5.0 In-Vehicle Navigation

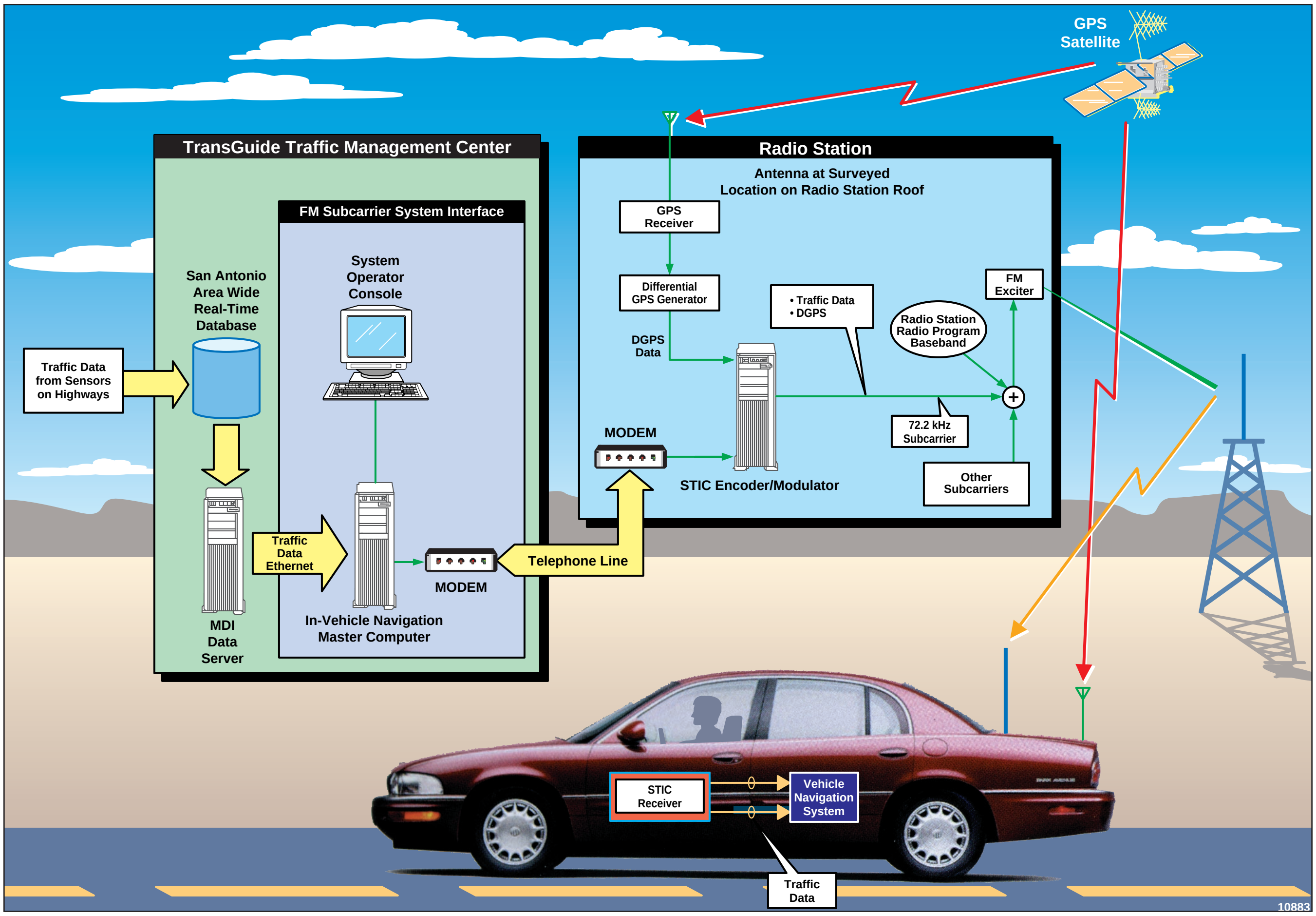

Figure 19. IVN Conceptual Overview

The In-Vehicle Navigation System obtains real-time traffic data from the MDI Data Server and distributes the data to moving vehicles (Figure 19).

5.1 Overview

The In-Vehicle Navigation System obtains real-time traffic data from the MDI Data Server and distributes the data to moving vehicles.

The IVN System consists of the following four major components:

- IVN master computer
- Subcarrier Traffic Information Channel (STIC) message encoder
- STIC receiver
- IVN unit

The IVN Master Computer obtains information from the Data Server and formats the information into efficient messages. The Master Computer then communicates the data over a dial-up modem connection to the STIC message encoder. The STIC message encoder, located in the transmission room of a commercial FM radio station, generates a data signal containing the traffic information that is modulated and broadcast as a subcarrier to the FM radio signal. The STIC receiver (installed in a vehicle) receives the FM radio signal, decodes the messages, and passes the messages to the navigation unit over a serial data link. The navigation unit decodes the messages, displays the real-time information along with the map data, and calculates the quickest route to a traveler-entered destination using the real-time data.

5.2 Design Information

The following subsections describe each of the four major subsystems of the IVN System. Also included is a description of custom software developed for the IVN Master Computer.

5.2.1 In-Vehicle Navigation Master Computer

The IVN Master Computer executes software that extracts real-time traffic information from the Data Server. The software encapsulates the real-time traffic data into messages that are delivered by the STIC transmission system to the IVN unit. The format and content of the messages adhere to the communications protocol designed and developed by SwRI for the IVN System that is described in the *TransGuide IVN System High-Speed FM Subcarrier Communications Protocol* document. The software sends the real-time traffic information messages to the STIC message encoder using a modem server and standard dial-up telephone line.

The IVN Master Computer is a Sun Microsystems workstation located in the computer room of the TxDOT TOC. The IVN Master Computer external electrical interfaces include an Ethernet connection for communication with the Data Server, a modem connection for communication with the STIC message encoder, and power connections.

5.2.2 Subcarrier Traffic Information Channel Message Encoder

The STIC message encoder, manufactured by Scientific-Atlanta, receives the messages sent by the IVN Master Computer over the modem connection, and depending on the command from the Master Computer, the encoder adds or deletes messages from a message queue. The encoder modulates the messages in the queue into a baseband signal that is centered at 72 kHz and outputs this baseband signal to the FM exciter of the radio station. The FM exciter adds the baseband signal from the STIC encoder to the regular audio program and other subcarriers. The composite signal is then modulated by the FM transmitter and broadcast over the entire San Antonio metropolitan area.

The STIC message encoder optimizes the data transmission throughput by embedding forward error correction information in the messages. A 15-byte Reed-Soloman forward-error correction code accompanies every 228 bytes of broadcast data. In addition, the encoder continuously cycles through the message queue, rebroadcasting messages that are not deleted by the master computer. This rebroadcast also improves transmission success.

The encoder is located at the Tower of the Americas in the radio transmission room of KTFM 102.7 FM. The encoder and associated components are mounted in a 19-inch equipment rack.

The STIC message encoder is a rack-mountable, environmentally hardened IBM-compatible personal computer with a STIC subcarrier modulator ISA board, built-in GPS receiver, and internal modem. The STIC message encoder external electrical interfaces include a modem connection for communication with the IVN Master Computer, a subcarrier output to the radio station FM exciter, and power connections.

The message encoder includes a GPS antenna and receiver that are used by the encoder to generate differential GPS (DGPS) data. These DGPS data are broadcast in the subcarrier along with the - traffic data. The DGPS data are separated from the traffic data by the STIC receiver in the vehicle and are not processed by the IVN units. This feature of the STIC message encoder is not used by the IVN system.

5.2.3 Subcarrier Traffic Information Channel Receiver

The STIC receiver, also manufactured by Scientific-Atlanta, continuously searches all FM radio frequencies for a station broadcasting the STIC subcarrier signal. When the receiver tunes to 102.7 FM, it finds the STIC subcarrier and begins to receive the messages broadcast by the message encoder. The receiver uses the forward error correction codes transmitted by the encoder to correct transmission errors. After error correction, the receiver sends the messages to the IVN unit through an RS-232 serial data link.

The time required by the STIC receiver to search through the FM frequencies varies. The receiver is designed to find 102.7 FM quickly, and, in the presence of a strong FM signal, the receiver will begin to decode data within 30 seconds. If the receiver loses lock because of a weak FM signal, it will regain lock within 30 seconds from the time the FM signal is re-established. If the broadcast signal moves to another frequency, the search will be slower. The STIC receiver could require as long as three minutes to find a subcarrier on a frequency other than 102.7 FM.

The STIC receiver's ability to lock onto the broadcast signal depends on the quality of the signal at the receiver input. Several factors can affect the signal quality. The strength of the receiver input signal is greatly dependent upon the type of antenna used, the mounting of that antenna, and vehicle location. For good reception of the STIC subcarrier, it is important that a quality antenna is used and is properly installed, including a connection to a sufficient ground plane.

For convenience and aesthetics, it is often desirable to input the same signal from the existing vehicle FM antenna to both the STIC receiver and existing FM radio using a power splitter. This approach, however, results in reduced signal strength to the STIC receiver and can affect the receiver's ability to lock onto the broadcast signal.

The location of the receiver is also an important factor for reception. Although the KTFM signal approaches an omnidirectional coverage pattern, the signal does not cover the San Antonio area uniformly. The primary lobe of the KTFM signal is centered in a southwesterly direction from the Tower of Americas, and reception of the STIC subcarrier will be best on that side of the city. In addition, the specific electromagnetic environment of any particular site may affect data reception. Decreased reception is especially true of sites that are within large structures containing metal (such as commercial buildings and parking garages) or in the electromagnetic shadow of such structures. At sites where reception is difficult, moving the receiver antenna by only a few feet can greatly improve the data reception.

In any case, the reception of the STIC subcarrier should not be compared with the reception of the KTFM audio program using a FM radio. The carrier signal that contains the audio program is ten times stronger than the STIC subcarrier. The audio program is also closer to the FM pilot signal, which greatly improves reception. For these reasons, the STIC receiver will not receive data in some places where the audio program is clearly received.

In a vehicle, the STIC receiver is typically mounted adjacent to the controller of the IVN unit.

The electrical interfaces of the STIC receiver include an FM antenna, data, power, and ground connection. The receiver either shares the signal from an existing FM antenna with the radio using a power splitter, or is connected directly to a dedicated FM antenna. For data communication, an RS-232 cable connects the receiver to the IVN unit interface. Also required are switched power and ground connections that are typically made with the vehicle ignition circuit.

The STIC receiver also decodes the DGPS data broadcast by the message encoder. The DGPS data are output on two unused pins of the RS-232 serial link; however, these data are not processed by the IVN units.

5.2.4 In-Vehicle Navigation Unit

The IVN unit is one of two commercially available products. Alpine Electronics Research of America and Zexel USA each supply a navigation unit capable of receiving and using real-time traffic data from the IVN system. Table 7 compares the features of both units.

The Alpine and Zexel navigation units include a controller and display head. The controller houses a microprocessor, GPS receiver, removable PCMCIA hard disk or CD-ROM, and gyroscopic sensor. The display head on the Zexel IVN unit has keys that the traveler may use to enter information. The display head on the Alpine unit has an infrared sensor and is accompanied by a handheld remote control that provides the traveler a means for data input.

The IVN units accept the real-time traffic messages from the STIC receiver. The messages are unwrapped by the navigation unit software, and the real-time information is incorporated into a map database maintained by the units. The navigation units display the map database information

Table 7. Navigation Unit Feature Comparison

Characteristic	Alpine NVA-N751A	Zexel NavMate
Current vehicle position	Yes	No
Destination memory types		
Previously entered destination	Yes	Yes
Editable address book	Yes	No
Multiple destination route planning	Yes	No
Routing guidance methods		
Shortest time route	Yes	Yes
Minimum turns	Yes	No
Maxmum freeways	Yes	Yes
Minimum freeways	No	Yes
Minimum toll roads	Yes	No
User-selected road avoidance	Yes	No
Man-machine interface features		
Map display	Allows panning	Centered on vehicle position
Map zoom	7 levels	5 levels
Map orientation	Heading up/north up	Heading up/north up
Guide display	Yes	Yes
Route maneuver preview	Yes	Yes
Name entry technique	Scroll list/“keyboard”	Scroll list
Brightness adjustment	Yes	Yes
Night/Day setting	Yes	No
Voice prompting	Max/normal/min	On/off
Volume control	Yes	Yes
Rerouting	Manual/auto	Manual
Map data source	NavTech	NavTech
Hardware		
Display	5.6-in. color LCD	4-in. color LCD
Data storage	CD-ROM	PCMCIA hard disk
User input device	Cordless remote control	Display-mounted keypad
GPS antenna	Yes	Yes
Gyro	Yes	Yes
Wire harness	Yes	Yes
Display cable	Yes	Yes
Display mount	Rigid shaft with ball joint	Flexible shaft with ball joint
STIC interface	external module	external module
Vehicle electrical connections		
Battery	Yes	Yes
Ignition	Yes	Yes
Ground	Yes	Yes
VSS	Yes	Yes
Reverse	Yes	Yes
Illumination	Yes	No

and real-time data to travelers on the liquid crystal display (LCD).

The Zexel and Alpine IVN units have GUIs that allow destination input by address, intersection, point of interest, or previous destination. The Alpine unit also allows the traveler to select a destination by map input.

The IVN units calculate a route from the current location of the vehicle to the traveler-entered destination. The traveler may select a computation of the shortest time route. In this mode, the IVN units calculate the shortest time route using the real-time information broadcast by the IVN system.

The IVN units present the real-time traffic and route information using a map display, guide display, and audible messaging. The map display shows a map of the area around the present location of the vehicle. The map display includes geometry of roadways, street names, and an icon indicating the current location of the vehicle. The traveler may zoom in or out to achieve the level of detail in the display that he or she requires. The map display highlights the roads appearing at the current zoom level that are on the calculated route and highlights areas of traffic congestion by color coding road segments.

The guide display provides turn-by-turn navigation directions to the traveler and indicates the direction of an upcoming turn with a large arrow pointing in the direction of the turn. The guide display also presents the distance to the upcoming turn as determined by the calculated route and vehicle position.

The IVN units generate a voice prompt to indicate the distance and direction of an upcoming turn. When a turn is pending, another audible prompt signals the traveler to make the turn.

The IVN units determine the location and heading of the vehicle using a GPS receiver, a gyroscopic sensor, and map matching. The GPS receiver provides coarse position information that is compared to map data, then the measured position is "snapped" to the map using map matching. The gyroscopic sensor provides accurate vehicle heading information to the IVN units.

The electrical interfaces of the IVN units include GPS antenna, RS-232, speed pulse, back-up light, ignition, power, and ground connections. The IVN units have a wire harness that taps into the vehicle speed pulse near the powertrain control module. In addition, the IVN unit wire harness taps into the back-up light, ignition, power, and ground in the most convenient place near the unit. The locations of these connections vary greatly from vehicle to vehicle.

Examples of IVN installations are shown in Figures 20 and 21.

5.2.5 In-Vehicle Navigation Master Computer Software

The IVN Master Computer Software (MCS) was designed and developed by SwRI personnel. The function of the IVN MCS is to extract real-time data from the MDI Data Server and transmit the data to the STIC message encoder.

The software consists of a single UNIX application that processes data from the Data Server real-time data stream and formats the data into the

Figure 20. IVN Unit Installed in a Passenger Vehicle

Figure 21. IVN Unit Installed in a Fire Truck

appropriate protocol for transmission over the FM STIC. The application manages the modem that sends data to the FM transmitter site. If the communication link is terminated, the IVN MCS is responsible for re-establishing the connection.

The IVN MCS has five external software interfaces as depicted in Figure 22.

The external entities to which the IVN process communicates include the Data Server, which is a process running on another workstation; the Real-Time Data Subsystem, which is a process running on the IVN Master Computer; the Status GUI, which is a process running on the IVN Master Computer; the Status Log, which is a text file maintained on the IVN Master Computer disk; and the STIC message encoder.

5.3 Tradeoff Decisions

5.3.1 FM Subcarrier System Selection

Three FM subcarrier data broadcast systems were considered for use in the IVN System: Digital DJ's DARC, Seiko HSDS, and Scientific-Atlanta's STIC. The primary factors considered in the selection process were radio station compatibility, data throughput performance, component cost, and licensing cost.

The DARC system was quickly eliminated because of compatibility issues. The DARC system uses more subcarrier bandwidth than the other systems. This increased bandwidth causes an incompatibility with other pre-existing subcarriers that were present on many of the candidate radio stations.

The HSDS and STIC systems were closely compared. The HSDS system offers a high raw data rate at the cost of more errors, and the STIC system data rate is slower with fewer errors. The net data throughput (after errors) of the systems is comparable.

The cost of the HSDS components are higher than that of the STIC components, and HSDS included a high annual license fee that STIC did not require. Overall, the HSDS system was much more expensive. Finally, the STIC system was developed with FHWA funding and therefore generates a non-proprietary waveform. This feature offers the possibility of future competition in the receiver market accompanied by competitive pricing—a possibility that did not exist for the HSDS system. Given this comparison, the STIC system was selected as the FM subcarrier technology for the IVN system.

5.3.2 Location Referencing Format Decision

During the development of the communications protocol for the IVN system, several techniques for referencing locations were considered. These techniques were under development at Oak Ridge National Laboratory as part of the Location Reference Message Specification effort.

Early in the location reference format selection process, the project team decided that TxDOT should not broadcast any vendor-specific map data. As a result of this decision, the navigation unit software would need to translate broadcast data regardless of the location referencing scheme. The translation process would convert the vendor-

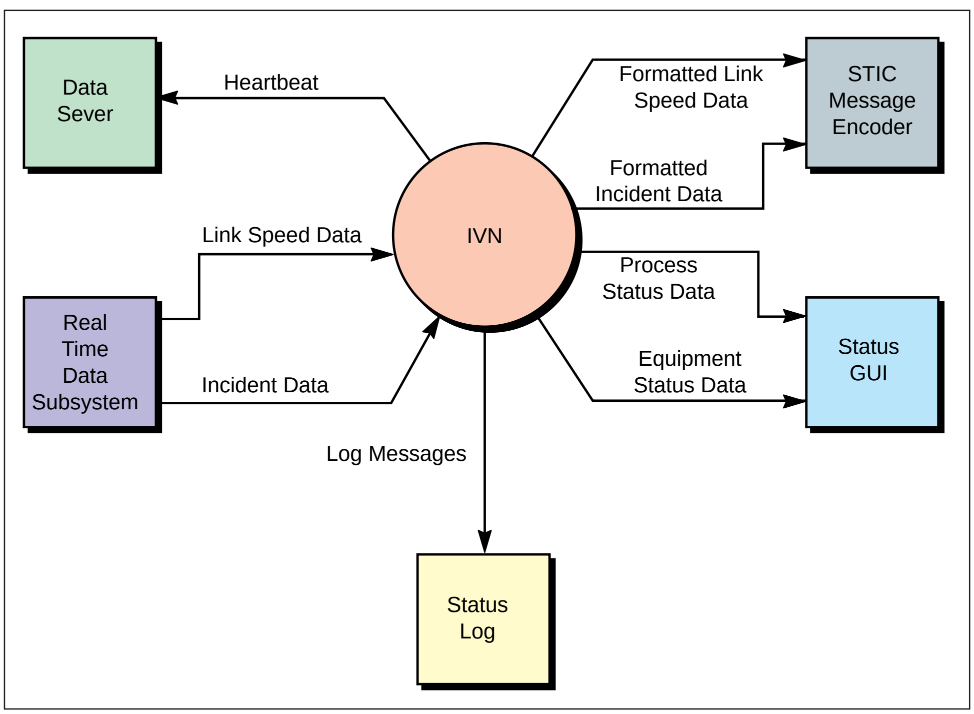

Figure 22. IVN MCS External Interfaces

independent data into vendor-specific data that could be displayed by the unit.

Two location referencing techniques were considered—point/link identification numbers (IDs) and latitude/longitude geographic coordinates. Point/link IDs allows the most efficiency during transmission; however, this technique forces the navigation units to use a lookup table during translation that must change any time the point/link IDs change. This characteristic is undesirable because the navigation unit software must be replaced in the vehicles with each change in the transmitted data. The latitude/longitude method is slightly less efficient during broadcast, but allows the navigation unit designers to choose between a decoding table and decoding algorithm design. The decoding algorithm approach does not require a software change when the broadcast data changes.

A rough analysis on the latitude/longitude method revealed that all the traffic data could be broadcast in well under one minute. Given this performance and the design flexibility offered by the latitude/longitude approach, the project team agreed that using latitude and longitude (in a lookup table) in the traffic data broadcast for location referencing was preferable.

5.3.3 Radio Station Selection Process

A subcarrier lease for use with the STIC was procured on a competitive basis from a commercial FM radio station. TxDOT began this process by issuing a request for offer (RFO) as a solicitation for bids for the subcarrier lease. The RFO contained the minimum technical requirements that contending radio stations had to meet. The minimum technical requirements included the minimum transmit power level, equipment space availability, and equipment access rights.

Of the radio stations that responded to the RFO, two met the minimum technical requirements. The radio stations were KXTN (Tichenor Media Systems) and KTFM (Waterman Broadcasting).

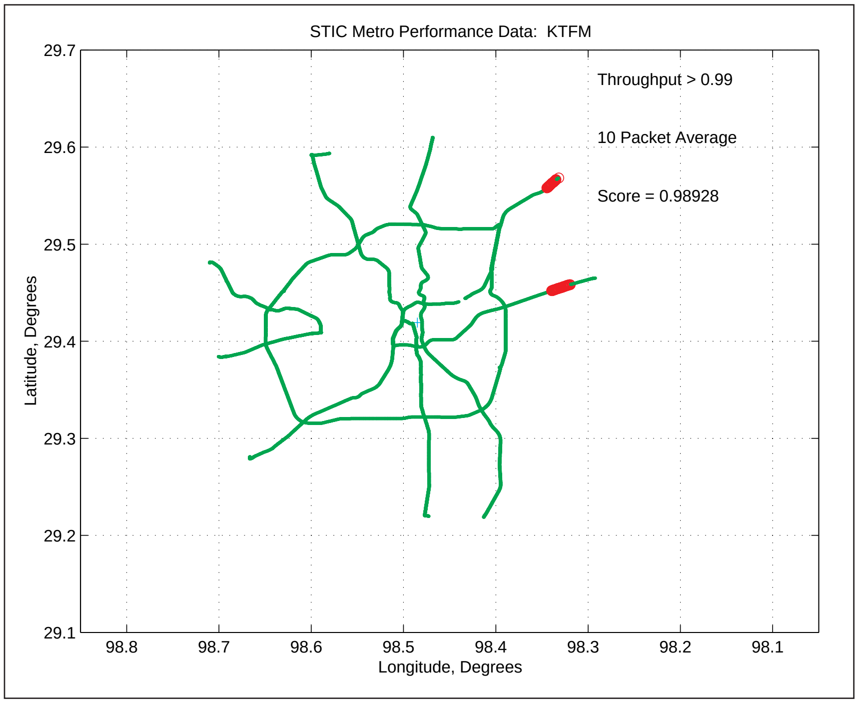

Figure 23. KTFM Coverage Plot

KXTN and KTFM were compared on cost and broadcast coverage.

Coverage data were collected by installing the STIC broadcast equipment at the radio station under test. The broadcast equipment was configured to send messages encoded with unique sequence numbers. A STIC receiver was installed in a test vehicle, and the output of the receiver was collected by a laptop PC. The PC recorded the sequence number of correctly received messages. Messages were broadcast and recorded at the rate of four messages per second, and messages were recorded automatically while driving the vehicle. The coverage data for KTFM are shown in Figure 23.

The coverage data were evaluated by post-processing. The data were inspected for missing sequence numbers, and each missing sequence number was counted as an error. The ratio of errors to correctly received messages was computed as the coverage score for the radio station under test.

The coverage score was given a 60 percent weighting in the selection decision, and the lease cost received a 40 percent weighting. KTFM was selected as having the best overall combination of broadcast coverage and cost.

5.3.4 In-Vehicle Navigation Unit Comparison

TxDOT purchased in-vehicle navigation units manufactured by Alpine Electronics of America and Zexel USA. Each unit has several individual traits, but also shares functionality with the other type. Table 7 summarizes the functionality of the two units.

5.4 Summary

The IVN System successfully delivers and displays real-time traffic data to drivers of equipped vehicles. The IVN System is an example to all navigation system and advanced ATIS product vendors of a practical and useful method of delivering real-time traffic data to travelers. The system has drawn the close attention of many product vendors and standards development organizations and has been a catalyst for their efforts to bring ATIS solutions to the travelling public.

The IVN System displays traffic speed and incident information to the traveler and uses the information when computing routes to destinations. The high-speed FM subcarrier communication system and protocol delivers all traffic data approximately once every 30 seconds, allowing the traveler to make decisions based on up-to-date and accurate data before leaving his or her point of origin. The system components and software were developed based on the latest product designs and emerging standards. This practice will ensure that the IVN system can be kept compatible with and a part of emerging ATIS services and systems with a minimum of maintenance costs.