

**MAXIMIZING RESOURCES IN AN ATIS IMPLEMENTATION:  
Integrating ATMS Loop Data, AVI, GPS and Theoretical Data  
into a Hybrid Travel Speed Database**

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## **ABSTRACT**

Implementing an Advanced Traffic Management System (ATMS) can be a costly venture. As expenditures from these systems become more apparent to our tax-payers, transportation agencies are having to meet the challenges of providing visible evidence of user benefits. Unfortunately, the transportation agencies are also being required to provide more user benefits with less money by effectively utilizing resources. Therefore, there is an ever-increasing need for the development of Advanced Traveler Information Systems (ATIS). This paper explains how San Antonio, TX has been able to optimize its' ITS resources in the development and implementation of a real-time integrated travel speed database.

In October of 1996, San Antonio, TX was selected as one of four metropolitan areas to participate in the Federal Highway Administration Model Deployment Initiative (MDI). One of the most exciting developments of the MDI will be the implementation of a comprehensive Advanced Traveler Information System (ATIS). The ATIS program will deploy 590 in-vehicle navigation units, 40 area-wide traveler information kiosks, and an internet site at <http://www.transguide.dot.state.tx.us>, and will also provide additional features for the existing low-power television station.

In order to optimize the effectiveness of the various ATIS components, a real-time travel speed database was developed for the San Antonio area. The Texas Transportation Institute, in partnership with Southwest Research Institute, developed a plan to integrate the travel speed data sources, ATMS loop data and AVI, with data collected using GPS technology, into a cohesive travel speed database. Unlike the majority of commercially available navigational databases, which use static estimates of speed, the San Antonio Areawide Travel Speed Database will contain up-to-the-minute speed information obtained from approximately 1600 loop detectors and 53 AVI receiver/transmitter stations located around San Antonio. This effort creates the foundation for the ATIS, by allowing the utilization of real-time data to provide accurate route guidance, and more importantly aid the motoring public in selecting the most time-efficient route for their desired trip.

This report focuses on the issues of real-time and historical data source integration to provide the most comprehensive and seamless travel speed database possible, using pre-planned information infrastructure investments. The integration of travel speeds, collected by means of ATMS loop detectors, Automatic Vehicle Identification (AVI) Systems, and probe vehicles using GPS technologies, will be discussed. Detailed data descriptions, data storage requirements, and real-time data transmission issues are also included. The report concludes with a summary of potential uses for the integrated travel speed database.

## INTRODUCTION

In October of 1996, San Antonio, TX was selected as one of four metropolitan areas to participate in the Federal Highway Administration Model Deployment Initiative (MDI). This selection was due in part to the extensive Intelligent Transportation System (ITS), TransGuide, that has been in operation since July 1995. The TransGuide Advanced Traffic Management System (ATMS) currently covers 26 miles of San Antonio freeways with loop detectors and video surveillance. TransGuide is in the process of expanding the current ATMS by 27 miles, and installing an Automatic Vehicle Identification (AVI) system on approximately 100 miles of additional freeway and arterials within the framework of Model Deployment. One of the most exciting developments of the MDI will be the implementation of a comprehensive Advanced Traveler Information System (ATIS). The ATIS program will deploy 590 in-vehicle navigation units, 40 area-wide traveler information kiosks, and an internet site at <http://www.transguide.dot.state.tx.us>, and will also provide additional features for the existing low-power television station.

In order to accommodate these additional data sources and computer systems in the TransGuide environment, the Texas Transportation Institute, in partnership with Southwest Research Institute, developed a comprehensive information system to collect, maintain, and distribute a variety of traffic and travel-related data. This effort resulted in the development of a data repository, the San Antonio Travel Speed Areawide Database, and a software application, the MDI DataServer, which provide a centralized information system for the collection and distribution of data within the TransGuide environment.

The MDI Data Server is responsible for managing a variety of data including travel speeds, traffic incidents, weather conditions, public transit routes, and equipment status. The system currently collects data from the TransGuide ATMS, the MDI Automated Vehicle Identification system, a historical database of travel speed data, VIA Metropolitan Transit System, the San Antonio International Airport, a road closure database, and the San Antonio Police Department. Data is currently distributed to a variety of systems, including the TransGuide Operations Real-Time Map, the MDI Traveler Information Kiosk system, the MDI In-Vehicle Navigation system, the TransGuide Low-Power Television station, and the TransGuide World Wide Web page.

The San Antonio Areawide Travel Speed Database is the central repository for the travel speed data within the data server. A large part of the effort in the development of the database revolved around the issues of collecting, maintaining, and distributing large quantities of rapidly changing travel speed data. This Areawide Travel Speed Database was developed in order to optimize the effectiveness of the various ATIS systems. Unlike the majority of commercially available navigational databases which use static estimates of speed, the San Antonio Areawide Travel Speed Database contains up-to-the-minute speed information obtained from approximately 1600 loop detectors and 53 AVI receiver/transmitter stations located around San

Antonio. This effort creates the foundation for the ATIS, by allowing the utilization of real-time and historical data to provide accurate route guidance, and more importantly, aid the motoring public in selecting the most time-efficient route for their desired trip.

Given the spatial nature of travel speed information, a geographic information system (GIS), Intelligent Map Objects, was developed by Southwest Research Institute. This proved to be a viable tool for storing, analyzing, and displaying the travel speed data in the Areawide Database. The use of a GIS allows the layering of travel speed data from the different sources. This became a very important feature, because the different data sources required varying polling frequencies, supplemental data fields, and maintenance schedules as will be discussed in the following sections. Although the data will reside in separate layers and also on separate processing units, the database will perform as a cohesive unit.

This paper discusses the alternatives that were considered in developing a system to collect and disseminate real-time travel speed data from a variety of sources. Detailed data descriptions, data storage requirements, and data transmission issues are also discussed and the benefits of our approach are considered.

## **SYSTEM ARCHITECTURE**

The design of the system architecture within the TransGuide environment was an important consideration for two reasons. First, through the MDI program, several new systems had to be integrated without disturbing the existing ATMS system. Second, with the rapid changes in ITS technology, provisions had to be made to accommodate the addition of new systems in the future.

One possible architecture would be a completely distributed system, where data consumers (or systems that need traffic and travel data) request the data directly from the data generators (the systems that produce the data). This architecture is depicted in Figure 1.

While this type of architecture is certainly plausible, it has several disadvantages. First, every system must develop a separate interface with every other system. Second, adding new systems in the future becomes increasingly difficult because changes must be made to each system to accommodate the new interface.

A more efficient architecture, and the one chosen for the TransGuide information system, is a distributed system with a centralized data repository. This system is depicted in Figure 2. The centralized repository reduces the total number of interfaces by providing a single interface for each subsystem. Another benefit is that future subsystems can be added by making a modification to the central repository. Other subsystems do not have to be modified.

The information system presented in this paper follows the architecture depicted in Figure

2. The TransGuide Data Server, which is the central server, collects the information from the data generators, stores the data in the San Antonio Areawide Database, and supplies the data to the data consumers.

The DataServer must interface with a variety of systems. These other systems are considered to be either data generators or data consumers/users. The data generators include the TransGuide ATMS and the MDI AVI system which generate real-time travel speed data, and the GPS and Theoretical travel speed database systems which generate travel speed data by time of day. Data generators that are not related to the areawide travel speed database are also shown and include: bus information, airport information, Police reports, and the road closure database. Several data consumers include the Traveler Information Kiosk, In-Vehicle Navigation, and World Wide Web server (WWW), which all use travel speed data in different ways. These systems are discussed in more detail in the following sections.

## **TRAVEL SPEED DATA GENERATOR SYSTEMS**

The data generators that generate travel speed data include the ATMS, AVI, GPS, and Theoretical systems. These systems either collect travel speed data in real-time or maintain historical travel speed data by time of day and report the data to the Data Server. Although the San Antonio Areawide Database must store a variety of travel-related data, one of the most important functions of the database is to store travel speed data. The following are descriptions of the various travel speed generators:

- TransGuide ATMS - real-time travel speed data collected from loop detectors.
- AVI System - real-time travel speed data collected by sensors that detect tagged vehicles acting as probes.
- GPS Data System - a historical database of travel speeds compiled by making travel time trips in differential GPS-equipped vehicles at scheduled intervals.
- Theoretical Data System - a historical database extrapolated from the GPS data through a decision matrix based on common roadway characteristics.

Together, these data sources make up a network of over 595 miles of travel speed data. This data is continuously written to the San Antonio Travel Speed Database and distributed to the data consumers for use in ATIS applications. Each of these data sources possesses their own unique characteristics which were considered in developing the central repository. These characteristics are discussed in more detail in the following sections.

### **Advanced Traffic Management System**

The ATMS system currently monitors 26 miles of highway in the San Antonio area using loop detectors and surveillance cameras. The system is expected to cover an additional 27 miles by early 1998 and will employ a mix of sonic and loop detector equipment. The detectors of the

ATMS are spaced approximately every 1/2 mile and collect speed, volume, and occupancy data for each lane of highway. The ATMS software polls the detectors every twenty seconds to collect their data and computes a two minute rolling average of the speed for use in the ATMS.

### Coverage

The placement of the ATMS loop sensors was determined by the Texas Department of Transportation (TxDOT). At the start of the database development, 26 miles of sensors were already in place, and the 27 additional miles were already under contract for installation. Apart from the mainlanes of the freeway, the system also covers entry and exit ramps.

### Link Segmentation Methodology

Both the ATMS and AVI sections are dependent upon the location of the data collection equipment in the field. The ATMS loop sensors are located on each lane at approximately half mile intervals. The ATMS links are defined from a node just prior to a loop sensor to a node upstream just prior to the next loop sensor (see Figure 3). The speeds determined by the sensors are spot speeds, but are used in this application as estimates of link speed.

### Data Description

The ATMS polling software computes a two minute rolling average of the speed values for use by the ATMS. The detector data are fed into the ATMS incident detection software and transmitted to the Data Server so that the data can be disseminated to the data consumers. The data that are sent to the Data Server is described in Table 1.

**Table 1. ATMS Data Field Definitions**

Lane Identifier	the unique TransGuide lane identifier of the segment
Average Speed	a two minute rolling average of the speed
Speed	the actual speed reported by the detector
Volume	the number of vehicles detected since the last poll

Occupancy	the duration that vehicles spent over the sensor
Status	the status of the detector

The speeds are reported by the system on a per lane basis. However, the ATIS is only capable of utilizing one speed reading for each link section. For this reason, an algorithm was developed to use the lane volume and average speed readings to calculate a speed based on a weighted average. This allowed a single speed reading to be broadcast to the various ATIS components for this link.

### **Automatic Vehicle Identification System**

The AVI system consists of 53 reader sites along highway and arterial roadways. The readers are spaced between 1 and 4 miles apart and cover one or more lanes of the roadway. Each reader site has a sensor that detects vehicle probe tags that are placed on vehicle windshields. When the reader equipment detects a probe tag, it relays the information to the AVI system, including the reader site identifier, the time the read occurred, and the probe tag identifier. The TransGuide AVI system collects the tag read data and processes it to match the tags of vehicles as they pass from one reader site to another. Based on these matches, the AVI system computes a rolling average of the travel time and travel speed along the link between the two readers.

### Coverage

The original number of AVI receiver/transmitter locations was reduced from 83 in the original MDI proposal, to 53 after the award, due to budgetary constraints. At that time, the Texas Transportation Institute was asked to re-evaluate the positioning of the AVI stations, and determine optimal locations for the remaining 53 stations. This methodology was also used to determine source coverage for both the GPS and theoretical systems.

Several information sources (1, 2, 3) were referenced prior to the development of the methodology. Included in these were the *Quantifying Congestion User's Guide* by the Texas Transportation Institute, the San Antonio Metropolitan Planning Organization *Travel Rate Study Technical Memorandum*, and a report by Mitretek Systems entitled, *Review of ITS Benefits: emerging successes*. The Mitretek report indicated that the majority of AVI system benefits can be obtained by locating receiver/transmitter devices in the most congested locations in an urban area. Specifically, this report concluded that reporting travel times for only the most congested links provides 90% of the system benefit at a lower cost. The San Antonio "Travel Rate Study Technical Report" was used as an initial guideline for the determination of San Antonio's most congested roadways. Lastly, the *Quantifying Congestion User's Guide* was used to determine the appropriate linear spacing of the receiver/transmitter stations. A few of the spacing guidelines were:

- Freeway/expressways: high access frequency, 1- to 3-mile segments

- Freeway/expressways: low access frequency, 3- to 5-mile segments
- Arterial streets: high cross-street and driveway frequency, 1- to 2-mile segments
- Arterial streets: low cross-street and driveway frequency, 2- to 3-mile segments.

The final spacing of the stations was typically in the range of 1- to 2-mile segments.

To maintain adequate and effective coverage with the reduced number of AVI readers, findings from the Mitretek report were applied to the San Antonio Model Deployment effort. In accordance with the report, an analysis was performed to determine where congestion exists on transportation facilities in San Antonio. After earmarking the sites mentioned in the “Travel Rate Study Technical Memorandum”, traffic volumes from the TxDOT1995 District Highway Traffic Map of the San Antonio area were correlated with the proposed AVI reader locations. These traffic volumes were representative of the annual average daily traffic (AADT) volume for a 24-hour period. In order to determine the peak hour traffic volume, peak hour percentages of AADT were taken from the TxDOT 1995 Permanent Automatic Traffic Recorder Station Data and applied to the daily volumes. The determination of relative congestion was based on the ratio of peak hour traffic volume of the roadway versus capacity of the roadway. Capacity was estimated for each AVI station using information on the total number of lanes in the roadway section, and the occurrence of traffic signals, if any. As the peak hour volume approaches hourly capacity, the volume to capacity (V/C) ratio approaches one, signifying increasing congestion. The resultant V/C ratios represented a macroscopic view used only to show relative estimates of congestion in the San Antonio area in order to methodically determine more effective AVI reader locations. The AVI readers were located primarily on freeway sections not covered by the ATMS, and a few were located on arterials in the extremely congested northwest side of San Antonio.

### Link Segmentation Methodology

The AVI readers are located, on average, at 1- to 2-mile spacing. The link endpoints are defined directly at the reader locations (see Figure 4). The information that is received by these readers is the vehicle tag number and time stamp, from which a travel time is determined by matching two consecutive readings from a single vehicle tag in the same direction of travel. The travel time can then be converted to travel speed using the known distance between the two reader locations.

### Data Description

Unlike the ATMS data which is measured for each lane, the AVI travel speed data is measured for each link, where a link may be composed of several lanes. The AVI system computes a rolling average speed and rolling average travel time for each of the links. The AVI data is collected and sent to the Data Server where it can be stored and disseminated to the data consumers. The AVI travel speed data is described in Table 2.

**Table 2. AVI Data Field Definitions**

Source Station	originating station of the link O-D pair
Source Time Stamp	time when vehicle passed by origin of the link
Destination Station	terminating station of the link O-D pair
Dest. Time Stamp	time when vehicle passed by the destination of the link
Link Identifier	the unique TransGuide identifier of the link
Link Length	the measured length of the link
Time Interval	the measured average travel time of the vehicles on the link
Speed	the calculated average speed of the vehicles on the link

### **GPS/Theoretical Data System**

Due to obvious financial constraints, it would be impossible to collect real-time travel speeds for an entire city the size of San Antonio using ATMS loop detectors and AVI technology. Therefore, in addition to the real-time data, the Texas Transportation Institute is using GPS travel-time data collection technology to collect speed and location information to supplement the Areawide Database. This GPS data source will provide information for an additional 150 miles of major arterials and collector-distributor roads. The GPS point data is aggregated by segment, and used to develop “typical” historical travel speeds for those roadway links. This GPS data is also used, along with information on signal spacing, number of lanes, and speed limit, to develop theoretical travel speeds on roadways for which no actual data was obtained. This theoretical information will be replaced with actual information upon future expansion of the data collection system.

#### Coverage

The project proposal allowed for full GPS travel time data collection on 150 centerline miles of roadway. The GPS coverage was comprised of the list of remaining congested

roadways from the AVI analysis. Care was taken to ensure that a wide sample of roadway characteristics, including speed limit, number of travel lanes, and signal spacing were covered.

The remaining major arterials and collectors were placed in the theoretical data evaluation group. These roadway sections typically consisted of lower volume, and lower speed roadways. Generally, the roadway selection process was organized to have the most accurate real-time information being collected on the most seriously congested roadways, and the historically-based information on the lesser congested roadways. Again, as the system matures and grows, the information will be replaced by more intelligent information sources in these latter coverage areas.

### Link Segmentation Methodology

The GPS and theoretical links were primarily determined by the characteristics of the various roadway sections. Characteristics of concern included number of lanes, number of signals, speed limit boundaries, and the location of major intersections. The links are defined to encompass sections with homogeneous characteristics, and typically range in length from 0.5- to 1-mile for GPS sections, and 0.5- to 2.5-miles for theoretical sections. A report by Darcy Bullock (4), entitled "A GPS Methodology for Conducting Travel Time Studies" states that GPS travel time data become increasingly vague with the use of sections greater than 0.5 miles in length. Unfortunately, some of the links were significantly larger than 0.5 due to the limitation on the number of links that can be broadcast to the ATIS systems. These limitations hinge on the bandwidth of the FM STIC Sub-carrier Broadcast System that will be used disseminate the link speeds to users. GPS/Theoretical links are typically defined at the first discontinuity in roadway characteristic (i.e., change in speed limit, addition or drop of a travel lane, significant changes in frequency of signal spacing, and some major intersection locations), as shown in Figure 5.

### GPS Data Collection

One of the most time consuming and costly portions of the project has been the GPS travel-time data collection. The GPS system encompasses 300 directional miles of arterials and collector-distributor roadways, and is composed of over 30 routes of approximately 7- to 12-miles in length. As of December 1997, over 2000 trip files have been recorded and included in the database. The data are collected for AM and PM peak hours as well as off-peak hours to determine changes in travel time by time of day. At a minimum, two hour samples were taken over 3 different days for each time period for each route. As has been noted in past studies, such as the TravTek evaluation, determining travel times for arterial roadways is not always easy. However, guidelines have been set in the *Quantifying Congestion* (2) guide to help determine the number of runs necessary to produce statistically significant travel times. Since this data is historical in nature, it can only be a best estimate for any time period on any day. Incident information will however be taken into account and reductions to this "typical" travel time will be made if necessary based on factors taken from previously observed incidents.

## Data Descriptions

The GPS and Theoretical databases are historical databases that reside on a workstation that is linked to the data server. Within the workstation, an automated polling program run to query the resident data by time of day in 15 minute intervals. The data sent to the Data Server are described in Table 3.

**Table 3. GPS/Theoretical Data Field Definitions**

Link Identifier	the unique TransGuide identifier of the link
Speed	the estimated average speed of the vehicles on the link
Time	the measured average travel time of the vehicles on the link

## **DATA STORAGE AND TRANSMISSION**

### **Link Identification**

In order to uniquely name each link in the TransGuide system, a naming convention was established. The source roadway sections are broken down into “link” segments using methodologies appropriate for the corresponding data types. Each directional link was given a unique ID that describes the data type, direction of travel, roadway name and closest cross-street or mile-marker information. Since the original TransGuide system used 19 character link names, this convention was continued in order to avoid a costly overhaul of the existing ATMS software. The format of the link ID follows:

ABCCCC-DDDDD-EEEE

where, A = type of data (I = AVI, A = ATMS, G = GPS, T = Theoretical)  
B = direction of travel (N = North, S = South, E = East, W = West)  
C = first five letters of the roadway name (e.g., Milit = Military Hwy)  
D = first five letters of the northernmost or easternmost cross-street, and  
E = first five letters of the southernmost or westernmost cross-street.

An example would be:

GNCalla-Babco-0010I

which would represent a GPS link, with a northbound direction of travel, on Callaghan between Babcock and Interstate 10.

A standard format was determined for all highway designations and roadways with less than 5 characters in the name. Also, several roadways in the San Antonio area have similar names, so a street name database was developed to avoid confusion. The following formats were used in these special cases:

- Highway designations
  - 0010I = Interstate Highway 10
  - 0281U = US 281
  - 1604L = Loop 1604
  - 3468F = Farm to Market (FM 3468)
- Roadways with less than 5 character names
  - Mill\_ = Mill Road
  - 9<sup>th</sup>\_S = 9<sup>th</sup> Street
  - Ox\_Bo = Ox Bow Drive
  
- Roadways with similar names
  - NWMil= NW Military Highway
  - Milit = Military Drive SE

The many ATIS system user components (i.e., in-vehicle navigation units and kiosks) employ privatized navigation databases that use a link identifier systems that are different from the TransGuide link identifier system. Because of this, a translation table had to be provided to map the TransGuide link identifiers to the privatized navigation database identifiers. Unfortunately, this translation table must be updated with each update of the privatized navigation database. This remains a problem, and will continue to incur unwanted costs in the TransGuide maintenance budget until solved.

### **TransGuide Data Server**

It is estimated that the Data Server will receive between 500 and 1,000 data requests each second from the data consumers. To determine the most effective way to accommodate this demand, several data storage techniques were investigated in the design phase of the Data Server system. One option would be to use a traditional database management system (DBMS) as a data storage mechanism. However, due to the volume of requests, the need to respond as rapidly as possible, the dynamic nature of the data, and the cost to purchase and maintain a DBMS, it was determined that a DBMS would not be the best solution. Therefore, the Data Server is implemented as a memory-based application in which the only data available for retrieval is the most recent data. Data can still be archived to flat files (i.e. traditional UNIX files) so that the

data can later be loaded into a database for analysis on a machine for post-processing.

## **Data Interface**

To provide a robust and consistent interface to data generators and consumers, the Data Server provides several Application Program Interfaces (APIs) which are used to access the Data Server. These interfaces, which were implemented in the form of software libraries, allow data generator and consumer applications to easily issue requests to store or retrieve data to the Data Server.

## **Data Transmission System**

In the TransGuide operational environment, it is common to have at least fifteen different data consumers active at any one time. This includes the FM STIC transmission as well as the map that is displayed on each operator's workstation. If each of these clients independently requested data from the Data Server, the Data Server would quickly be overwhelmed by requests. Since these requests are for the same data (i.e., TransGuide link identifier data, incident data, speed data), a more efficient data transmission paradigm needed to be established.

To satisfy the requirement of efficiently distributing the large amounts of real-time data, a "real-time broadcast" subsystem was developed. This subsystem extracts the real-time data from the Data Server and encapsulates these data into a packed-byte TCP/IP broadcast package. Using this mechanism, all of the TransGuide MDI real-time data can be compressed to approximately 3,100 bytes. This data package is broadcast once every five seconds over the TransGuide operational network. A program on each operator workstation receives the data and "explodes" it into its full format. This real-time broadcast system allows the TransGuide maps to be updated every five seconds and minimizes the overall Ethernet traffic required to communicate the real-time data to all active consumers.

To disseminate information to remote systems like the kiosks and in-vehicle navigation units, it is necessary to use a wireless medium. A technology called FM STIC is employed that takes the real-time data broadcast of the Data Server and attaches it to the sub-carrier signal of an FM radio broadcast. FM STIC receivers in each Kiosk and In-Vehicle Navigation unit receive the signal and convert it into a data stream that can be processed by the unit.

## **TRAVEL SPEED DATA CONSUMERS**

The data consumers of the TransGuide environment that use travel speed data are the Traveler Information Kiosk system, the In-Vehicle Navigation system, and the TransGuide World Wide Web (WWW) server.

## **In-Vehicle Navigation System**

The In-Vehicle Navigation system was implemented as part of the TransGuide MDI program and involves approximately 600 navigation units that provide real-time travel speed data and route guidance to drivers in their vehicles. Data is broadcast to the navigation units every 30 seconds using the FM Sub-carrier technology which is described in more detail above.

### **Travel Information Kiosk System**

The Traveler Information Kiosk system was also implemented as part of the TransGuide MDI program and includes 40 kiosks placed in key locations around the city of San Antonio. The kiosks provide real-time travel speed data on a graphical map, as well as route planning, bus route information, and weather information. Data is broadcast using the same FM Sub-carrier technology that is used for the kiosk system.

### **TransGuide WWW**

The TransGuide WWW server provides real-time traffic information to WWW users via a graphical map. Detailed information about each link is also available. The WWW server receives this data directly from the Data Server.

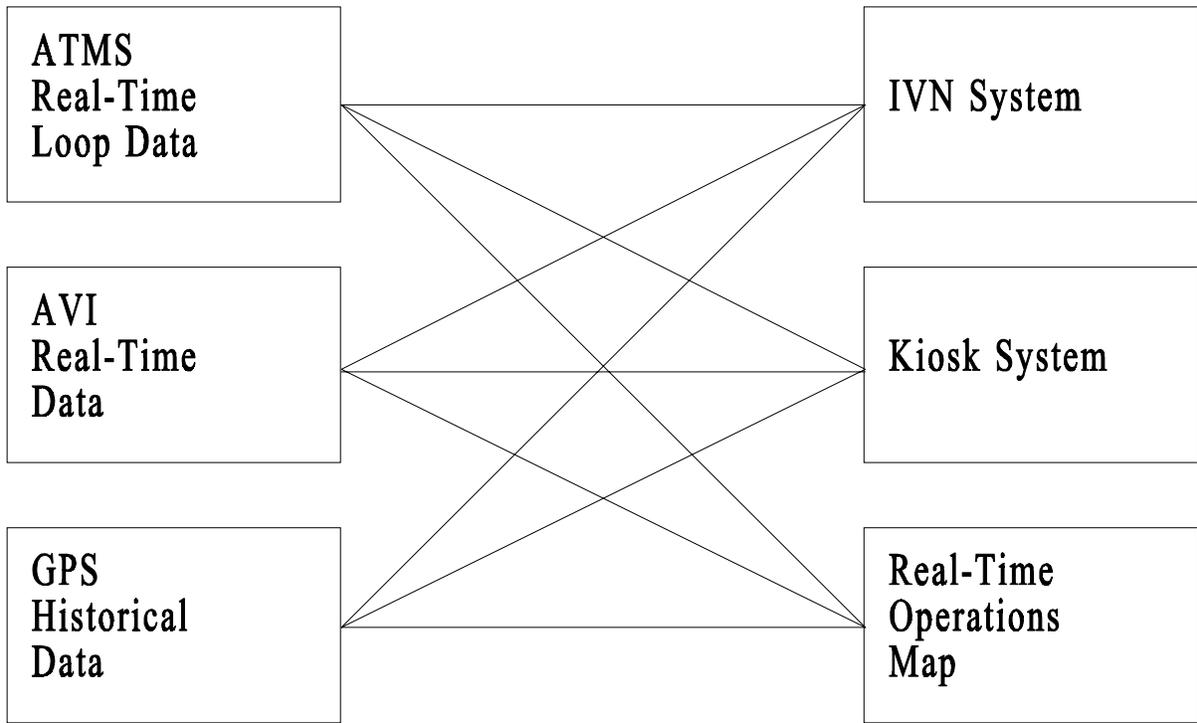
### **Other Potential Users**

Many uses for the real-time database have been discussed by both transportation operations and planning groups. The planning group is extremely excited at the prospect of having such a comprehensive travel time database on hand. Planners will be able to access the original historical database for microscopic travel time data analysis, or use macroscopic version that has been aggregated for network analysis.

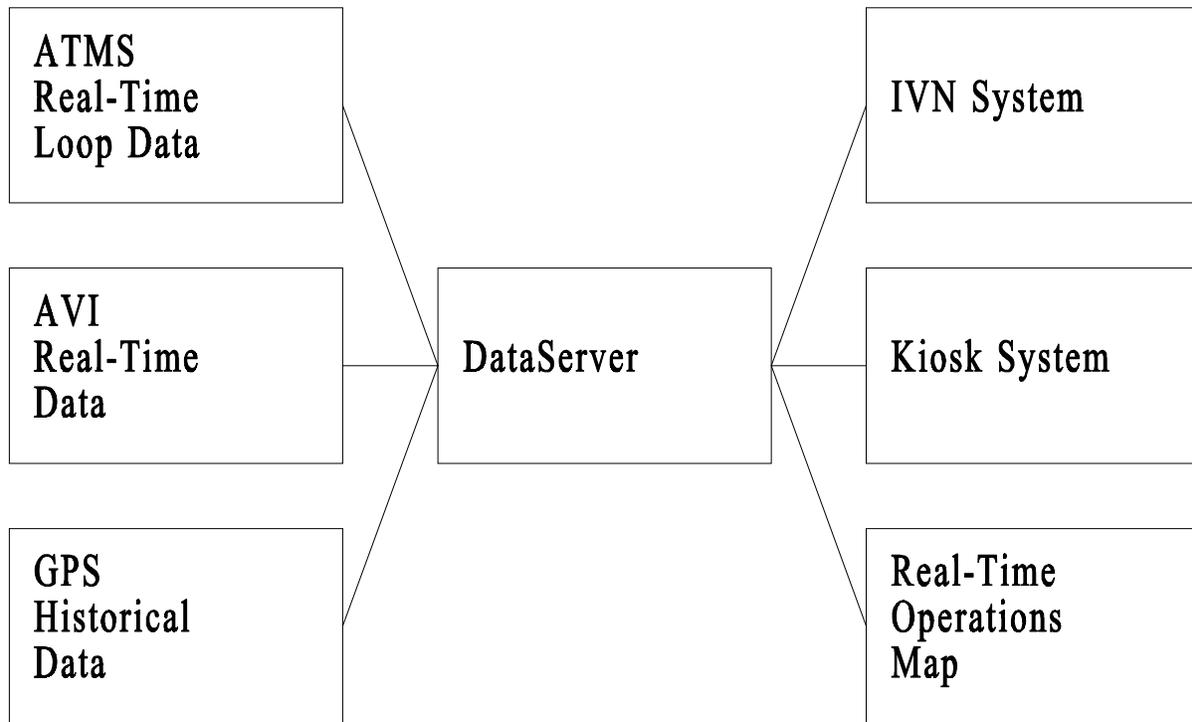
The operations group has already planned to archive all of the AVI data coming in to the Areawide Travel Time Database for use in the development of an extended historical database based on time of day analysis. This same information is also of interest to the planning groups for purposes of research, specifically to see if this type of data can be used in origin-destination studies.

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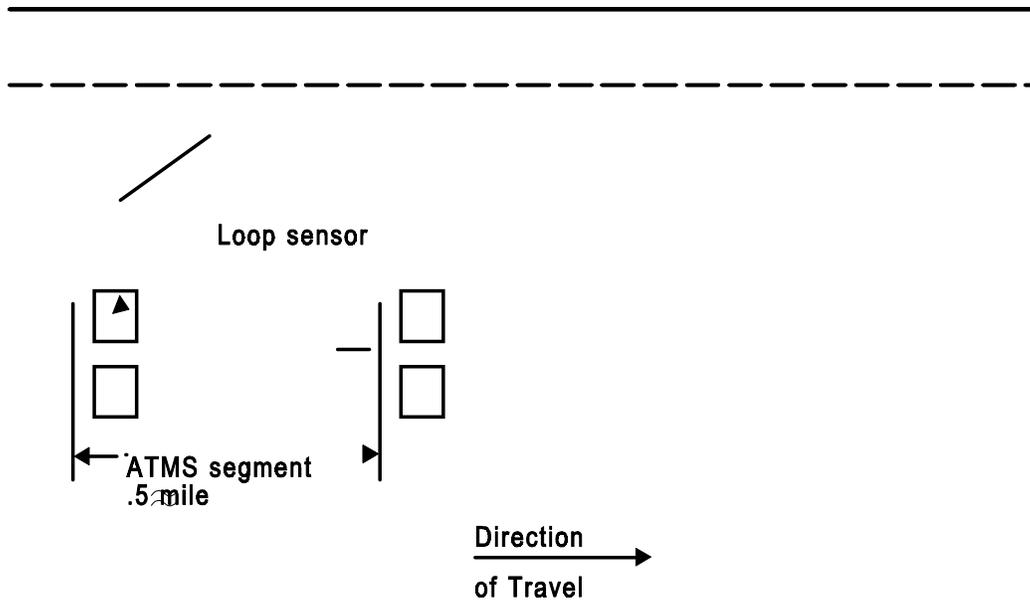
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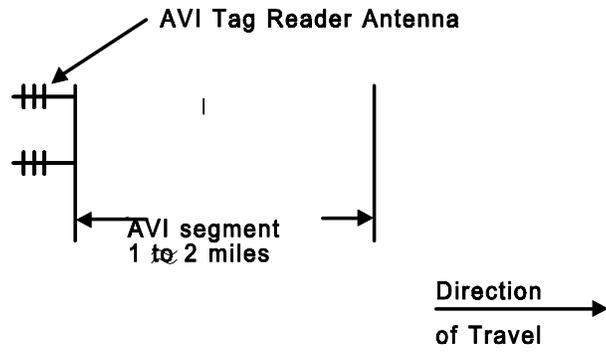
**Figure 1. Completely Distributed Architecture**



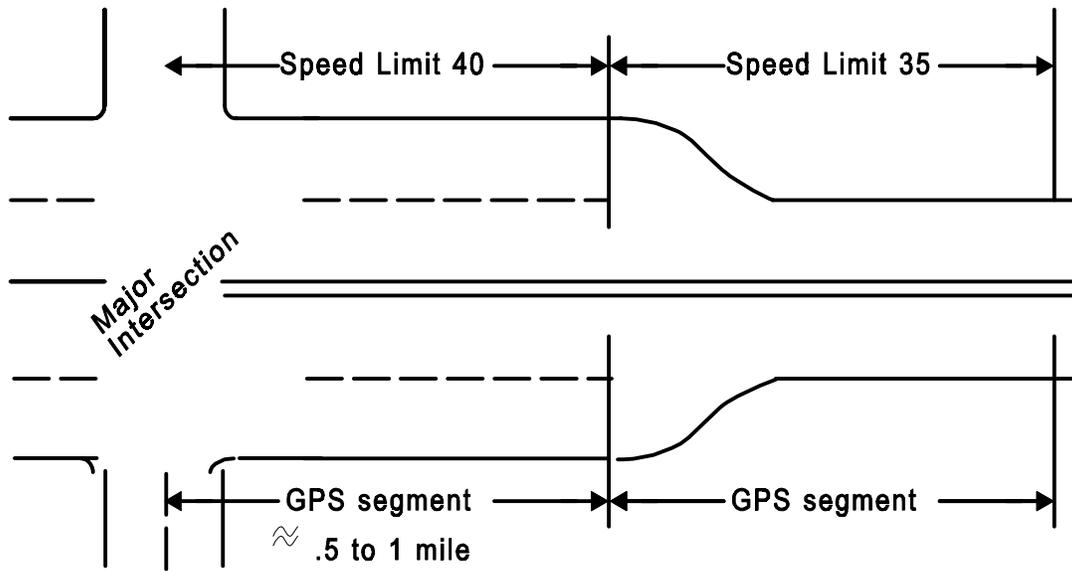
**Figure 2. Distributed System with Centralized Repository**



**Figure 3. ATMS Link Segment Definition**



**Figure 4. AVI Link Segment Definition**



**Figure 5. GPS/Theoretical Link Segment Definition**

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