Data collection costs would be reduced, post-processing of the speed data would be automated, the data could be displayed graphically (e.g., with GIS software), and both spot speeds and average speeds would be available. GPS deserves serious consideration for a wide variety of transportation planning and traffic engineering applications. This report highlights many of these opportunities.

General GPS Concepts

The Global Positioning System (GPS) is a $13 billion satellite-based positioning and navigation system sponsored by the US. Department of Defense. It is free to all users and can provide exact position and the current time - 24 hours-a-day, anywhere in the world, in any weather. GPS operates on the principle of triangulation. The GPS receiver uses the signals from multiple satellites to calculate the latitude, longitude, altitude, time, and velocity vectors of the receiver. Most receivers can update this information at the rate of once per second.

In order to operate effectively, the GPS receiver needs to have an unobstructed view of at least three or four satellites. (Three satellites are needed for two dimensional (i.e., latitude and longitude) position fixes and four satellites are needed for three dimensional positioning). The signal can be interrupted by tall buildings, dense tree cover, and underpasses and tunnels. The quality of the position information is also effected by a concept called Selected Availability (SA). The Department of Defense (DOD) intentionally builds random errors into the signals available to the general public (and foreign countries). The time stamp sent by each satellite is changed on a second by second basis. For each nano-second of error in the signal, the location calculation will be off by one foot. Until recently, SA had the effect of reducing the accuracy of the GPS location to plus or minus 100 meters. DOD currently provides accuracy at the 70 meter level, and there is significant pressure to reduce the error further or eliminate it altogether. If SA is eliminated, the accuracy of the GPS position would be approximately plus or minus ten meters.

The problems caused by SA can be generally overcome through a concept called Differential Correction or Differential GPS (DGPS). Since most GPS receivers include data filters, the errors caused by SA are generally consistent as long as the same set of satellites are used. When the GPS receiver switches to a different set of satellites, the relative error will change and the position can jump dramatically. These types of errors can be corrected with real-time or post-processing differential correction services. DGPS adjusts the position identified by the GPS receiver according to the position errors calculated by a stationary GPS receiver. The user subscribes to a correction service that transmits position errors on FM radio frequencies that are received by a DGPS unit in the vehicle. Alternatively, the GPS data can be shipped to a post-processing center that applies the position errors to the recorded information. Since corrections must be applied using a receiver within close proximity to the data collection site, at nearly the exact time the data was collected, a correction service may not be available for a specific area. In general, DGPS services are available near navigable waterways and most cities. In addition, there are programs currently in place to implement 100 percent coverage of the United States within two years.

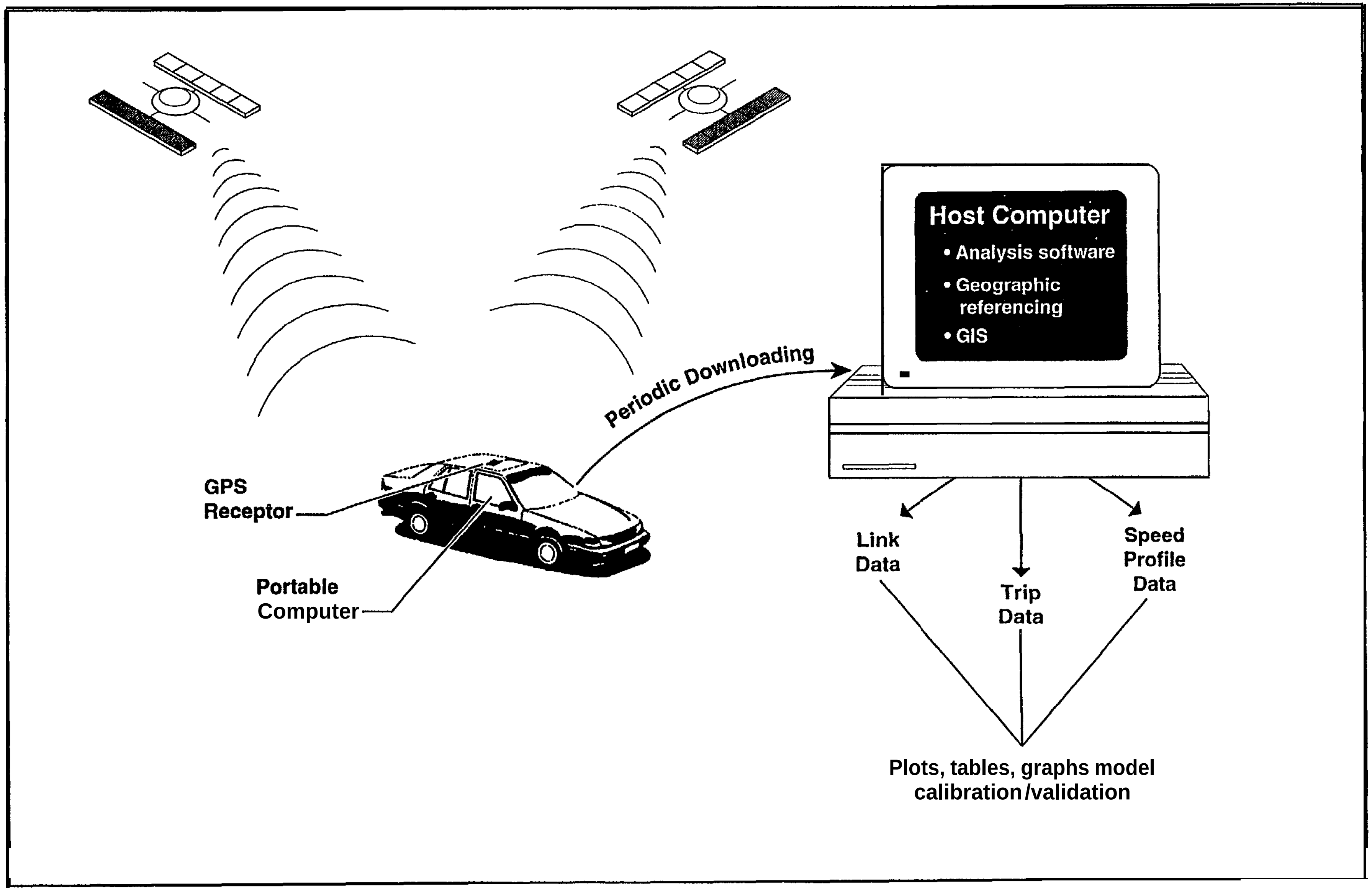
GPS and Travel Time

GPS is a proven technology that has already revolutionized marine navigation and land-based engineering surveys. It is quickly becoming an essential component in vehicle navigation systems and a variety of ITS applications. Since GPS data collection hardware is easy to use, portable, and inexpensive, the potential applications of GPS technologies for transportation planning and traffic engineering are attractive. It can be used to perform traditional travel time and speed studies, but it also has the potential to revolutionize the collection of network-based performance measures.

The general concept is to link a GPS receiver to a palmtop (or laptop) computer to record trips through the transportation network. The GPS unit will generate latitude, longitude, time, and velocity data at one or two second intervals. The data will be uploaded to a master database on a regular (perhaps weekly) basis. The location coordinates will be associated with a geographic reference and processed to tabulate link travel time and delay. Incident data will be screened, and travel time runs for the same timeframe and link will be averaged. This will serve as the basis for travel model calibration and validation, and as the documentation of existing conditions for problem identification and public presentation. Figure 1 is a simple illustration of the process.

One of the benefits of GPS-based data collection is that speed and position information is recorded at a greater level of detail than is possible through traditional travel time studies. This enables the analyst to visualize and quantify the variability of speed within a given roadway segment. Figure 2 shows a typical speed profile for U.S. Route 1 in Northern Virginia. The stop and go effects of the traffic signals are clearly visible. The dotted line in the middle of the plot shows the average segment speed available through a traditional travel time study. The detail provided by the GPS data reveals a totally different perspective on the level of mobility provided by the arterial. It also shows the acceleration-deceleration and speed variations that affect network capacity and vehicle emissions.

One of the interesting observations drawn from an assessment of repetitive travel time measurements, such as those taken in Phoenix, is that the travel time varies from day to day. Figure 3 shows that the average speed over a 17-mile section of Interstate 10 in downtown Phoenix varies significantly from day to day. Individual links are even more variable. This speaks to the need to measure travel time over multiple days, not just in several runs over a one or two day period. By building average speeds through multiple observations, the overall reliability of the speed estimates are significantly improved. In addition, the standard



Conceptual Diagram of GPS Travel Time System

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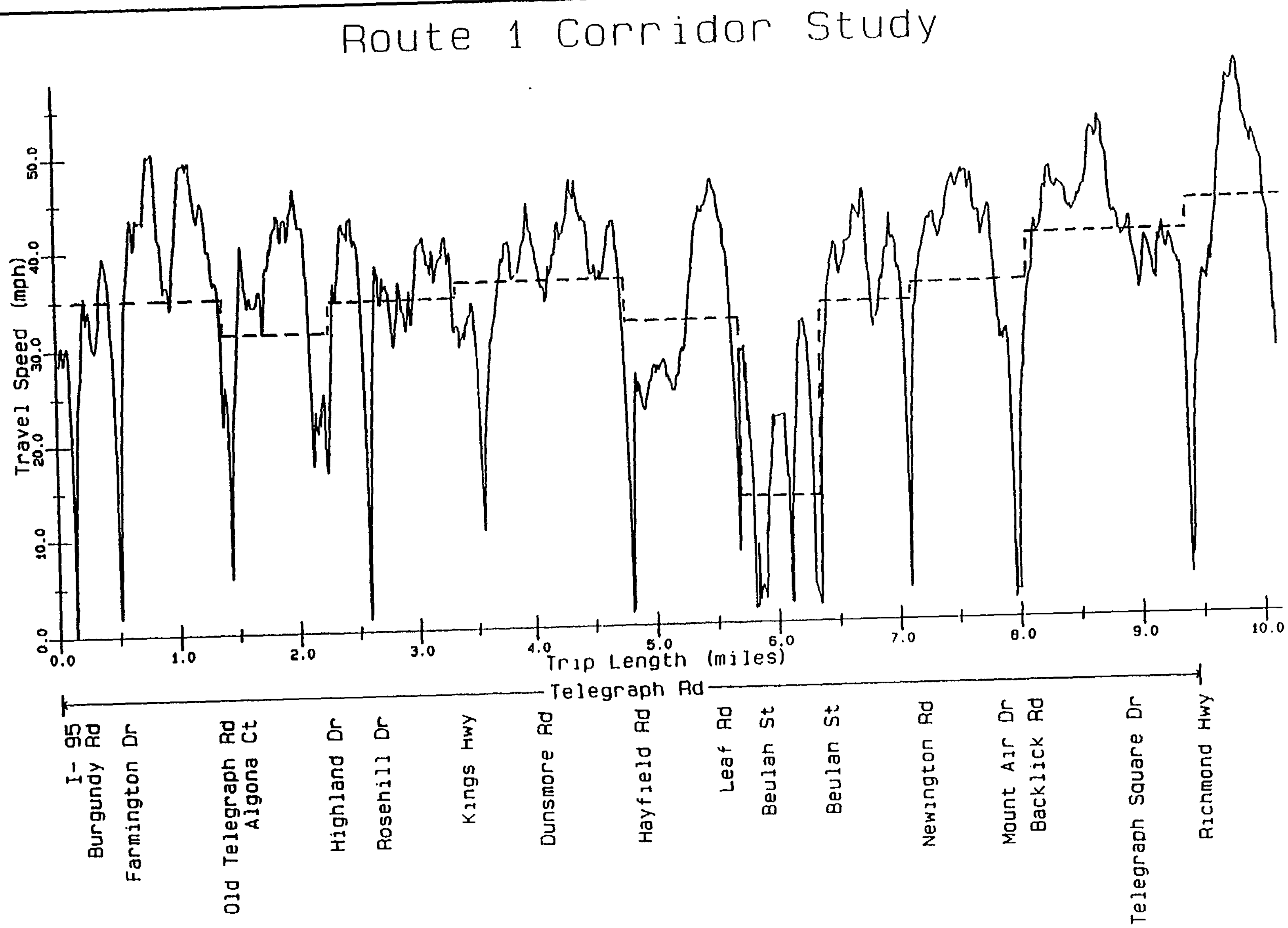
Figure
1



Typical Speed Profile

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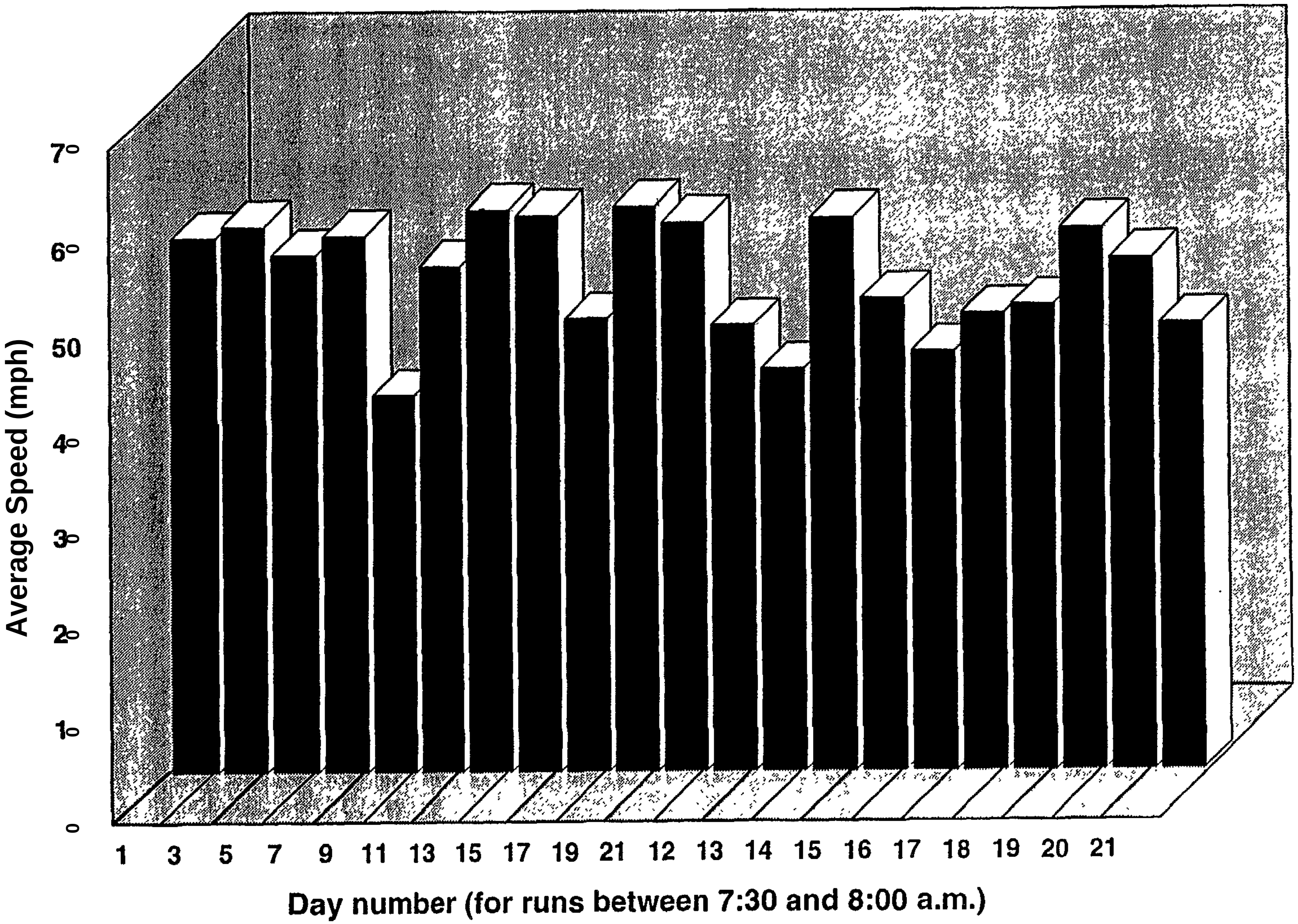
Figure
2



Average Speeds from a 17-Mile Freeway Section in Phoenix
(7:30-8:00 A.M., each bar represents one weeday run)

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Figure
3

deviation in the speed estimate can be accurately calculated. This deviation in speed has the potential to become a very important performance measure for defining the quality of service provided by a given roadway. Measures such as these can be helpful in developing investment priorities.

GPS Hardware and Software

If travel time data collection is to be practical and cost-effective, it must be cheap, portable, accurate, and easy to use. GPS-based travel time data collection systems can effectively respond to these requirements. A GPS receiver and a Palmtop computer are extremely portable and simple to operate. The cost of a data collection unit is currently less than $1,200, and the prices are steadily dropping. Over the last three years the price of GPS receivers has dropped by as much as 2000 percent. A unit with a 1992 cost of $8,000 may sell for as little as $100 in 1996. The units that are readily available for travel time data collection applications currently cost around $500. A Palmtop computer adds about $700 to the unit price.

In addition, GPS receivers are currently available on PCMCIA cards for laptop computers. In the near future, the power requirements of PCMCIA receivers are expected to be low enough to operate on Palmtop computers. The potential of a GPS receiver in a PCMCIA card operating off a Palmtop computer will make installation and operation extremely simple and the data collection unit highly portable. This would expand GPS-based data collection to include pedestrian, bicycle, taxi, and transit trips.

For GPS technologies, accuracy beyond the standard 100 meters is directly related to price. Differential correction options that provide lo-meter, &meter, l-meter, or sub-meter accuracy are readily available. DGPS services that utilize FM radio stations to broadcast data corrections can provide lo-meter accuracy for as little as $75 a year. These prices increase to around $250 for 5-meter service and $600 for l-meter service. The FM receiver required for real-time correction costs as little as $375. These prices suggest that logical tradeoffs between accuracy, price, complexity, and portability are readily available to travel time applications.

Notwithstanding, there are several considerations beyond price that are important in selecting a GPS receiver for travel time data collection. For example, the number of channels and the types of filtering algorithms are important. Many low cost GPS receivers use only one channel to track satellites. Consequently, the receiver must poll satellites one at a time to gather the data required to determine the current position. This results in less accuracy and slower response. In addition, because they are not necessarily tracking the same set of satellites that a 10 channel stationary receiver is using, these receivers do not function as reliably with differential correction.

Travel time data collection equipment should include at least three channels in order to provide one second response rates. Receivers with five or six channels can be useful in areas where tall buildings and tree cover are prominent. Higher channel receivers are also better suited for differential correction. Since differential correction provides more accurate position information, which in turn effects the accuracy of the speed estimates and improves the correlation of GPS points to a network map, the choice of a higher channel receiver is directly related to the need for more accurate data.

Filtering algorithms are used by GPS receivers to smooth the position and velocity data. As the filters "warm up" the stream of data points will be more uniform. This does not necessarily mean that the data are more accurate. It simply makes the output more logical. One of the important filters relates to the velocity data. If the data collection software uses the GPS velocity in estimating travel distance or speed, it is important to know how the GPS receiver calculates velocity. Some receivers use the doppler effects of the satellite signals to determine the velocity vectors. Other receivers use the change in position and time to determine velocity. If the velocity is being used to verify or calculate distance and position, the velocity should be calculated independently of the position data. This implies that a doppler-based velocity algorithm is necessary for advanced data smoothing.

Getting this type of information from a GPS manufacturer is not always easy. Trimble Navigation Ltd. is the world's largest manufacturer of GPS receivers and has a good reputation for quality and sophistication. It also manufactures the most expensive products. Magellan Systems Corporation has a good reputation and is actively pursuing the low price markets. Garmin and Rockwell also have low cost offerings that satisfy the general requirements of travel time data collection; however, several low cost receivers sold by Magellan and Garmin do not have the features mentioned above.

Another issue that should be considered in selecting a receiver is the interface protocol. All major manufacturers have their own proprietary protocols for communicating GPS data to the data processing software. If the software only supports one or two of these formats, it is important to purchase a receiver that matches the available software. In addition to their proprietary protocol, most GPS receivers generate a quasi-standard format called the National Marine Equipment Standard A (NMEA-0183). Since NMEA was developed for marine navigation it has several limitations that make it unsuitable for a variety of applications. For example, it does not include altitude measures and can not function at speeds over 250 mph. Since these limitations are not especially important for travel time studies, the NMEA format can be used for most travel time applications.

Perhaps the biggest barrier to GPS travel time applications is the data collection software. Most of the software available for GPS applications is engineering and navigation oriented. Software that records the location of physical features or provides bearing and heading for navigating travel paths is readily available. It is also feasible to collect GPS data and import this data into a GIS package. Trimble even sells software that collects GPS data from within ESRI's ArcView GIS package.

It is problematic that little of the current market GPS software is able to process GPS data in useful ways for travel time studies. MITRE has developed a prototype system called GOP that uses GPS for traditional travel time studies. JHK has a system called the GPS Data Logger that gathers GPS data, matches it to network maps, and generates travel time and speed summaries. There is a product developed by GEOLINK that matches GPS data to a GIS database and performs a variety of analyses that can be useful for travel time studies. Universities in Florida and Louisiana are developing similar procedures for other GIS packages. In general, there are a number of development activities underway that are likely to make GPS-based travel time data processing more convenient in the near future.

Travel Time and Speed Studies

Traditional travel time and speed studies are based on a floating car technique. The driver attempts to replicate the average travel speed of a given facility by passing as many vehicles as pass the survey vehicle. A second person is needed to operate two or more stop watches and record the time data at identifiable check points. Alternatively, the driver uses a tape recorder to identify time point and the tape is transcribed later. When the travel time is combined with distance information from maps or vehicle odometers, the average speed on the roadway segments between check points can be calculated.

In a traditional travel time study the overall accuracy of the results is rather poor, the quantity of data that can be collected is relatively small, and all of the variability of speeds within a given segment is lost. If a significant investment is made in the installation of customized distance, time, and speed recording equipment to the survey vehicle, the overall accuracy is greatly increased, but the cost and quantity of data collection will suffer. Problems of this nature have severely limited travel time data collection in the past.

There are two basic approaches to resolving the problems of traditional travel time data collection using GPS technologies. The first approach mimics the traditional process in methods and procedures, but uses GPS technologies to reduce costs and increase productivity. This is the approach that MITRE has used for their GOP prototype. GOP uses a predefined travel path and a set of user specified reference points to guide the driver through a travel time data collection run. The computer prompts the user to mark each reference point as it is passed. The travel time, speed, and distance are summarized for each segment in exactly the same way as a traditional travel time study. It also provides the detailed speed profiles and delays for the complete trip.

This method has the advantage of operating in a stand alone environment, because it is not tied to a network map or global positions. All of the geographic references are provided by the user. Since the user interacts with the software at each reference point, all that is needed from the GPS receiver is the time and velocity data. The data are used to calculate segment lengths and plot speed and travel time profiles.

The primary disadvantage of this approach is its dependance on user input. Requiring the user to note the cross street locations and to hit a keyboard key as these locations are passed, is a relatively simple procedure, but there are inherent safety and insurance implications which will limit its application to trained technicians and transportation professionals.

If the goal of the travel time data collection effort is to gather the same data provided by traditional travel time studies, the approach outlined above will satisfy the requirement in a cost-effective way. It does not, however, take advantage of the full capabilities of GPS technology. If the whole concept of data collection is reexamined within the context of GPS technology, a significant number of added benefits can be envisioned for the transportation industry. The transportation planning and traffic operations professions are under considerable pressure to enhance and modernize the analysis procedures used to evaluate advanced technologies and environmental impacts. If these procedures are to be improved, new data will be required to calibrate and validate the model enhancements. GPS technologies may be the most cost-effective way to gather this data.

If the goal of a GPS-based travel time data collection program is to serve the needs of a variety of new and emerging transportation information requirements, a significantly different approach to GPS data collection should be considered. This approach envisions a GPS-based travel time data collection program as an areawide sampling procedure that builds a database of statistically accurate speed and travel time data by time-of-day for all parts of the region. As the database matures it could enhance the interpretation of traffic counts and serve as a primary performance measure for regional analysis. The data can be used to calibrate model relationships and address the requirements of Congestion Management Systems and air quality analysis.

If an area-wide data collection program is implemented, the GPS technology and user interface would need to be simple enough to be used by volunteers from the general public. There may be opportunities for sampling employees of government agencies and larger private companies strategically located around the region. A regional ridesharing database is another potential source from which a sample could be drawn. Additional data could be collected on fleet vehicles such as UPS and FedEx Fleet vehicles would enable the capture of diverse set of facilities in peak and offpeak conditions. This coverage would not be represented by typical commuters. It would also be possible to use traditional telephone recruiting techniques similar to those used for home interview and travel diary surveys to identify a representative sample of survey participants. In fact, a well designed GPS data collection unit could easily replace travel diaries altogether. A GPS-based travel survey instrument would be more accurate, easier to use, and automatically geo-coded. It would gather the network performance information and the travel data simultaneously. The quantity and quality of data that could be collected using GPS technologies would be a boon to all transportation modeling applications.

Though not as simple as the first approach, a GPS data collection unit that meets the requirements of an area-wide data collection program could easily be used for traditional travel time studies. In fact, the data collection procedures would be easier, while the post processing of the data would be more involved. All that is required for data collection is to have a technician (or a volunteer) drive along the roadway of interest with a portable GPS unit recording the time and position information. No interaction with the GPS unit is required before, after, or during the trip. All the driver needs to do is turn the unit on and turn it off.

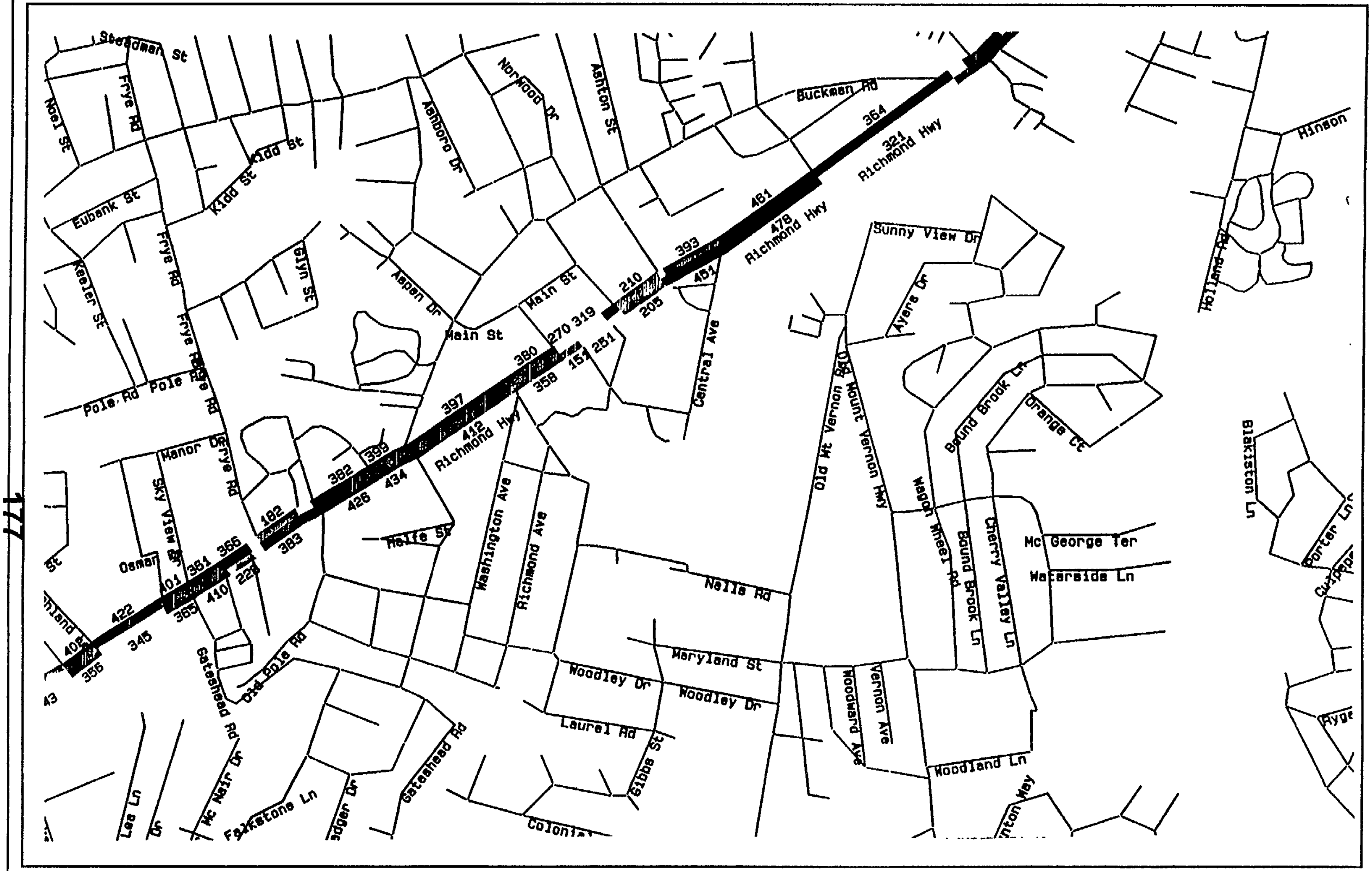
In the data processing step, the GPS data is uploaded to a database that matches the position information to a network map. Once the data is matched to the network, street name and cross street information is automatically available. The user can define reference points and have the data summarized by these or any other set of roadway segments. Since the data are related to network links, they can also be aggregated and averaged in a variety of ways. The average and standard deviation speed for each link can be calculated based on a single trip or the combination of any number of trips that traveled through the link or roadway segment during a specified time-of-day or day-of-week.

The network-based approach has the added benefit of presenting speed data as color coded maps. These can be particularly useful in presenting performance data on one or more roadways to the general public. Figure 4 shows an example map from the U.S. Route 1 Corridor Study in Northern Virginia. The map provides the general orientation for the facilities of interest drawn with colors that represent speed classifications. It becomes quite clear where traffic congestion and signal delays are unacceptable. This information can be integrated with other GIS data such as accident rates and vehicle emissions to create composite measures that meaningfully communicate the performance of the transportation system. Most Congestion Management Systems use this type of analysis to facilitate priority- and decision-making.

Network Matching

If the overall goal of the travel time data collection program is to develop a database of network-based performance measures, the data points from a GPS-based collection system will need to be matched to roadways in the transportation network. The network may be defined in a Congestion Management System, a geographic information system (GIS) or as part of a transportation planning model. In either case, the overall accuracy of the network map may be significantly less than the location accuracy of the raw GPS data with selective availability. This is especially true on curved roadways where GPS points every 10 to 20 meters would be difficult to beat by even the most sophisticated GIS database.

This suggests that map matching tends to be more difficult than might typically be expected. The selective availability of GPS satellites results in raw location data that have errors of as much as 100 meters. Since most GPS receivers include data filters, the errors are generally consistent as long as the same set of satellites are used. When the GPS receiver switches to a different set of satellites, the relative error will change and the position can jump dramatically. These types of errors can be corrected with real-time or post-processing differential correction services. This increases the cost substantially, but reduces



Speed Classification Map

JHK & Associates
An SAIC Company

Figure
4

the error by an order of magnitude. If large amounts of GPS data will be collected over several months, differential correction can be a cost-effective investment.

Even if differential correction is used, the map matching algorithm will need to include data smoothing and shape matching algorithms to adequately assign data points to network facilities. In other words, the map matching algorithm must do more than assign each GPS point to the closest network link. For example, if the GPS data is even slightly offset from a given roadway, the closest link method will cause points to jump from the roadway to the cross street and back to the roadway as they pass through each intersection. This problem can be minimized if the direction of travel is included in the closest link algorithm. Even so, GPS points that fall between parallel roadways have a tendency to flip flop between the roadways. If these types of problems are to be avoided, the GPS points must be matched as a group rather than as independent records.

Data smoothing and shape matching algorithms will straighten out the kinks in the GPS data and simulate the differential shift that will cause the GPS coordinates to more closely match the coordinates of links in the network. Smoothing algorithms generally compare individual points against a group of points to determine if the point fits within the pattern implied by the group. For example, if the general direction of travel defined by a group of ten neighboring points implies that the vehicle is moving north and the orientation of a specific point is east, the algorithm will reorient the point to fit the orientation of the group.

Shape matching algorithms are used in map matching to fit corners and curves in the GPS data to similar features in the network. Once a corner or curve is identified, the set of GPS points represented by the shape is shifted to match the network coordinates. Unfortunately, this process is complicated by the frequency of GPS data. In the GIS or transportation network, the roadway is generally represented by a centerline that joins with other roadways at sharp angles. The GPS data, on the other hand, represents a turn as a series of points along a smooth curve. The data smoothing and shape matching algorithms need to identify the smooth curve as a turn and convert it into a sharp change in direction so that it can be matched to the most appropriate network intersection.

Data smoothing and shape matching will significantly improve the GPS point assignment, but they are not quite sufficient. Problems can occur if the network is geographically inaccurate, the GPS trip does not include right angle turns, or the network is a dense grid with a large number of similar shapes. In these situations, path tracing algorithms are the best way to identify a feasible solution. Assuming the GPS vehicle is traveling on roadways that are included in the network, the map matching algorithm should be capable of using a network path to connect successive GPS points. If a particular movement cannot be made from the currently assigned link, the algorithm can identify the best match for the new point and reassign the previous points along a new path until a common link is found.

If path tracing algorithms are used, the map matching should consider traffic prohibitions in assigning links. This can be especially important for oneway streets, freeways, and intersections with turn prohibitions. Path problems also occur frequently in GIS networks. A GIS often includes a node at an overpass to represent the intersection of geographic shapes. If the network or path tracing algorithm do not recognize this intersection as an overpass, the map matching can generate link movements that do not exist in the real world. When traffic rules are included, most path inconsistencies can be avoided.

There are situations in which the map matching algorithm should break a GPS trip into several independent paths. If the network is incomplete, or the GPS trip has left the roadway to enter a parking lot or private driveway, it is perfectly reasonable to terminate the map matching until the trip reenters the coded network. Adding this capability significantly increases the complexity of the algorithm. Rules that distinguish between off network travel and path assignment errors consider search distances, angles, travel direction, goodness of fit, and path consistency. This simply reiterates the assertion that map matching must be performed based on the relationships and patterns of GPS points rather than as a set of independent records.

General Conclusion

Applying a GPS-based approach to the collection of travel time data will help to overcome some of **the** limitations of traditional approaches and open up a host of options that would otherwise be unavailable. GPS technology provides the opportunity to significantly change, if not revolutionize, collection of travel time and trip data. If properly planned, **GPS** can be used for ongoing support of congestion management and air quality analysis as well. The use of the GPS approach has implications that reach well beyond the specific needs of a corridor study, as described below:

- The GPS data collection using volunteer commuters and fleet car drivers can serve as an ongoing congestion tracking methodology for the Congestion Management System. This can be done at far less cost than through traditional methods. Trend analyses can be developed for a variety of measures, including travel time, delay, and trip time.

- It provides data not only for link travel time, but also for trip travel time. This will allow the travel models to be validated against travel time for links and trip time for selected origins and destinations.

- The GPS-based method is capable of screening data for incident influences, which can be important for accurate representation of non-incident travel times. Incidents can be screened by comparing an incident-impacted travel time run against an average travel time profile for a given facility (see Figure 5 for an example). These data could be used to build an ongoing incident database.

- Repetitive measurements over the same route provide a measure of travel time variability (induced by traffic incidents, volume variations, weather influences, etc.) that is important in expressing the level of mobility. Only one or two days of travel time data collection is insufficient for most applications of tracking congestion location, time, and duration. Figure 3 previously showed the variability of travel time for a given facility and time period over multiple days, illustrated from repetitive measurements from a GPS-equipped vehicle used in the Phoenix study.

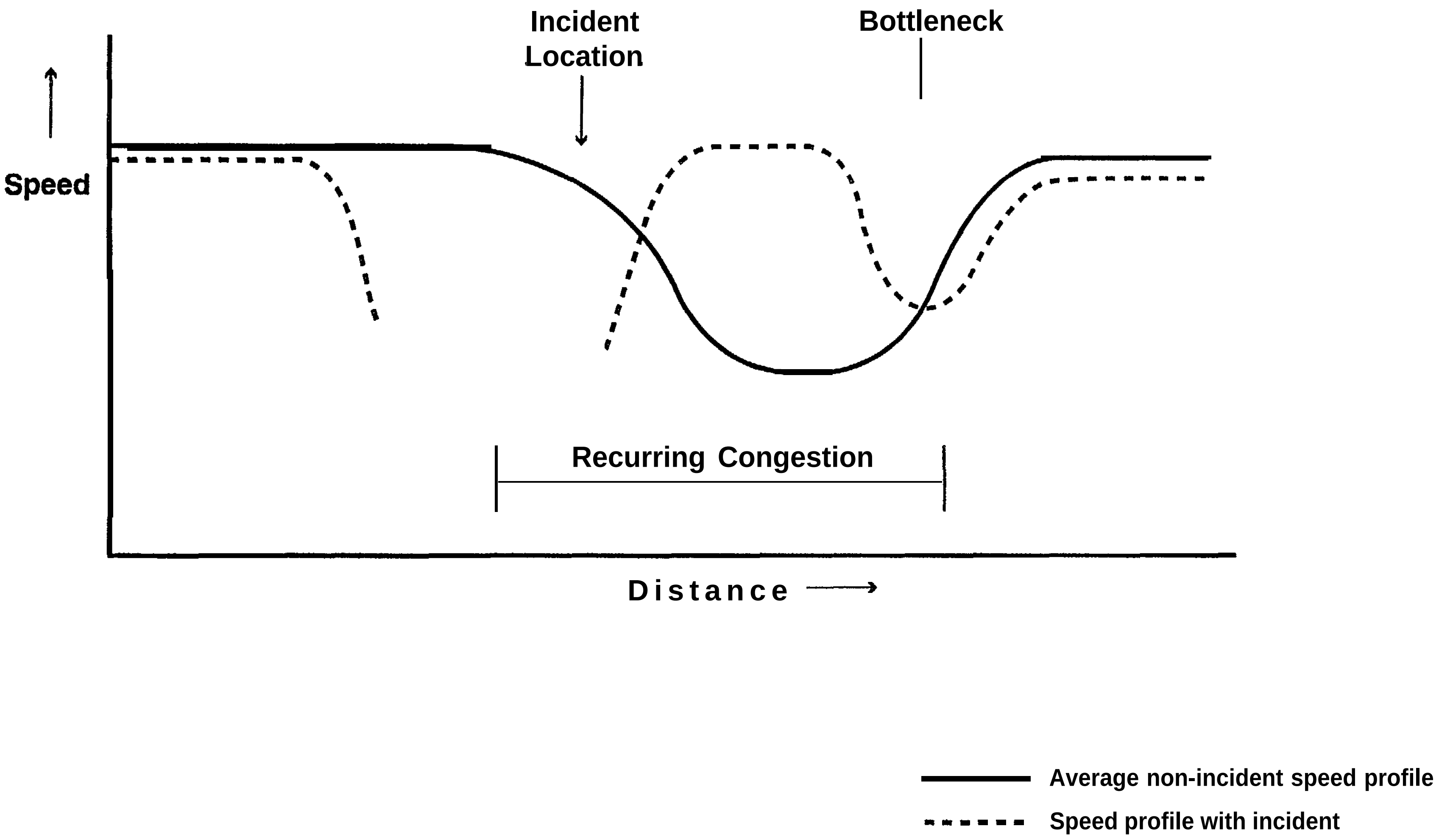
- The trip-tracking ability of GPS **may** be useful as a partial replacement for or supplement to traditional origin-destination surveys. One of the particularly useful features is the alleviation of the need for geo-coding the origin and destination. This would require the coding of trip purpose into the data generated by the GPS unit. Ultimately, the trip records could be referenced to a GIS land use coverage to assess the activity type associated with each origin and destination. This could become a data set useful for activity-based modeling at some point in the future.

Public agencies should seriously think through the broader opportunities that an ongoing GPS-based travel time data collection system affords. At the same time, there are many pitfalls that require careful management of the process. There are sampling and recruiting issues: How are volunteers selected? How do you insure a representative sample? Should volunteers be paid? Does trip purpose, time-of-day, sex, and age factor into your data collection plan? There are hardware and software issues: Which GPS receiver to purchase? Should differential correction be applied? Is there software that communicates with the selected hardware and provides the data processing you desire? There are training and security issues: What level of training or instruction is needed? How do you keep tract of each user? How do you minimize the potential for lost, damaged, or stolen hardware? There are safety and liability issues: Does GPS data collection have accident insurance implications?

Are there procedures that would minimize the potential for accidents? Should you insure the hardware and ask the volunteers to sign indemnity wavers?

Prior to embarking on a large data collection exercise, it is wise to determine the intended data use. Certainly, estimating network performance measures and improving speed/flow relationships for modeling purposes are important applications of travel time data; but there are others as well: tabulating delay at intersections, merge/weave sections and network bottlenecks; tracking origin-destination trip time and trip distance; screening incident data; and building an incident database. For example, a recent NCHRP study used GPS concepts to map and summarize the speed and delay profiles at signalized intersections to validate microscopic traffic simulation models. This type of data could also be used for level of service analysis and transit or traffic operations studies.

To get the most out of the collection process, the range of data applications to congestion management, air quality, and travel modeling should be thoroughly anticipated. This needs to be done at project initiation, so that all project activities are conducted in the context of the broader planning process. This could include overall agency plans for GIS-based data integration, the transportation model improvement program, and the technical analysis tools and methods used to address federal requirements. In the transportation planning and traffic engineering professions the trend is toward increasingly more detailed analysis. GPS-based data collection is likely to be a cost-effective method of supporting the current and future needs of the industry.



Sample Incident and Non-Incident Speed Profile

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Figure