Geographic Information Systems/Global Positioning Systems Design for Network Travel Time Study

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In October 1993, Maricopa Association of Governments (MAG) con-
ducted travel speed and delay studies in the metropolitan Phoenix area.
This paper concentrates on a Geographic Information Systems
(GIS)/data base systems approach to process the field data collected
with Global Positioning Systems (GPS) units and portable computers
after a brief discussion of the travel route selection and preparation and
a brief comparison of the several different travel time survey techniques
using the test vehicle method. The three system modules are described:
the Field Data Conversion and Validation module uses the data base
approach to combine the GPS data (position and speed) and event data
into a data base format and uses ARC/INFO to check GPS run validity;
the Link Topology Definition module extracts topological informa-
tion of the selected travel routes by data base programming and
ARC/INFO's Dynamic Segmentation; the Data Analysis and Reporting
module structures the continuous GPS data on a link-by-link basis and
calculates travel time, delay, and speed information for each link. This
module also feeds the results to a SAS program for statistical analysis
and to ARC/INFO for generating graphics reports. The system design
is based on the interface between ARC/INFO 6.11 on the SUN Sparc
Station and FoxPro 2.5 for DOS on PC.

Geographic Information Systems (GIS) are useful analysis and pre-
sentation tools in the field of transportation planning, engineering,
and management. When combined with the capabilities of Global
Positioning Systems (GPS) as a data collection tool and the power
of a relational data base system, GIS yields new solutions to area-
wide travel speed and delay studies.

Travel speed is a direct measure of road network performance.
Low speeds are an indication of congestion, delay, increased fuel
use, and higher pollution emissions. Decreasing auto travel speeds
may signal a need for increased road or transit capacity or for
greater attention to travel demand management. Travel speed sur-
veys are an important component of Congestion Management Sys-
tems. Quality speed data result in better travel demand and air qual-
ity modelling.

TRAVEL SPEED FIELD DATA
COLLECTION METHOD

Areawide travel speed studies consist of collecting, processing, and
presenting automobile travel speed and delay information for a
street and highway network. There are many methods available for
conducting travel time surveys. The test vehicle method in its vari-
ous forms is used most often when a comprehensive evaluation of
travel time in a transportation network is needed.

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Manual and Distance Measuring Instruments
Test Vehicle Method

In its original form, the test vehicle method requires two data col-
lectors, one for driving the vehicle, the other for recording time and
events using a stop watch and tally sheets (1). This results in labor
intensive data collection and data reduction processes. The inven-
tion of Distance Measuring Instruments (DMI) offered an auto-
mated way to collect and process travel time information using the
test vehicle method. In a typical configuration, the DMI mounted on
the test vehicle automatically logs travel distance and time, and the
driver codes events that occur during the survey process. However,
there are two major disadvantages of using DMI. First, it gives no
spatial information about the route the vehicle travels on. This
makes it difficult to have travel data mapped into a GIS coverage or
to check whether the driver followed the designated travel route for
quality management purposes. Second, if travel time is needed on a
link-by-link basis, the driver may need to keep track of the time the
test vehicle passes each major intersection along the route, in addi-
tion to recording other events. The more human interface required,
the greater the likelihood of errors.

GPS Technology

GPS is a positioning and navigational system. This space-age tech-
nology has found a variety of applications in natural resource man-
agement, urban development and analysis, agriculture, and social
sciences. A GPS consists of three segments: space, control, and the
user. The space segment consists of 24 Navstar satellites that broad-
cast a signal providing information on their orbital path. The con-
trol segment is the U.S. Department of Defense, which monitors the
movement of the satellites and transmits data to each satellite to
ensure that they are broadcasting accurate information on their
orbital path to earth. The user segment is a receiver, which receives
the signal and uses information contained in the signal to calculate
latitude, longitude, and altitude (2).

Data collected using a test vehicle equipped with a GPS unit give
both temporal and spatial information about the travelling vehicle,
thus naturally lending itself to GIS-based postprocessing. The data
collection method makes validity checking of the travel runs possi-
ble by overlaying GPS runs on the GIS base map, in addition to
allowing the driver to concentrate on driving and recording of other
incidents. GPS was used in test vehicles to collect travel speed data
for the Maricopa Association of Government (MAG) travel speed
study.

DATA COLLECTION

Travel Route Selection and Route Data Preparation

The selection of routes for the travel speed survey was based on a procedure agreed on by the Maricopa Association of Governments Transportation Planning Office (MAGTPO) and Lee Engineering. Route selection began with 14 significant routes identified by MAGTPO for inclusion in the 1993 travel speed study. The remaining routes were randomly selected in such a manner to balance the number of roadway miles for each roadway functional classification of each area type. This was accomplished by developing a data entry program that allowed a route to be entered into a data base table in a link-by-link fashion with the MAG functional class. Links on a route were identified using the reference street scheme, in the form of on-street, from-street, and to-street. A data base program was developed that output a matrix of roadway miles for each functional classification of each area type. Using this matrix, routes were selected in an iterative manner to obtain a balance of roadway miles between each cross-classification in the matrix. The routes selected include over 1288 km (800 mi) of arterial roadways and over 161 km (100 mi) of freeway and high occupancy vehicle (HOV) lanes. A total of 61 routes were selected. Each link on the selected routes was then assigned a unique link identification (ID). Other attributes such as the MAG area type, MAG functional class, speed limit, number of lanes, and average daily traffic (ADT), were collected and keyed into the table. There are a total of 1,790 links for the 61 routes selected, each representing a roadway segment for a given travel direction.

GPS Data Collection Design

Travel speed data on the selected routes were collected for representative weekday conditions (Monday through Friday) for the three time periods: morning peak (7:00 am to 9:00 am), off peak (10:00 am to 2:00 pm), and evening peak (4:00 pm to 6:00 pm). Travel speed data were collected for all 61 routes during the evening peak. In addition, 18 routes had morning peak data collected, and 19 routes had off-peak data collected.

The data collection vehicles or test vehicles were equipped with GPS units that were set to record the date, time, vehicle position, and velocity of the vehicle on a 2-sec sampling interval. Each vehicle was also equipped with a portable computer that was used for collecting other data such as identifying the time and type of delays encountered. The data collectors (drivers) were instructed to start each route at a particular location and time. The data collectors were also given a starting direction. Travel speed data for a route were collected for a minimum of three runs for each period. To avoid bias in the data, for any given route during a period, the starting points and the direction of the travel were varied. The data collectors were instructed to record any event that caused a stop delay other than general intersection delay on a portable computer. A stop delay is defined as the time during which the vehicle is travelling at a speed less then or equal to 8 km/hr (5 mph). Such events included traffic accidents, school zones, begin/end construction zones, pedestrians, emergency vehicles, and trains. Careful consideration was given to categorizing the types of delay so that remembering the classifications and corresponding keys would not be difficult.

Accuracy and Validity of Field GPS Data

The positional accuracy that can be achieved with GPS ranges from 100 m to millimeters, depending on the type of receiver used and if the data collected are differentially corrected. To obtain the highest level of accuracy for any receiver requires differential correction, a process of placing a receiver on a known location, called a base station, and using the collected satellite data to adjust GPS positions computed by other receivers at unknown locations during the same time period (2). The differential correction can be done in real time, if the receiver is equipped for real-time correction and a correction signal is being received, or in a postprocess fashion. Postdifferential correction was used for the travel speed study to improve the accuracy from 100 m to 2 to 5 m. Base station data for postdifferential processing was provided by Maricopa County.

The majority of the travel time data collection effort was completed in October and November of 1993. Additional runs were made for those routes requiring more data runs to meet the designated travel time tolerance. By April of 1994, a total of 416 runs had been collected, of which 392 had at least partial useful GPS data. The runs without useful GPS data were mainly attributed to drivers' failure to set up the GPS unit correctly on wire due to unavailability of the base station data for correction. Total loss of data could be reduced or eliminated through better training of the data-collecting personnel and the use of real-time differential GPS. Partial GPS data loss occurred because portions of the data were missing or not correctable against the base station because of unfavorable satellite configurations. Partial GPS data loss also occurred because of obstruction of GPS signals from tall buildings, bridges, tunnels, and so on. A link without complete GPS data in a run was combined with its adjacent links to form a longer link for travel speed data analysis whenever possible.

POSTPROCESSING SYSTEM DESIGN

The field data collection produced more than 40 megabytes of the raw GPS data and event data. Successful reduction and analysis of data in such volume can only be achieved through a carefully designed data analysis procedure that takes full advantage of an integrated GIS, data base, and statistical analysis packages of different platforms to maximize efficiency and minimize errors. Most of the data conversion and manipulation were performed through programming in FoxPro on the PC platform with a PC SAS interface for statistical analysis and an ARC/INFO interface for spatial analysis and graphics reporting. The integrated data analysis system is shown in Figure 1. There are three major components in the system, the functions of which are discussed in the following sections.

Field Data Conversion and Validation

This module prepares the field-collected GPS data and portable computer data for analysis. First, the field-collected GPS and portable computer data are downloaded to the PC. The GPS data are then corrected using base station data to increase accuracy. After correction, the GPS data are exported to an ASCII file using NAD 27 and State Plane Coordinate Systems, a system that the GIS base map uses. A set of data base programs (ASC2DBF) merge the GPS ASCII data with field event data to create a table in the dBase format. The events are put in a temporal order, and the coordinates of the events are determined by interpolating in the newly created dBase file.
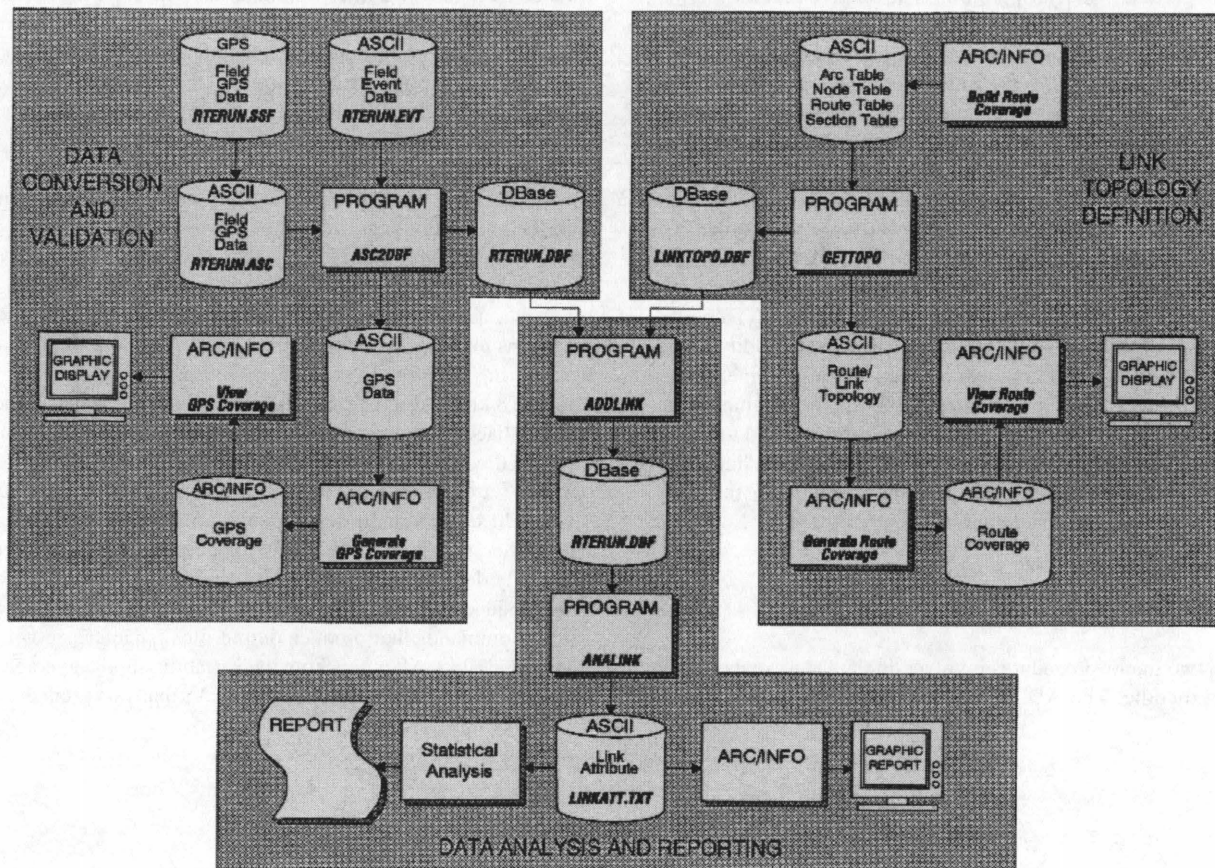
FIGURE 1   Data processing flow chart.

Validation of the GPS data is an important part of the module. The ASC2DBF programs also produces ASCII GPS and event data files with coordinate information, which serve as input files to an ARC/INFO Macro Language (AML) program. This AML program generates two-point coverage, one for the GPS points and the other for the event points for a given run. Once the coverages are generated, a menu-driven AML program overlays the GPS points and event points on the GIS street network, a process used for checking the validity of the runs. Figure 2 shows an ARC/INFO screen in which a GPS run was overlaid on the street network. If the trace of a GPS run showed a different or incomplete path of the designated route for the run, causes for such abnormality, such as driver negligence, bad GPS signal reception, or improper route definition, were identified, and appropriate measures were taken. Except for the part for GPS validity checking, which requires human interaction and judgment, the process is designed for batch processing with log files for error reporting.

Link Topology Definition

There are several notations to define a link on a route. The reference street notation (in the form of on-street, from-street, to-street) is easy for human comprehension. However, computers prefer the segment-node notation (on-segment, from-node to-node, or on-segment from-XY to-XY) or the route-measure notation (on-route, from-measure, to-measure). The task of this program module is to convert links already defined in the reference street form into the segment-node notation and to the route-measure notation. Segment-node notation is needed to structure the GPS data, which are continuous throughout a run, on a link-by-link basis using the coordinates of the control nodes of the links. The route-measure notation is needed to map the link attributes onto the GIS coverage, in addition to obtaining the length of each individual link.

Link topology was defined by extracting information from the base map; therefore, an accurate base map is the key to the success of the process. The base map used for the study was digitized from stereo aerial photography in 1991 at a scale of 1:24,000 by the Maricopa County Department of Transportation in cooperation with the

FIGURE 2   A GPS run was overlaid on the street base map for validity checking.

Arizona Department of Transportation. The relative accuracy of the map is 7.5 m (25 ft), which was deemed adequate for the study.

The first step in the module is to build a route feature that contains the travel routes and links for the study. Special attention was given to ensure that each route was continuous and without any unwanted offshoots. Programs were written to detect discontinuity between adjacent arcs on each route in the base map so such gaps could be corrected. Once the route feature was built, various attribute tables relating to the study routes and sections/arcs were exported to the PC, where the data base programs convert the already defined reference street link definition into segment-node definitions by making reference to these tables. The resulting link control nodes, in X,Y coordinate form, were exported to ARC/INFO to check their validity. Once the control nodes passed the validation, their measures or linear positions on the routes were generated using Dynamic Segmentation commands in ARC/INFO. These measures were then used to calculate the from-measure and to-measure and the length of the links. The LINKTOPO table resulting from the procedure contains the three different notations of route-link definition.

Data Analysis and Report Module

There are two major procedures involved in the Data Analysis and Reporting module. The ADDLINK procedure structures the con-

tinuous GPS data on a link-by-link basis. It inserts the control node in the GPS data and labels each link with a link ID. The time the vehicle passes through the control node of a link is interpolated based on the times for the two adjacent GPS points and the distance of the control node to the two adjacent GPS points. This procedure generates the second version of RTERUN.DBF.

The ANALINK procedure then calculates travel time, running time, and delays (including different types of stop delay) on each link for each individual run and generates a report of mean travel time, mean running time, mean delay, and types of delay for each travel link. Stop delay is defined as the time that the vehicle is travelling at a speed less then or equal to 8 km/hr (5 mph). The program first scans for delay groups on a given link. A delay group is the time span during which the vehicle is travelling at a speed less than or equal to 8 km/hr (5 mph). It was arbitrarily decided that if the time gap of adjacent delay groups is within 10 sec, these delay groups are combined as one group. The ANALINK procedure then tries to associate a delay group with any event recorded within the time span of 20 sec before the delay group or 5 sec after the delay group. The 20-sec and 5-sec time spans for event association were also arbitrarily decided.

Embedded in these procedures are Structured Query Language (SQL) commands that produce output files for interface with SAS and ARC/INFO. After checking the variability of the average travel speed and average running speed, the SAS analysis procedures cal-
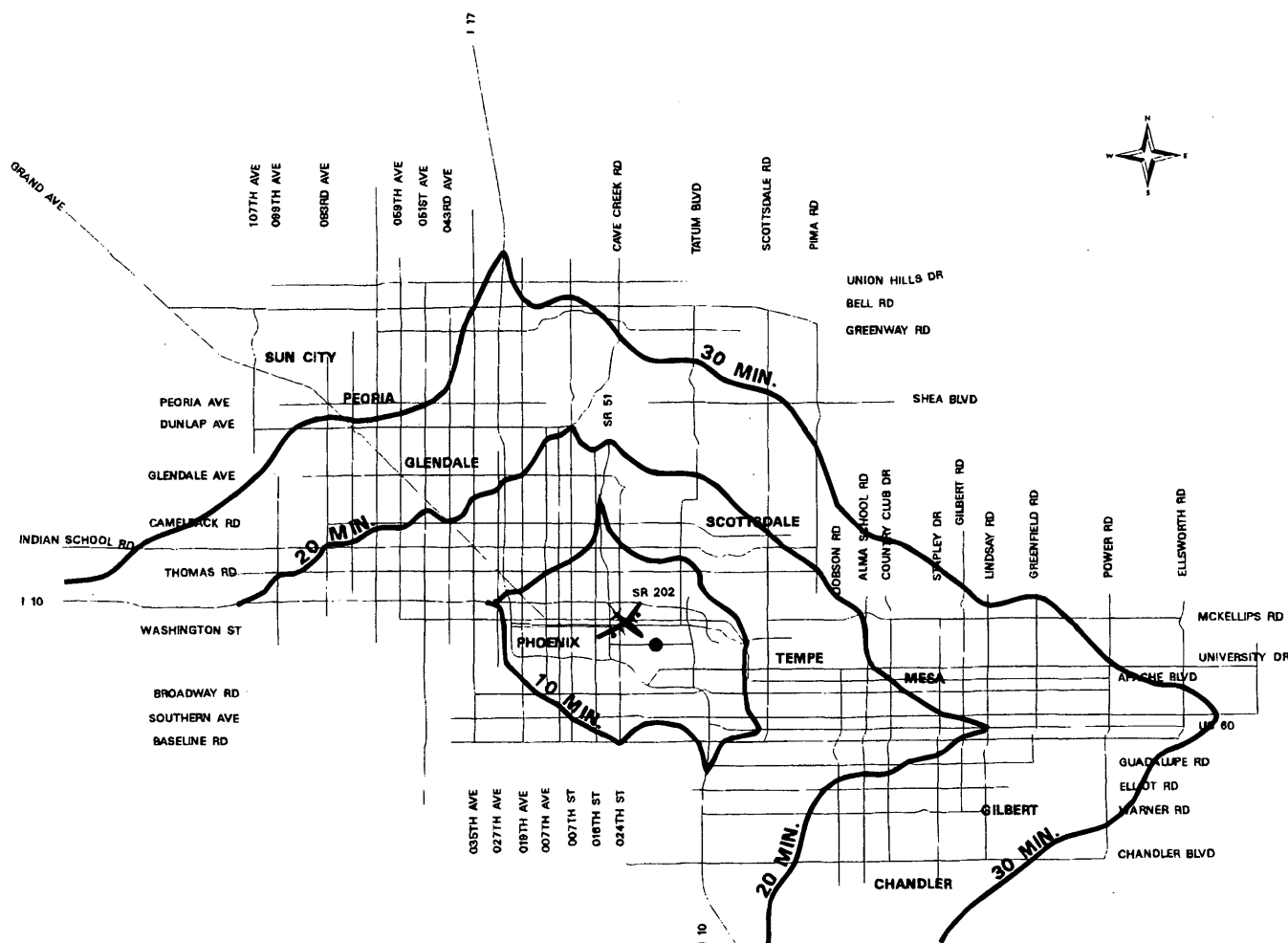

FIGURE 3   PM travel time from Sky Harbor Airport.

culate the mean travel speed, mean recurring and nonrecurring stop delay, and mean free-flow speed for different combinations of area type, number of lanes, and functional classification during a given period. The SAS procedures were also used to calculate miles of roads surveyed by functional class. The resulting data were then used to estimate travel speeds for the links that were not surveyed but shared the same combination of the above mentioned attributes. The tables containing such link-based information as mean travel speed, mean running speed, mean recurring, and nonrecurring stop delay are then passed on to ARC/INFO to conduct network analysis and to generate graphics reports. The preliminary network analysis produced the travel time contour maps and the minimum paths to and from major activity centers during all three periods. A left-turn delay of 51 sec and a right-turn delay of 37 sec resulting from the intersection delay study conducted as part of the project were used as turn impedance for the network analysis. Figure 3 shows travel time contour from Sky Harbor International Airport during typical weekday pm peak hours.

CONCLUSION

GPS technology provides a new way of collecting network travel speed data for processing in the context of GIS. Although it is not the intention of this paper to evaluate the effectiveness of this method, that GPS has its advantages in areas of GIS integration, data collection effort, and data validation. However, GPS units are expensive to purchase or to rent. The postprocessing can be very complex and requires a good electronic base map. If real-time differential GPS is not available, postdifferential correction adds another burden to the postprocessing. Furthermore, a number of factors can affect good GPS reception, many of which are difficult to prevent or even to predict. In summary, the success of an integrated GPS/GIS system in network travel time study relies on good GPS reception, accurate base maps, a well designed postprocess system, plus a good planning and quality control for field data collection.

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