SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-96/15
Final Report

BORMAN EXPRESSWAY ATMS EQUIPMENT EVALUATION

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IVHS-9418 (301)

Program for ITS Research and Education
Purdue University

by

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Joint Highway Research Project
Project No. C-36-75C
File No. 8-9-3

In Cooperation with
Indiana Department of Transportation
and
U.S. Department of Transportation
Federal Highway Administration

Purdue University
West Lafayette, IN 47907
August 20, 1996

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/IN/JHRP-96/15	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Borman Expressway ATMS Equipment Evaluation		5. Report Date August 20, 1996 6. Performing organization code
7. Author(s) J. Krogmeier, K. Sinha, M. Fik, S. Peeta, and S. Nof		8. Performing Organization Report No. FHWA/IN/JHRP-96/15
9. Performing Organization Name and Address Joint Highway Research Project 1284 Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284		10. Work Unit No. 11. Contract or Grant No. M-Is-9418 (301)
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN46204		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

An Advanced Traffic Management System (ATMS) is under development in northern Indiana by the Indiana Department of Transportation (INDOT) in conjunction with Hughes Transportation Management Systems. The study area comprises a sixteen mile segment of the heavily used Borman Expressway and its associated corridor, beginning at the Indiana/Illinois border and stretching east to the Indiana Toll Road interchange. The most important operational problem on the Borman is non-recurrent congestion, arising primarily through accidents and stalled vehicles. In order to mitigate the sign&ant bottleneck delay problems due to non-recurrent congestion, INDOT is developing an ATMS for real-time incident detection and response on the Borman Expressway. INDOT has implemented a functional "mini" ATMS which incorporates small numbers of each of the components being considered for the future Borman ATMS, for ***validation*** and analysis of their capabilities. The prototype, or Phase I, encompasses three interchanges covering about three miles of the expressway. Phase I was designed and implemented to identify an architecture for Phase II which will expand the system in coverage and functionality.

The overall conclusion of this evaluation is that the Phase I Borman ATMS has demonstrated the feasibility of the basic ATMS design. It is the opinion of the evaluation team that a cost effective Phase II ATMS can be developed using the basic Phase I architecture. However, experience with the Phase I system suggests certain issues must be addressed as the Phase II ATMS is planned.

17. Key Words ITS; ATMS; System Architecture, INDOT.	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassitied	Unclassitied	60	

Form DOT F 1700.7 (8-69)

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1 Introduction

An Advanced Traffic Management System (ATMS) is under development in northern Indiana by the Indiana Department of Transportation (INDOT) in conjunction with Hughes Transportation Management Systems. The study area comprises a sixteen mile segment of the heavily used Borman Expressway and its associated corridor; beginning at the Indiana/Illinois border and stretching east to the Indiana Toll Road interchange. The Borman is an important link in the Gary-Chicago-Milwaukee (GCM) Corridor – one of four such corridors nationwide which have been designated by the U.S. Department of Transportation for federal support to enhance multi-modal transportation and to reduce air pollution. The average daily traffic on the Borman Expressway is approximately 140,000 vehicles, with trucks making up around 30 percent of the total, peaking at about 60 percent at night. Traffic volumes are relatively constant from the morning through the early evening. Previous studies of the origin-destination trips indicate that a significant proportion of the motorists both enter and exit in the study area of the Borman Expressway [Smith 89].

Operational problems arise on the Borman Expressway due to non-recurrent congestion, primarily through accidents and stalled vehicles. The high percentage of through traffic in the form of cargo-carrying trucks increases the likelihood of their involvement in these accidents. This increases the potential severity of the accidents by increasing the average duration of the operation of the Expressway under reduced capacity around the bottleneck area and posing severe congestion problems. Creating further complications are major construction projects currently underway and planned for the next five to ten years. Recurrent congestion is not a significant operational problem at this time, but is expected to be problematic in the future. At present, recurrent congestion is limited to weekends during the summer months. The traffic consists of a Friday afternoon exodus from metropolitan Chicago to resort areas along Lake Michigan and the return traffic on Sunday evenings.

In order to mitigate the significant bottleneck delay problems due to non-recurrent congestion, INDOT is developing an ATMS for real-time incident detection and response on the Borman Expressway. To this end, INDOT has implemented a functional "mini" ATMS which incorporates small numbers of each of the components, being considered for the future Borman ATMS, for validation and analysis of their capabilities. The prototype or Phase I ATMS encompasses three interchanges covering about three miles of the expressway. From west to east the interchanges are: Kennedy Avenue, Cline Avenue, and Burr Street. Site details for these interchanges are depicted in Figures 1, 2, and 3. The prototype ATMS was designed and implemented to identify an architecture for Phase II which will expand the system in coverage and functionality. The following INDOT objectives were fundamental to the development work:

- The ATMS should be integrated with existing infrastructure and response services to the maximum possible extent.
- The ATMS should use a flexible and robust communications system in order to remain operational during major road construction projects that were ongoing or planned.
- The ATMS should be remotely operable by incident response crews (called "Hoosier Helpers" in Indiana) in order to minimize the need for a staffed traffic management center.

Meeting the objectives above required INDOT and Hughes to introduce a number of innovative concepts into the ATMS design including: 1) an emphasis on above road traffic sensors, 2) a communications system based upon spread spectrum radio, and 3) a mobile traffic management center (TMC) operating out of the incident response vehicle (IRV).

Traffic surveillance systems are an important component of the Phase I ATMS. Under perfect operational conditions the Borman Expressway is at or near to its capacity volume during most of the daylight hours. This fact coupled with the high percentage of large commercial vehicles which constitute the typical traffic mix makes incidents on the expressway a particularly difficult operational and safety related problem. Rapid and accurate incident

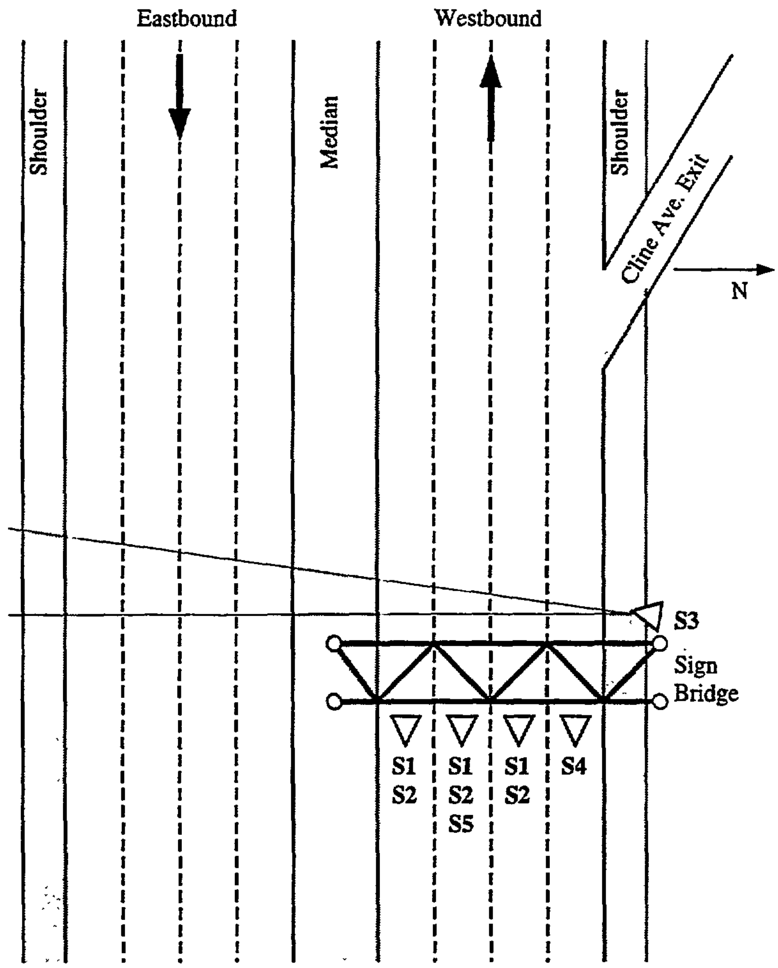


Figure 1: Site Detail for Cline Avenue. S1 is the TDN30 microwave radar, S2 is the 833M6 passive infrared, S3 is the RTMS microwave, and S5 is the AUTO laser radar.

detection and localization are essential requirements in INDOT's efforts to improve Borman operations via the Hoosier Helper Program. A strong emphasis has been placed in the Phase I ATMS on above road traffic detectors because it was believed that current technological developments would allow for the required reliability and accuracy. This emphasis on advanced sensors has made the Borman one of the first tests of these next generation sensors in real world and very far from ideal conditions. Given the volume of traffic, the weather, the dirty conditions, and the high percentage of large vehicles, the challenge presented by the Borman to traffic sensor developers is considerable.

One of INDOT's major concerns in the design of the Borman ATMS was scheduling

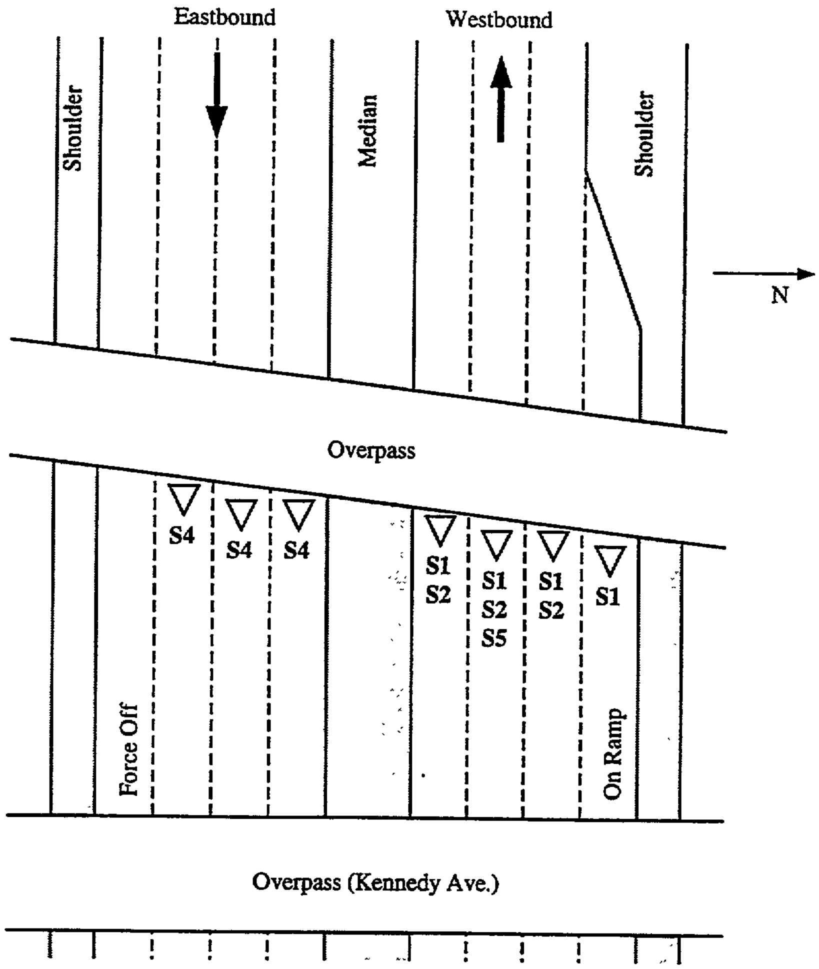


Figure 2: Site Detail for Kennedy Avenue. S1 is the TDN30 microwave radar, S2 is the 833M6 passive infrared, S4 is the TC30C active ultrasonic, and S5 is the AUTO laser radar.

the project during a period of frequent construction along the expressway. Even though construction would dictate some design choices (particularly in communications strategy and in traffic sensor selection), it was deemed imperative to proceed with the ATMS during the construction rather than to wait. Under perfect conditions the expressway is near capacity and major operational problems could be expected relating to construction work zones. It was therefore felt that the time was ripe for operational improvement. Experience has shown that communications systems using buried cable or fiber can experience frequent and prolonged outages during construction phases. This led the design team to choose wireless communications as the backbone of the system. Some of the factors that came into play

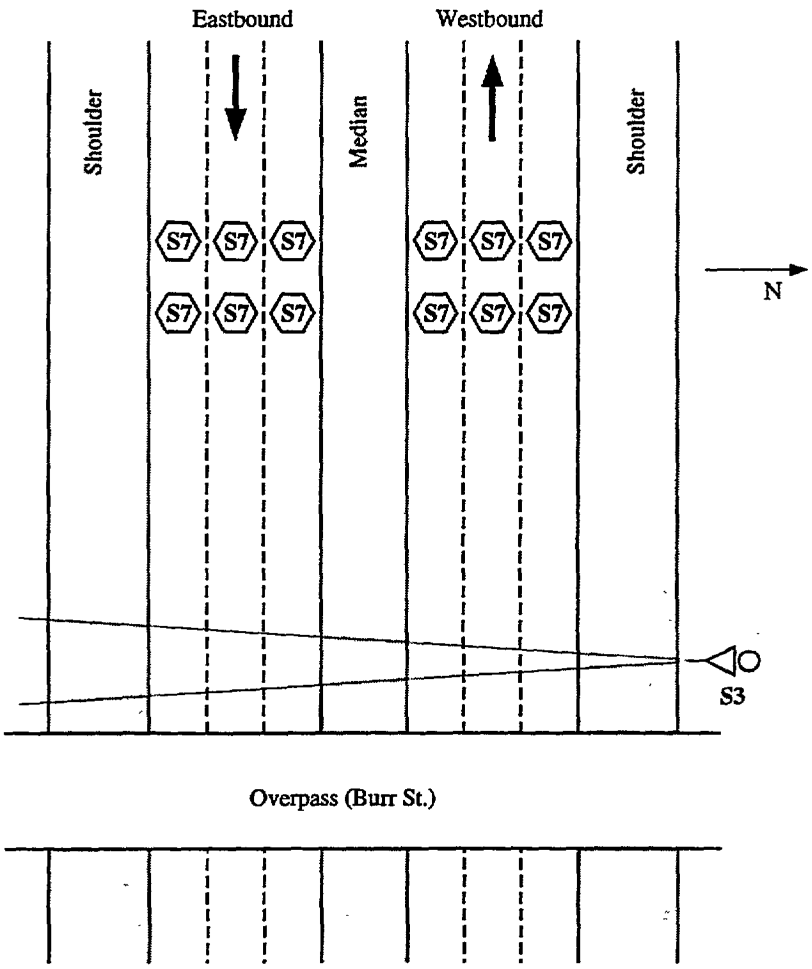


Figure 3: Site Detail for Burr Street. S3 is the RTMS microwave and S7 is the inductive loop.

during the communications architecture selection were the need for a large bandwidth for video transmission over a geographically dispersed area, a requirement for fast deployment, and a need for low operating cost. To best meet the design constraints, a communications architecture based upon spread spectrum radio technology was chosen.

The idea of a remote TMC based in the IRV was born of INDOT's realization that staffing a fixed TMC on a 24 hour basis may not be possible for budgetary reasons. This notion requires that the IRV be capable of executing most of the TMC functions, in addition, it places some constraints upon the communications system.

The Joint Highway Research Project (JHRP) of Purdue University was contracted by

INDOT and the Federal Highway Administration (FHWA) for the task of evaluating the performance of the Phase I ATMS. The report that follows is the result of that evaluation, The Purdue evaluation team consisted of the following individuals: M. P. Fitz (communications), J. V. Krogmeier (sensors), S. Nof (cost/benefit), S. Peeta (architecture): and K. C. Sinha (institutional issues). Prof. Sinha served as the team leader. In addition to the Purdue researchers, the following persons contributed to the evaluation process: Dan Shamo (INDOT), Richard Anderson (Hughes), and Larry Tucker (FHWA).

This report is outlined as follows. In Section 2 an overview of the Barman Expressway ATMS is given, including the system architecture (Section 2.1), the surveillance system (Section 2.2), the communications system (Section 2.3), the incident response system (Section 2.4), and the effect of institutional issues (Section 2.5). In Section 3 the goals, objectives, and hypotheses of this evaluation are listed. The results of the evaluation are contained in Section 4 and conclusions are offered in Section 5.

2 Overview of the Borman Expressway ATMS

2.1 The System Architecture

The Borman Expressway Phase I ATMS architecture consists of five systems: 1) the TMC system (both central and remote operation), 2) the traffic surveillance system, 3) the communications system, 4) the incident response system, and 5) the traveler information system. A functional block diagram of the ATMS architecture is shown in Figure 4.

The functions of the TMC system are to serve as a central command, control, and information distribution post. The main spread spectrum radio link terminates at the TMC which serves as a hub for radio communications throughout the system. In addition, the TMC contains operator consoles and computing equipment for the processing and display of traffic state information gathered by the surveillance system. Three video display terminals in the TMC can be connected to video cameras located at the three interchanges via a

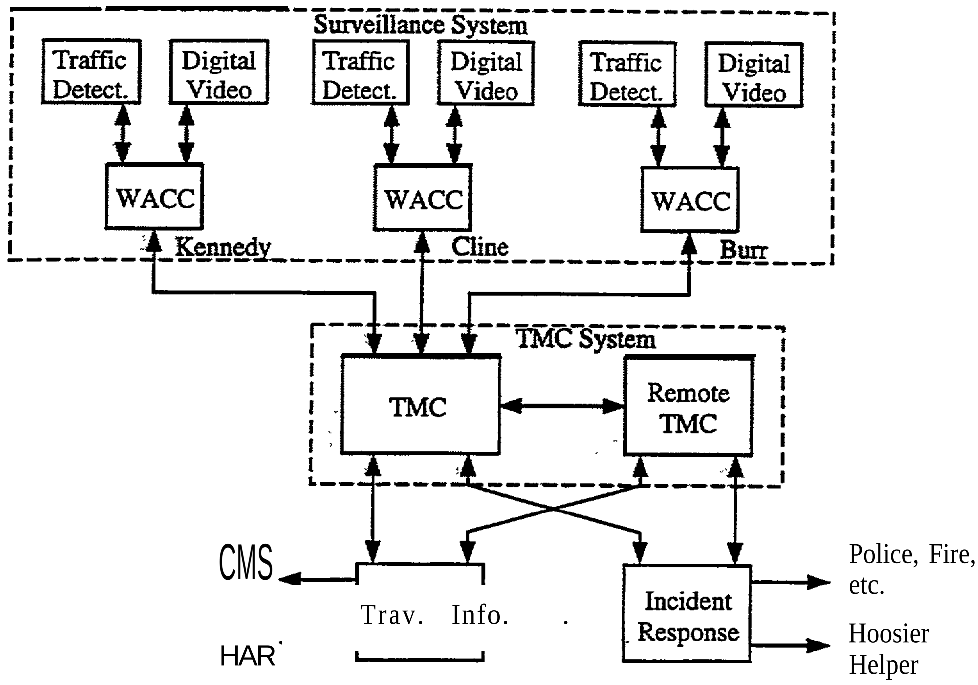


Figure 4: The Phase I Borman ATMS Architecture.

compressed video stream carried by the spread spectrum radio communications system. One additional uncompressed video feed (carried by an analog radio) is available from a camera located at the Borman/I-65 interchange. A data logging system, located in the TMC, provides the capability to record real time sensor event data which can easily be cross referenced to the video feeds captured by a computer controlled video cassette recorder (VCR). An additional important component of the TMC function is the capability to be remotely controlled via the IRV. This desired capability puts some constraints upon the communications and data processing equipment as well as on the expertise required of the IRV operator.

The function of the traffic surveillance system is to measure basic traffic parameters including volume, speed, and occupancy of the traffic lanes at the three interchanges included in the Phase I system. The surveillance system is also responsible for certain preprocessing or averaging of the data from the sensors if required by a particular application. The video cameras are a part of the surveillance system along with the video compression equipment.

The surveillance system of the Phase I ATMS was also designed to include sensors with capabilities to supply signatures of vehicles which could be used for purposes of pattern recognition in next generation incident detection algorithms.

The primary communications system for the Phase I ATMS consists of spread spectrum radio links between each of the three interchanges and the Gary subdistrict site. There is a Tl rate spread spectrum radio (SSR) link between Gary and the TMC. All of these links are full duplex. In addition, the IRV is linked via SSR to the three interchanges. The radio channel used is determined by which interchange is closest as determined by a global positioning system (GPS) receiver located in the IRV. All IRV to TMC communications are multiplexed along with the-sensor telemetry and video for transmission to the TMC.

The incident management system is a central part of INDOT's future plans for the Borman ATMS. The IRV is-a medium sized truck equipped to clear up minor incidents and with a full capability to call in help from other authorities (police, fire, towing, etc.) for larger incidents. The IRV has the capability to record data on each incident, to operate the traveler information system, and to design detours using the information from the surveillance system and TMC processors.

2.2 The Surveillance System

Twenty-one above road traffic sensors and twelve inductive loops have been deployed in the Phase I system. Six different devices were used covering five technologies and involving six manufacturers. We refer to the different devices using the notation introduced in the Phase I report prepared by the project contractor [Hughes 95]. The sensors are: (Sl) TDN30, an active microwave radar manufactured by Whelen Engineering Company, (S2) 833M6, a passive infrared sensor manufactured by Eltec Instruments, (S3) RTMS, an active microwave radar manufactured by Electronic Integrated Systems, (S4) TC30C, an active ultrasonic sensor manufactured by Microwave Sensors, (S5) AUTO, an active infrared laser radar manufactured by Schwartz Electra-optics, and (S7) LOOP, a traditional inductive loop. The

Site	Lane								Technology
	E-4	E3	E2	El	WI	W2	W3	W4	
Kennedy					TDN30 833M6 TCSOC	TDN30 833M6 TC30C AUTO	TDNSO 833M6 TCSOC	TDN30	Microwave Infrared Ultrasonic Infrared
Cline	RTMS	RTMS	RTMS	RTMS	TDNSO 833M6 RTMS	TDN30 833M6 RTMS AUTO	TDN30 833M6 RTMS	RTMS TC30C	Microwave Infrared Microwave Ultrasonic Infrared
Burr	– – –	RTMS LOOP LOOP	RTMS LOOP LOOP	RTMS LOOP LOOP	RTMS LOOP LOOP	RTMS LOOP LOOP	RTMS LOOP LOOP	– – –	Microwave Induction Induction

Table 1: Sensor deployment in Borman Expressway ATMS. Lanes are numbered from one to four from the center median out to the road's edge.

deployment of Borman sensors is also shown in Table 1 below. More details are available in [Hughes 95].

We differentiate between active sensors, which transmit energy toward a target and then measure the return signal, and passive sensors, which measure energy emitted by the target itself. Four of the Borman sensors are active (TDNSO, RTMS, AUTO, and TCSOC) and two are passive (833M6 and LOOP).

2.2.1 The Active Sensors

Among the active sensors deployed on the Borman, two are microwave devices (TDNSO and RTMS), one is based on an infrared laser (AUTO), and one is an ultrasonic device (TCSOC). All operate by transmitting a signal toward a spot on the road to determine if a target is present in the field of view.

A. Microwave. Both of the microwave radars tested in the Borman project operate at a center frequency of 10.525 GHz in the X-band. This is typical of traffic (police) radars. The two models, however, rely on different mechanisms to detect vehicles and estimate speed.

The TDNSO **is** a continuous wave radar which continuously transmits the unmodulated carrier, focused by its antenna into a narrow beam, and aimed at a particular spot covering a single lane. It detects moving vehicles based upon the Doppler shift in the frequency of the reflected radar signal. The magnitude of the Doppler shift is directly proportional to the vehicle's speed. When a vehicle moves through the detection zone a portion of the transmitted radar signal is reflected back with a Doppler effect shift in the center frequency. Vehicle detection is done by thresholding the Doppler shift and vehicle speed is estimated based upon the magnitude of the Doppler shift. The device includes two mixers which allows it to detect the sign of the Doppler frequency shift and hence, the direction of vehicle movement through its beam. The biggest advantage of the TDN3O relative to most other detectors is that it estimates vehicle speed directly. A potential disadvantage is that it can only detect moving vehicles (since the Doppler shift from a stationary vehicle is zero).

The RTMS is a frequency modulated continuous wave radar. It does not use the Doppler effect but rather measures the range to a target in its detection zone by demodulating the return signal and comparing the phase of the demodulated return signal with that which was transmitted. It can operate in forward looking or sidefire modes with up to twelve detection zones specified by programmable range gates. In the Borman application, operation is in the sidefire mode. The fundamental outputs in this mode of operation are detections and presence times for each detection zone (it actually provides only averages of these over a user-selectable time window). The device computes an average speed estimate based on presence time and an assumed average vehicle length.

The performance of the detection and estimation algorithms for either radar is primarily determined by the signal-to-noise ratio (SNR) via the radar equation [Skolnik 62]. The only variable parameters in the Borman application are the radar cross section of the vehicle and the integration time (other parameters include: the antenna gain, transmitted power, and geometry). Integration time varies directly with vehicle length and inversely with vehicle speed. At high vehicle speeds, performance degradation is expected because of a smaller integration time. At low vehicle speeds, performance degradation is expected because of the small magnitude of the Doppler shift frequency.

Attenuation at microwave frequencies is small through plastic or fiberglass allowing these devices to be completely enclosed from the weather. This is a significant advantage in the Borman Expressway application where dirty conditions are a problem. For the same reason the devices are relatively insensitive to weather conditions.

B. Ultrasonic. An active ultrasonic detector transmits acoustic energy focussed by an antenna towards a detection zone located on the roadway. Ultrasonic devices can base detection upon range estimation, Doppler frequency shift, or a combination, just as is the case for microwave detectors. Many of the same considerations and the same basic equations describe the operation and performance of both ultrasonic and microwave devices. The center frequency and the form of transmit energy (acoustic versus electromagnetic) are the only essential differences.

The TC30C transmits an ultrasonic carrier at 49.7 KHz which is amplitude modulated by a relatively short pulse (about 10 msec). After transmission of the pulse, the device listens for a return in a programmable range gate (field adjustable via a potentiometer located in the unit). The round-trip time delay is proportional to the distance to the target in the detection zone. If the echo is in range, then a counter is triggered. The detection signal stays high for as long as the target is in the range gate plus a user selectable hold time from 0.25 to 10 seconds. In this sense, the device is a true presence sensor.

Since ultrasonic sensors rely for operation on sound wave propagation through the air, they have the potential to be sensitive to noise pollution and weather conditions (temperature and humidity) which may change the propagation velocity. Such changes can be large enough to change the perceived range gates significantly. In addition, the device has fairly strict pointing requirements.

C. Infrared. Active infrared devices contain lasers operating in the infrared spectrum which transmit short coherent pulses of light which are focussed by optical systems and directed towards a detection zone on the road. The round trip propagation time is proportional to the distance to a target in the detection zone.

Sensor AUTO is such a device. It uses a InGaAs diode laser which emits in the infrared at 904 nm as a transmitter and a Silicon PIN photodiode as the receiver. The output of the transmitter is split into two divergent fan beams with a preset (10 degree} angle between them. For moving or stationary vehicles, AUTO provides detection, presence, speed, and range profiles. Detection and presence are obtained by setting a threshold on the range. Speed is calculated from the time between sequential detections on the two beams. Range profiles (and return signal intensity) are sampled at 3KHz from the range estimates on each of the two beams. The device measures the return signal level and uses it to adjust for weak signals (e.g., as on black cars or windshield) by applying a correction to the range measurement. The potential of this device to provide vehicle signatures opens the possibility to use it in innovative incident detection and travel time estimation algorithms which are based upon notions from pattern recognition [Duda 73] and multiple target tracking [Bar-Shalom 78].

2.2.2 The Passive Sensors

A. Infrared. The 833M6 senses vehicles based upon the thermal contrast they present with the road surface. All matter emits thermal radiation as a function of its temperature. In solids, thermal radiation is a surface phenomenon in that it depends largely on the properties of the object at its boundary with the volume into which it radiates. For most objects the thermal radiation released is a broadband phenomenon, extending over a wide range of wavelengths (possibly from the near ultraviolet to the far infrared) [Dewitt 88].

The thermal radiation from real physical objects is always referenced to an ideal black body radiator and the parameter which makes the connection is the emissivity which may be a function of wavelength, direction, and position on the surface of the object. The wavelength of the peak of the black body radiation curve is inversely proportional to temperature varying from about 0.5 μm which is in the visible spectrum at a temperature T = 5800 K (corresponding the solar radiation) to 9.6 μm at room temperatures (this is in the wavelength band of the 833M6). Certain types of thermal radiation detectors convert absorbed radiation into heat causing the detector temperature to rise. The temperature rise is sensed in terms of its effect on the physical properties of materials. In pyroelectric detectors, such as the 833M6, the material property used is electrical polarization.

The 833M6 is not a general radiation thermometer in that it does not have to estimate the object's temperature; it is only used to sense thermal contrast which signals that a vehicle is in the field of view. This requires that the 833M6 perform a sort of averaging to determine a reference temperature. This explains the rather particular attribute of the device where it ceases to "see" a vehicle if it is in the field of view too long [Eltec 921.

B. Inductive Loops. The inductive loops used in the Borman Phase I ATMS are standard. They use 4 turns of wire (14 gage copper) per loop in a 6 foot diameter octagonal shape. The loops are each connected to a Detector Systems Model 262C dual digital loop detector and the loops are configured in pairs to act as speed traps. Inductive loops use a tuned circuit to detect the presense of a vehicle which changes the inductance of the loop and results in a change in the center frequency of the tuned circuit. The detector senses the change in frequency.

Inductive loops typically suffer from poor reliability arising from bad connections and pavement sealant failure. They are often destroyed by road work and utility excavation alongside the road. The loops installed as part of the Phase I ATMS are intended solely for comparison to the more sophisticated overhead sensors.

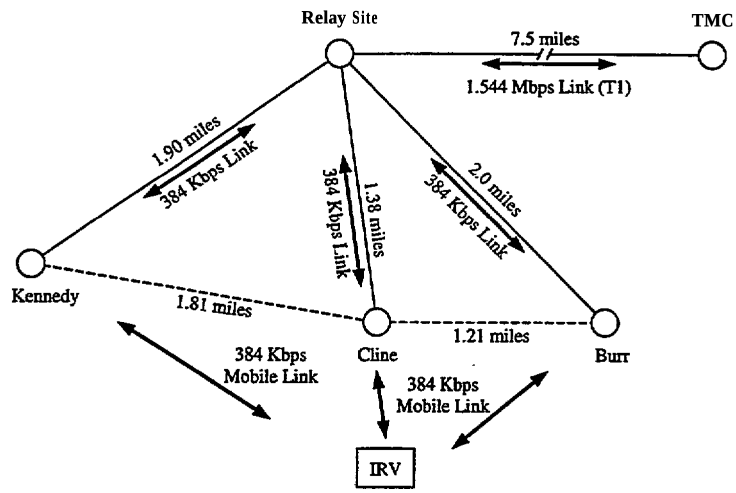


Figure 5: Communications Architecture.

2.3 The Communication System

The Phase I Borman Expressway ATMS project takes a great deal of its novelty from the extensive use of wireless communication technology. Wireless communication greatly reduces the amount of new cabling and infrastructure needed to implement an ATMS, but bandwidth for wireless transmission is hard to obtain. For the Phase I deployment three sensor sites are connected with the TMC via multiple wireless radio data communication links. Since the desire for real time video images dominates the bandwidth requirements for this communication architecture, the information transfer rate from each sensor site is high enough to allow video (384 Kbps) and the total input to the TMC is 1.544 Mbps. In order to reduce cost a significant effort was made to ensure that no FCC licensing was required for radio operation. The Borman communication systems also needed fast deployment time, high availability, and low installation and maintenance costs. For these reasons the fairly mature technology of spread spectrum radio communication in the ISM and Part 15 bands were chosen for the wireless portions of the ATMS communication system. A block diagram of the spread spectrum communications system is shown in Figure 5.

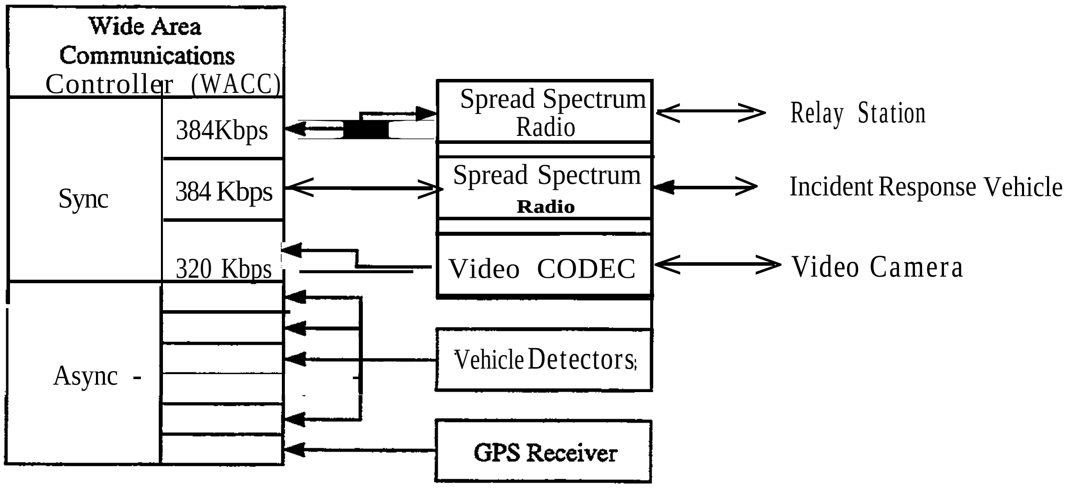


Figure 6: Wide area communications controller and various interfaces.

WACC/MCC. There were a number of very complex requirements driving the design for the Borman Expressway system. One of the most challenging was the seamless integration of all subsystems into a single homogeneous system and an initial design goal of the project was to incorporate a distributed architecture that supported multiple application processes.

To meet this goal using off-the-shelf components, a reconfigurable, intelligent communications preprocessor was created. It is comprised of a 32 bit microprocessor that is the Master Controller, and a series of additional sub-processors which are added as application demands become more complex and require additional processing power. The configuration of hardware and software components determines its functionality and capability. When configured for Remote Site and IRV use, the multi-processor system is called the Wide Area Communications Controller or WACC. Similarly, when configured for TMC functionality, it is called the Main Communications Controller or MCC. The WACC and its various interfaces are shown in Figure 6.

The processor system serves a myriad of functions, but when configured as a WACC, its primary purposes are to preprocess sensor data, to combine narrowband information into the compressed video stream, and to provide an interface to the spread spectrum radios. When configured as an MCC, it is programmed to execute TMC functions. There are actually two independent Master Controllers per WACC or MCC. One is dedicated to managing the compressed video streams while the other acts as a system coordinator for all narrowband sub-processes. During the system configuration process, each subprocessor is informed as to the type of subsystem to which it will be connected. Thus, when the WACC or MCC is initialized, the Master Controllers ensure that each subprocessor is prepared to manage their respective installed subsystems.

When installed at a remote site, the WACC is programmed to perform the following functions: 1) sensor preprocessing or fusion of the detector data, 2) video camera control interface, 3) video coder/decoder (CODEC) interface, 4) GPS receiver interface, 5) subsystem power control, and 6) subsystem status monitoring and control. When installed in an IRV, the WACC is programmed to perform the following functions: 1) video camera control interface, 2) video CODEC interface, 3) GPS receiver preprocessing, 4) on-board computer network interface, 5) subsystem power control, and 6) subsystem status monitoring and control. Finally, when installed in at the TMC, the MCC is programmed to perform the following functions: 1) master CCTV camera control interface, 2) interface for multiple video CODECs, 3) GPS tracking of the IRV, 4) establishment of real-time connections to all sensor interfaces, 5) format of the sensor data for ATMS functions, 6) IRV's on-board computer interface; 7) remote site power control, and 8) remote site status monitoring and control.

384K S-Band Spread Spectrum Radio (SSR). The 384K S-band SSR made by Cylink provides a point-to-point solution for high speed data communication in the FCC Part 15 allocation at 2.4 GHz. The Model 384K can be configured for point-to-point, repeater, or hub applications. This radio uses a master-slave full duplex transmission for point-to-point applications. A total of 8 frequency multiplexed channels are available with this radio, but these channels are overlapping so that it is essentially a two channel radio (though some additional channels may be available by giving users different spread spectrum codes). The receiver sensitivity is -87 dBm and the claim is that a carrier to interference ratio (C/I) of

Figure 7: Equipment cabinet located near the comnumications tower at the TMC. Shown is the LYNX spread spectrum radio.

0 dB can be maintained with a bit error rate of less than 10^{-6}.

Tl S-Band SSR. The S-band Tl SSR is the Model LYNX radio made by the Western Multiplex Corporation (see Figure 7). This radio uses the same FCC Part 15 spectrum as the abovementioned 384 Kbps SSR and provides full duplex Tl rate (1.544 Mbps) transparent digital signaling for point-to-point applications. Essentially this radio provides the same functionality as the 384 Kbps radio with a four times faster data rate.

Tl C-Band SSR. The Cylink Model Airlink T1 radio is a spread spectrum transceiver that operates in the 5.725 to 5.860 GHz (C-band) Industrial Scientific Medical (ISM) band. The Airlink Tl uses a spread spectrum modulation technique to create a high-quality, point-to-point radio link between itself and another AirLink T1 some distance away.

The AirLink Tl provides full-duplex, radio-to-radio communication that follows a ping-pong analogy: while one unit transmits a radio burst, the other unit receives that burst. The terminals alternate between transmitting and receiving in this way. This protocol is called Time Division Duplex and is transparent to the Tl equipment on either end of the link because the digital buffering of the AirLink Tl produces a smooth Tl bit stream at the user interface.

Analog Video Radios. The analog video radios are made by Wireless Technologies Inc. and provide wireless analog (uncompressed) video transmission in the same S-band (Part 15) spectrum as the SSRs discussed previously. This radio essentially frequency modulates (FM) the analog video for transmission and can utilize a total of 9 channels.

2.4 The Incident Management System

The Hoosier Helper IRV is a medium-sized truck equipped with a 384 Kbps spread spectrum radio link, an on-board computer, a video camera mounted on an extendible boom, and a GPS receiver (see Figure 8). In addition, the IRV contains equipment for aiding stranded motorists and for clearing minor incidents. INDOT's goal for the IRV is that it also have the capability to serve as a mobile TMC. To this end it needs to have powerful communications capabilities and computer support in order to be able to transmit and receive messages, sensor data, images, and control information. In addition to the TMC radio link, the Hoosier Helper must communicate with outside authorities including police, fire, hazardous materials specialists, and towing companies. Several features of the Mobile TMC approach to distributed information and control are summarized below.

- An expert system for controlling Changeable Message Signs (CMS) and Highway Advisory Radio (HAR) stations directly from the IRV vehicle is under development. The expert system prompts the Hoosier Helper for details about an incident and then prepares appropriate messages for all upstream CMSs and HARs.
- The IRV will be equipped with an automated emergency services call out system. This capability is particularly important on the Borman since the 16-mile expressway includes nine different communities providing emergency response services. The sys-

Figure 8: The Borman ATMS incident response vehicle.

tern uses GPS positioning which enables the computer to determine the appropriate emergency response agency and automatically place a cellular telephone call.

- To further enhance the all important communication between the Hoosier Helper and the response agencies, freeze frame photographs will be captured from the incident response vehicle's on-board video. These images will then be faxed from the vehicle to the appropriate emergency responders. This is particularly useful for wrecker services, fire fighters, and maintenance crews who must make quick decisions about what equipment to deploy to an incident scene.

- In certain instances it is necessary to partially or completely close the road. The Hoosier Helper will soon have the ability to design a detour right from the vehicle. After entering the point of closure and the return link, the host computer will then quickly generate the most efficient alternate routes around the incident scene. In some cases this will entail designing multiple detours, one for immediate rerouting and others for vehicles that have not yet arrived at the problem area. The plans for this system include a travel time monitoring system which will continually compare current incident reopening times with detour travel times so that the detours can be lifted at just the right time to minimize unnecessary loading of local routes.

Finally, this same on-board terminal is used for several everyday tasks like recording details of each incident, maintaining the inventory of materials carried on the incident response vehicle, and eventually "help desk" information for various tasks such as automatic troubleshooting and medical emergency procedures. This information is always needed to keep a complex incident response program operating smoothly.

2.5 Institutional Issues

The design of a complicated system such as the Borman ATMS must take careful account of certain institutional issues. For the Borman, an important consideration is the effectiveness of planned coordination with local authorities such as police, fire, ambulance, and towing services. Fast and effective communication between these groups and INDOT will be required to implement the planned incident response strategy. In addition, given the extensive use of spread spectrum radio in unlicensed bands by the Borman ATMS, there is an issue of the availability of the spectrum and the potential for radio interference from outside users of the same spectrum. These issues are considered later in the evaluation.

3 Evaluation Framework

A framework was established by the study team for evaluating the Phase I ATMS in consultation with INDOT and FHWA representatives. The framework identified the goals, objectives, and hypotheses associated with the Borman ATMS as listed below. The results of the evaluation and discussion follow in later sections of this report.

- Goal 1. Evaluate the System Architecture.
  - Objective 1.1. Assess the suitability of data for traffic management algorithms (current and future).

    * Hypothesis 1.1.1. The data collected are suitable for current and future traffic management algorithms.
- Objective 1.2. Assess the flexibility of the system for future growth.
    * Hypothesis 1.2.1. The sensor equipment is flexible for future growth.
    * Hypothesis 1.2.2. The data processing equipment is flexible for future growth.
    * Hypothesis 1.2.3. The communications equipment is flexible for future growth.
    * Hypothesis 1.2.4. The architecture is flexible for future growth.

- Goal 2. Evaluate the Sensor Technologies.
  - Objective 2.1. Assess the performance of the traffic sensors.
    * Hypothesis 2.1.1. The individual sensors detect at least 95% of vehicles.
  - Objective 2.2. Assess the reliability of the traffic sensors.
    * Hypothesis 2.2.1. The individual sensors are 95% reliable.

- Goal 3. Evaluate the Communication System.
  - Objective 3.1. Assess the performance of the communication system.
    * Hypothesis 3.1.1. For each link, the bit error rate is less than 10^{-5}.
  - Objective 3.2. Assess the potential for interference problems.
    * Hypothesis 3.2.1. Radio interfence does not degrade the SSR link performance.
    * Hypothesis 3.2.2. The likelihood of future interference causing significant system degradation is low.

- Goal 4. Evaluate the Mobile Incident Response Vehicle (IRV) Equipment.
  - Objective 4.1. Assess the suitability of equipment to support the planned use of the IRV.
    * Hypothesis 4.1.1. The CMS and HAR will support IRV needs.
    * Hypothesis 4.1.2. The ability exists to support electronic revolving call out for wrecker service.
    * Hypothesis 4.1.3. The ability exists to contact emergency services (police, fire, ambulance, state police office, hazardous material responders).
    * Hypothesis 4.1.4. The ability exists to define a dynamic detour routing system.
  - Objective 4.2. Assess the human factors issues.
    * Hypothesis 4.2.1. 99.5% of IRV operators can perform the required data collection.

- Goal 5. Evaluate the Institutional Issues.
  - Objective 5.1. Assess the capability of the system to integrate with the existing local infrastructure and emergency response services.
    * Hypothesis 5.1.1. It is likely that local wrecker, police, fire, and ambulance services will be equipped to respond to the planned coordination.
    * Hypothesis 5.1.2. Local authorities are willing to cooperate with **INDOT.**
  - Objective 5.2. Assess the communication system requirements for effective inter-agency communication.
    * Hypothesis 5.2.1. The communication system requirements are consistent with the capability of the local emergency services.
    * Hypothesis 5.2.2. The planned communication architecture will support additional communication links.
  - Objective 5.3. Assess the issues associated with radio frequency utilization.
    * Hypothesis 5.3.1. The proposed spectrum is sufficient at this time.
    * Hypothesis 5.3.2. The proposed spectrum will be sufficient for future expansion.

4 Results of the Evaluation

4.1 Goal: Evaluate the System Architecture

4.1.1 Objective: Assess the suitability of data for traffic mangement algorithms (current and future)

An important function of the Phase I ATMS is that it serve to gain experience regarding the most appropriate and effective architecture for deployment in the full scale system. The Phase II system is planned to make heavy use of automatic incident prediction and detection algorithms which use traffic related data provided by the surveillance system, weather stations, motorists, and the IRV operator. As a design aide for the Phase II system, the Phase I system is to provide an extensive database containing such information. It is also planned to use incident databases like these for training purposes.

A PC-based data logging system was developed for the Phase I ATMS. It consists of a computer controlled VCR, an IBM compatible computer with two serial ports, a removable disk storage device, and the data logger software. The system is able to record both live link and averaged data from the traffic surveillance system and to cross reference it to a video tape. The logging system resides in the TMC and is interfaced to the surveillance system via the spread spectrum radio and the TMC Main Communications Controller.

The various sensors installed under the Borman ATMS Phase I Evaluation individually provide data on some of the following traffic attributes: vehicle presence, speed, occupancy, volume, and time headway. For example, the RTMS sensor generates multi-lane data on occupancy, volume and speed while the TDN30 sensor generates only single lane speed data [Hughes 95]. Data on vehicle presence and headways are direct outputs from the detectors (also, speed is obtained directly from some detectors). Data generated on vehicle occupancy, volume and speed are 20-second to l-minute average values that are preprocessed by the field processing equipment. Depending on the functionality, the data is collected over short-term (20 seconds) intervals (called tactical data), medium-term (5 minutes) intervals (called strategic data), and long-term (15 minutes or one hour) intervals (called historic data).

HYPOTHESIS: The data collected are suitable for current and future traffic management algorithms.

Current traffic management algorithms [May 90] primarily make use of loop compatible information such as averaged speed, volume, and occupancy. The traffic surveillance and data logging systems provide this information in a form that is easily used by these algorithms. Therefore, the hypothesis is verified as regards the requirements of current traffic management algorithms.

Future traffic management algorithms will probably be based largely on traffic parameters in common use today (speed, volume, and occupancy) [Hughes 93]. The biggest change arising from the use of advanced detection and communication technologies will be in increased surveillance coverage and a far greater volume of data that will be generated. There will be more use of next generation traffic sensors which will provide information relevant to the classification of individual highway vehicles as well as speed, volume, and occupancy. In addition, it is likely that vehicle transponders will play a large role in the near future. The Phase I ATMS has included one sensor of this new class (AUTO) which has the capability to capture signatures from vehicles in the form of height and reflectance profiles. Unfortunately, AUTO did not perform well in the sensor tests and its potential capabilities could not be verified. The current data logging system does not fully support the high data rate produced by AUTO (i.e., not all of the information generated by the sensor can be logged). It is likely that software and hardware changes will be required in the WACC for purposes of data reduction and sufficient statistics generation when using such sensors.

There are several different types of traffic management algorithms in the literature. Some have existed for about the last decade while others represent the new generation of traffic management algorithms that are using or propose to use the advanced technologies envisaged under ITS. They include incident detection, incident likelihood prediction, ramp metering, route diversion, route guidance, signal control, and truck routing algorithms. Most of them require the collection, processing, and management of real-time traffic flow data. Some of them require the integration and/or coordination of different ITS technologies such as ATMS, ATIS, APTS and CVO. For example, route guidance requires an integrated ATIS-ATMS architecture. Also, depending on the operational need, short-, medium-, or long-term data may be required. For example, incident likelihood prediction requires historical traffic and weather data that is updated based on current traffic conditions.

The data processing capabilities of the Borman sensors meet the functional requirements of current traffic management algorithms for the most part, in terms of the type and resolution of the data required. However, it is important to note that none of the detectors met all of the performance criteria in the field tests, and require further refinements. For example, the most promising technology evaluated, the TDN30 detector, missed about 10-15 percent of the vehicles under high speeds and very low headways (of the order of a second). Thereby, errors in the measurements can affect the effectiveness of the various traffic management algorithms.

From the perspective of existing and future needs:

- The currently installed detectors on the Borman Expressway cannot classify vehicles as required by the congestion management systems under ISTEA. The Phase I evaluated laser-based detector, AUTO, did not meet the performance requirements for vehicle detection or classification.

- Both the temporal and spatial resolutions of the traffic data are important. While data can be obtained at sufficient temporal resolution using the Phase I detectors if one ignores the performance problems, it is also important to ensure that data is available at various levels of spatial resolution. Future traffic management algorithms will require microscopic traffic data such as flow and/or vehicle counts on a lane-by-lane basis for applications ranging from high accuracy incident detection to monitoring compliance with route guidance and user behavior.

- A very important element of the new generation traffic management algorithms is the availability of dynamic origin-destination (O-D) estimates and/or predictions [MM 95]. These algorithms require an automated ability to track vehicles from their origins to their destinations to develop current O-D estimates and/or future O-D predictions, and for modeling user behavior under ITS. These are useful in developing high accuracy route guidance and congestion management strategies. The currently installed detectors cannot provide this functionality. Additional technologies such as automatic vehicle identification (AVI) and image sensing detectors are necessary.

4.1.2 Objective: Assess the flexibility of the system for future growth

It is relatively difficult to envision the myriad directions in which computing, communication, and sensor technology may go in the future though it is important to provide certain near term flexibility particularly in a preliminary ATMS design,

HYPOTHESIS: The sensor equipment is flexible for future growth.

The future will probably see a greater use of powerful sensors which provide more information about individual vehicles. These sensors may capture vehicle signatures and will therefore require more communications bandwidth and powerful local processors for distributed data reduction. Although several advanced sensors were tested in the Phase I ATMS, certain technologies were omitted including: imaging radars (microwave and laser), infrared imaging, video image processing, and acoustic antenna arrays. The computing system in the Phase I system has been implemented as a form of distributed system (based on the WACCs) and it is therefore safe to say that the surveillance system is sufficiently flexible to accommodate near term growth in sensor technology. It may be necessary to modify the WACC to provide more serial ports, however.

In the longer term it is likely that the bandwidth requirements of traffic sensors will overwhelm the communications architecture and the processors in the current generation of WACC.

HYPOTHESIS: The data processing equipment is flexible for future growth.

In the future there will likely be a stronger emphasis on distributed computing which is driven by sensor capabilities and the need to control communication bandwidth requirements. The Phase I system will be sufficient in the near term but much more powerful microprocessors will be needed over a ten year horizon. The current WACC and MCC is based on Intel 486 technology which is nearing obsolescence in some applications.

HYPOTHESIS: The communication equipment is flexible for future growth.

The communication system is flexible for future growth. The use of powerful communications controllers to preprocess and pass data from a wide variety of sources theoretically allows for an arbitrarily large system by allowing the controllers to be feeders to a main communications backbone (much like a cellular structure employed in land mobile telecommunications). The real limitation on the future growth of the system is the data rate the main communications backbone can support and how many links accessing this backbone are feasible given the current design. Currently, the main communications backbone is operating at Tl rates (1.544 Mbps). If one excludes transmission of real time video, then the rate is more than adequate for any possible future expansion on the 16 mile Borman Expressway. Likewise, the current wireless SSR configuration will provide adequate access capabilities. If real time video is to be transmitted, then this Tl rate will quickly limit future growth of the system. Realistically, at most five simultaneous, high quality video images could be communicated with the TMC at one time (while maintaining the other ATMS functions) with a T1 rate. While multiple backbones (e.g., an eastbound and a westbound backbone) are possible to increase the data input into the TMC, it is highly dependent on the capacity of the wireless links composing the backbone. Similarly, a more careful design of the access links to the backbone will be needed (i.e., frequency plans will become very important) if video capabilities are required from each feeder point. The overall capacity of the wireless backbone and the feeder links will be addressed later in this document.

Recommendation: If large numbers of real-time video feeds are at some point deemed to be important in the ATMS functionality, then a higher capacity fixed backbone might be appropriate (e.g., fiber optic cable or a connection to the landline telecommunications infrastructure).

HYPOTHESIS: The architecture is flexible for future growth.

The final conclusion is that the overall system is flexible for growth over about a ten year horizon. After that point it is likely that sensor and computer technology will require a substantial redesign.

4.2 Goal: Evaluate the Sensor Technologies

Most of the functions of the Borman ATMS depend upon collecting, processing, and managing real-time data on expressway traffic flow. Congestion monitoring is used for response functions like incident detection, route diversion, traveler information, traffic planning and

Sensor	Tech.	Outputs Count	Pres.	Speed	Occ.	Class.	WACC corm.	Mount
TDN30	microwave	X		X			serial	overhead
833M6	pass. infrared	X					digital	overhead
RTMS	microwave	x	x	x	x		serial	sidefire
TCSOC	act. ultrasonic	x	x				digital	overhead
AUTO	act. infrared	x	x	x		X	serial	overhead
LOOP	inductive	x	x				digital	pavement

Table 2: Details of the Borman Phase I ATMS traffic sensors (Occ. = Occupancy, Class. = Classification).

analysis. Therefore, the surveillance system is essential to the successful operation of the Phase II ATMS.

The choice of traffic sensors to test in the Phase I ATMS was based on the results of an earlier study of sensor technology which was done for the FHWA [Hughes 93]. The study included a development of sensor requirements for use in several ITS applications in addition to laboratory and field testing of the available technologies. The sensors chosen for the Borman field trial were a subset of the group with acceptable performance in the earlier study.

The deployment of the Phase I traffic sensors is given in Table 1. Additional details regarding the types of traffic parameters measured and the WACC connections are listed in Table 2. A summary of the capabilities for each sensor is given in Table 3. The traffic sensors at Kennedy Avenue are shown mounted in Figure 9. Those at Cline Avenue are shown in Figure 10. The video camera located at Burr Street is shown in Figure 11.

An important aspect of the equipment evaluation for sensor selection is the integrated evaluation of short- and long-term economic and technological sensor parameters. This consideration is particularly relevant where there may exist an overlay of capabilities among alternative sensor technologies, and is essential in decisions involving sensor reliability and maintenance. Models for such integrated evaluation have been developed at Purdue [Edan 95, Remski 93]. However, initial evaluation is this study has shown that this step may be delayed

Sensor	Detectable Objects	Center Freq.	Detection Zone	Speed Accuracy	Detection Range	Detection Accuracy
TDN30	All vehicles moving > 5 mph	10.525 GHz	8° BW	± 2 mph NA	< 100 ft.	NA
833M6	All vehicles	–	1.3 × 7.2 ft.	NA	16 - 98 ft.	NA
RTMS	All vehicles	10.525 GHz	15° Az. 25° El.	± 10%	< 200 ft.	NA
TC30C	All vehicles	49.7 KHz	20° BW	NA	3 – 23 ft.	NA
AUTO	All vehicles	–	9.5"Az.	± 1 mph	5 - 50 ft.	NA

Table 3: Specifications for Borman ATMS Phase I sensors. "_" = not applicable, NA = information not available.

until the technological feasibility of the sensor has been stabilized.

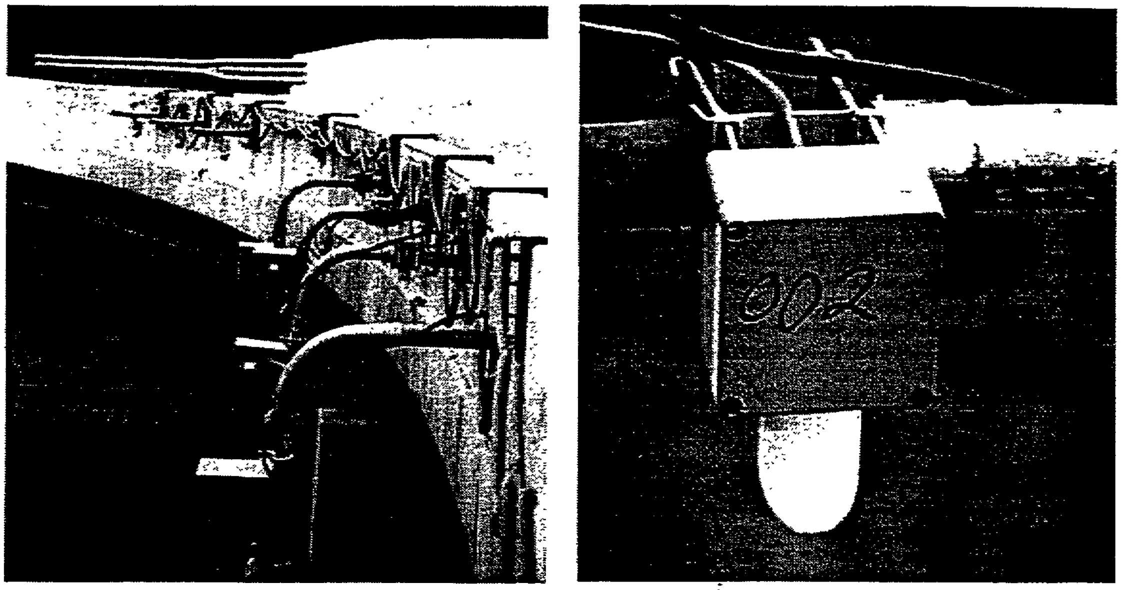
4.2.1 Objective: Assess the performance of the traffic sensors

A performance test of the Phase I sensors was conducted by Hughes and INDOT personnel under good conditions (clear weather during summer months) in high traffic volume, high speed conditions which are typical of Borman operations. The design team has determined that the following five traffic parameters are essential for planned incident detection and route diversion functions: 1) instantaneous vehicle detection, 2) vehicle presense, 3) instantaneous speed, 4) inter-vehicle headway, and 5) detection time interval.

HYPOTHESIS: The individual sensors detect at least 95% of vehicles.

None of the sensors in the test passed the hypothesis of detecting 95% of vehicles. This assesment also applies to the loop detectors which were never reliable enough to test. According to Hughes and INDOT engineers, the loop detectors suffered from calibration problems which should be easily corrected. Typical Borman operating conditions where vehicle speeds are in excess of 65 mph and time headways are significantly less than one second have proven to be an extremely challenging situation for current detector technologies. Of all sensors tested, the TDN30 performed the best, although it under counted vehicles by around 10%. The rest of the sensor complement had far worse performance.

One factor that may have a significant impact on the Borman sensor performance is

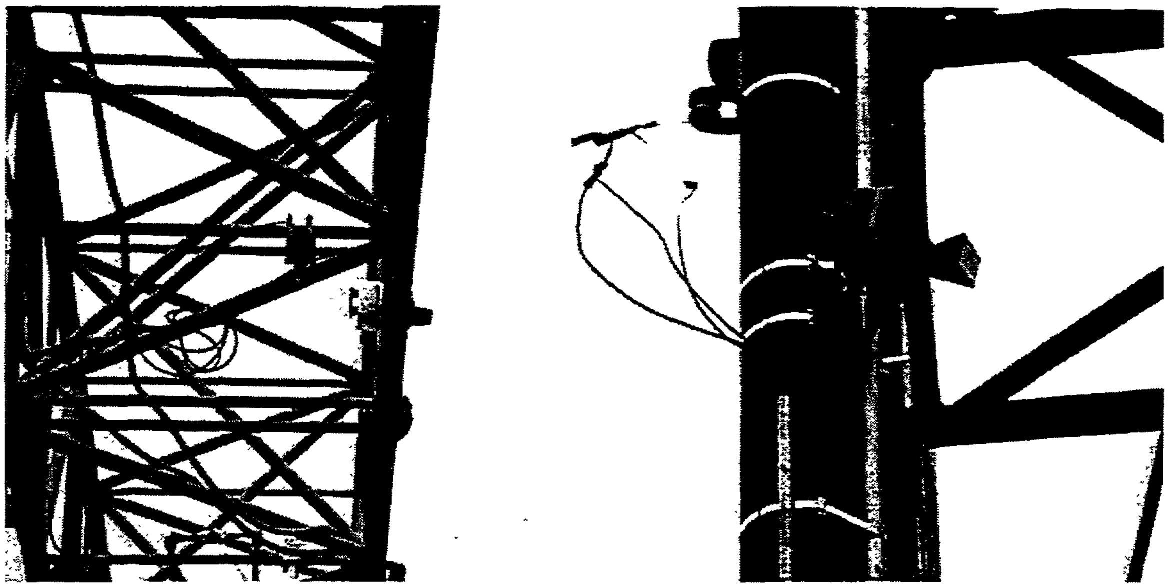


(a) (b)

Figure 9: Traffic sensor mounting at Kennedy Avenue. In (a) is shown the TDN30 single lane microwave (front of the picture) and the TC30C active ultrasonic detector (background). Shown in (b) is the 833M6 passive infrared detector.

the rather high percentage of tall vehicles (trucks) coupled with relatively short time and distance headways. Tall vehicles can present a problem for overhead mounted sensors. Figure 12 shows the detection geometry for the TDN30 sensor when mounted on an overpass 22 feet high. The objective here is to estimate the minimum distance headway between a tall truck (13 feet) and a following vehicle. Using the TDN30 manufacturer's specification [Whelen 91] it has been determined that the effective aperture (the 3 dB beamwidth) of the radar is approximately 8 degrees. Using the geometry of the figure it may be determined that the minimum headway to allow discrimination between a tall leading truck and a following vehicle is about 18 feet (or about 0.2 sec. at 60 mph). If the leading vehicle is a car (5 feet high), then the required minimum headway reduces to about 15 feet (or 0.12 sec. at 60 mph). These minimum headways are not always satisfied by Borman traffic and their violation can be expected to result in undercounting.

In fact, the results of the earlier sensor technology study [Hughes 93] contain clear evidence of these problems. A- test track experiment revealed that the TDN30 requires a



(a) (b)

Figure 10: Traffic sensor mounting at Cline Avenue. In (a) is shown the sign bridge along with the 833M6 passive infrared and the AUTO active infrared. The RTMS sidefire microwave detector is shown in (b).

separation of between 15 and 20 feet to discriminate between two short vehicles. In addition, it was noted in the study that the minimum response times for the microwave sensors is on the order of 0.3 seconds.

Recommendation: To verify the hypothesis that tall vehicles coupled with short headways are responsible for the poor counting performance in the Borman ATMS test, more testing should be done under a wider variety of traffic conditions. In particular, some tests should be done when the Borman is operating at its minimum daily volume; if the hypothesis is correct, then counting accuracy should improve in light traffic.

Recommendation: A careful evaluation of the accuracy requirements for planned traffic management algorithms must be completed before the Phase II ATMS design is frozen. If the performance of the current group of sensors cannot be improved significantly it may be necessary to consider other technologies for ATMS surveillance needs. A possibility would be to use certain vehicles as probes, for example, state highway patrol (suitably equipped) or trucks equipped with transponders for automatic vehicle identification.

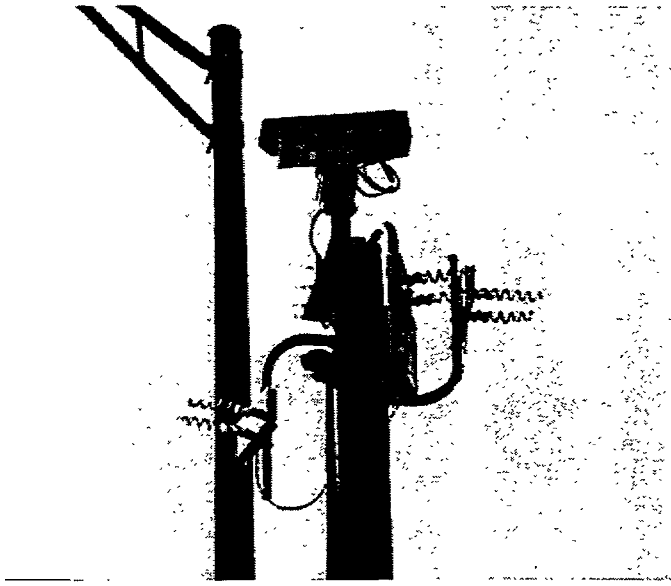


Figure 11: Video camera mounting at Burr Street along with antennas for SSR communication links.

4.2.2 Objective: Assess the reliability of the traffic sensors

HYPOTHESIS: The individual sensors are 95% reliable.

Only the TDN30 meets the reliability requirement of this hypothesis. The laser radar AUTO and the sidefire microwave RTMS were never sufficiently reliable to even run accuracy tests.

Recommendation: A careful study must be performed regarding sensor performance and reliability before the Phase II sensor design is completed. It is felt that some of the performance problems of the sensors were coupled with their reliability problems and the fact that adjustment and tuning was difficult, costly, and dangerous given the overhead mounting and the resulting necessity of lane closures for even the most minor repairs. A procedure must be developed for removing sensors from overhead which does not involve lane closure and the associated cost and danger to the public.

4.3 Goal: Evaluate the Communication System

4.3.1 Objective: Assess the performance of the communication system

The Hughes team has performed a fairly comprehensive set of tests on the deployed communications system. The wireless communication links are in general the most likely ones

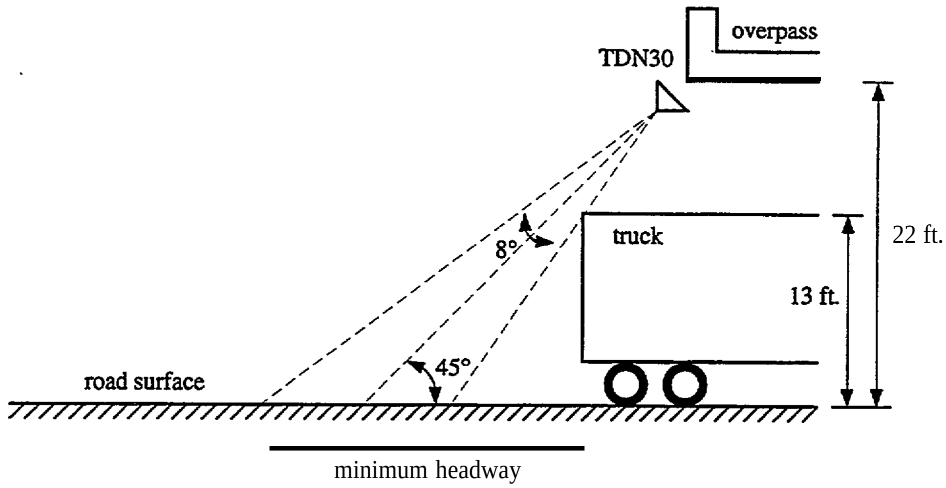


Figure 12: Geometry for computation of minimum allowable headway for vehicle discrimination.

to induce errors so the testing focused on these links. The wireline links were appropriately tested as well. Hardware failures were at a normal level for a system integration of this size. The frequency plan and antenna placement have adequately isolated the different SSR links such that interference is maintained at a negligible level.

Recommendation: Since antenna pointing is critical to system performance (i.e., to maintain link margins and to adequately reject other emitting sources) it might prove useful to rerun a subset of the tests after "burn-in" of the system (i.e., let the wind blow around the antennas for a couple of months and see if performance has degraded).

The fixed site links work very well (at most sites tested the error rate is not measurable in a reasonable amount of time) and probably have excess fade margin. The wireless links to the IRV have a widely varying performance due to the mobile nature of the link. This performance is not surprising since the SSR radios were not designed to operate in a fading environment. While a redesign of the radios could help improve performance (i.e., to maintain synchronization when traveling at highway speeds), maintaining 384 Kbps transmission rate is probably not needed from the IRV except when stopped at an accident. The operator can probably find a fixed position near an incident that would provide high performance.

The packet error rate performance is most critical to the understanding of how well the system performs. Since missing a packet of data is not catastrophic for the operation of the system, it is assumed that an automatic repeat request architecture is not implemented. Consequently, a packet with errors detected in it will be dropped. Dropped packets for the video will cause glitches in the video sequence. This is inconvenient but, as long as the number of packets dropped is reasonably small, it will not reduce the functionality of the traffic management system. Dropped packets for narrowband sensor data will remove detections from the TMC input. Again as long as this is a reasonably low number, it should not affect the functionality of the TMC[1].

> **Recommendation:** For mobile data communications with the IRV, use a radio link optimized for land mobile communications (i.e., a digital cellular phone type architecture). This could be done with the next generation of cellular phones or with a modem using the ITS 220 MHz allocations. While neither of these options could provide transfer rates supporting real-time video transmission they would be sufficient for all other data transmission requirements with the IRV and would perform well at highway speeds.

HYPOTHESIS: For each link, the bit error rate is less than 10^{-5}.

This hypothesis is certainly validated by the field testing for all of the fixed SSR links. The SSR links to the IRV are more suspect but will be able to provide acceptable performance with the suggested redesign (higher antennas) if they do not have to operate while the vehicle is moving. It is noteworthy that when considered as a network the percentage of successful packets transmitted from the TMC to a remote site and back to the TMC becomes greater than 10^{-5}. Consider the worst case scenario (Cline Ave. remote site) where the percent of packets dropped is 0.05%. Since there are four wireless links in the connection, at best this implies that the best probability of dropped packet per link Pi is

$$Pi = 1 - (1 - P_T)^{1/4} = 1.27 \times 10^{-4}.$$

This calculation suggests that at least one of the links is operating above the 10^{-5} level. It might be interesting to investigate where the weak link is in the overall system as indicated

[1]Since requirements for the incident detection and traffic management algorithms are not defined as of yet, it is hard to quantitatively evaluate the effect of dropped packets on system performance.

by these packet integrity tests.

Recommendation: Before requirements are set for the communications link performance, it might be useful to specify the level of performance needed in the incident detection and traffic management algorithms. This might prevent a gross overdesign of the communication system and greatly reduce the cost of the Borman ATMS. Certainly qualitative tests could be run on the compressed video with varying bit error rates to better qualify the required error rates the SSR needs to maintain.

4.3.2 Objective: Assess the potential for interference problems

HYPOTHESIS: Radio interfence does not degrade the SSR link performance.

Since the SSRs for the Borman operate in the ISM and Part 15 bands, the potential for radio interference does exist and must be evaluated. SSRs have robustness to in band interference due to the spread spectrum demodulation algorithms but a large high power in-band emitter could seriously degrade link performance. The Borman architecture has two advantages: 1) it is outdoors and 2) it uses highly directional antennas. Most interferers in the S- and C-band frequencies will be deployed indoors (e.g., microwave ovens and medical equipment), so that the signal will be at a low level outside of buildings due to attenuation induced by propagation through walls. The narrowbeam antennas limit the directions from which an interferer can significantly degrade system performance. Qualitatively, it does not appear in the data we have seen that radio interference was a significant problem, but a new system could be deployed at any time. In actuality the greatest source of interference for the Borman SSR links are probably the broadcasts from other Borman SSRs. Again the use of narrow beam antennas and careful frequency planning will limit the self-interference.

A majority of the field tests indicate that interference is not a significant problem. Certainly, the individual link tests show no indications of interference. The packet integrity tests as mentioned above have a performance which strongly indicates that at least one link had a reduced performance. This "weak" link might be subject to interference either from a non-Borman source or a radio emitter associated with the Borman project. Tracking down this "weak" link would enable a better evaluation of whether interference was responsible. One possible explanation (though certainly not the only one) of the bursty nature of packet errors on the Kennedy Avenue packet integrity tests is also radio interference. The worst case packet error rate per sequence in the data supplied to us was 7.8×10^{-3}.

Recommendation: Further detailed tests might be warranted to assess whether interference played a part in the degraded performance seen in the packet integrity tests.

HYPOTHESIS: The likelihood of future interference causing significant system degradation is Kow.

Only the interference due to non-Borman equipment will be considered here as the self-interference is intimately related to the spectrum utilization to be discussed later. The potential for interference in. the spectrum used for the Borman wireless links is likely to increase over time as more and more applications for wireless communications become apparent. The probability that interference will degrade the system more in the future than it is currently is low. This is true because interference rejection capability in antenna directionality is not really a function of the number of potential interferers. Narrowbeam antennas are the biggest asset of the Borman deployment in interference rejection.

4.4 Goal: Evaluate the Mobile Incident Response Vehicle (IRV) Equipment

4.4.1 Objective: Assess the suitability of equipment to support the planned use of the IRV

In evaluating the five hypotheses related to the IRV planned use, there are two issues: 1) the availability of reliable information for timely decisions by the IRV operator, and 2) the information and task overload on the human operator. Evaluation of the IRV design and performance statistics indicate that it is, in principle, able to serve the intended function. In terms of timely information availability, the previous comments about person information and communication are also relevant here. It is expected that over the next five to ten years, new software for information integration, and protocols for automatic analysis of information will further reduce the information load over the IRV operator.

HYPOTHESIS: The CMS and HAR will be able to support IRV needs.

Changeable message signs (CMS) and highway advisory radio (HAR), which do not form part of the Phase I Borman ATMS equipment installation, can be effective in incident response and management when coordinated with the Borman traffic management center. CMS and HAR can be used to provide real-time descriptive information on current traffic conditions, and prescriptive route diversion and/or guidance information, especially under incidents. Thereby, traffic flow in the affected region is reduced or effectively diverted, providing IRV with favorable traffic conditions for a quicker response. However, CMS and HAR can be effective only when their operations are coordinated with that of the IRV through the traffic management center. This implies that the detectors must process the data in real-time and the traffic management algorithms must prescribe real-time solutions to be implemented through the CMS and/or HAR. The difference in the implementation through CMS and HAR is that CMS is limited to the locations where installed while HAR is widespread and disseminates information to a large area.

HYPOTHESIS: The ability exists to support electronic revolving call out for wrecker service.

Electronic revolving callout for wrecker service should be easily implementablein software on the computing equipment already available in the IRV and the TMC. This feature should involve no special equipment on the part of wrecker service providers.

HYPOTHESIS: The ability exists ***to contact emergency services (police, fire, ambulance, state police office, hazardous*** material ***responders).***

To serve as an effective system operator who controls and coordinates the response to an incident, the IRV will need on-board computers that can process the real-time data on the incident and/or access diversion strategies from the TMC or from the onboard computer database. Though, currently, there is no coordinated mechanism for an integrated response involving the IRV and law/emergency agencies, the communication and data processing equipment and the interfaces required for initiating such response actions have been tested and verified by Hughes. The ability to contact emergency services is even more critical if the IRV, and not the traffic management center, coordinates and initiates the response action.

HYPOTHESIS: The ability exists to define a dynamic detour routing system.

Figure 13 illustrates the extended Borman area network that could be part of a potential dynamic detour routing system. As indicated in the figure, there are several alternative detours possible in response to an incident. This means that an IRV requires knowledge of the current traffic conditions, possibly viewed using computer graphics, as well as high performance computers to determine an effective detour routing system on-line. Due to the intensive information processing, communication and computational needs, it **is** more likely that the traffic management center will determine the dynamic detour strategy, and coordinate the response using the CMS/HAR and emergency/law agencies. From the IRV's perspective, this requires the use of possibly a GIS-based system to aid in the implementation of the dynamic detour routing strategy conveyed by the traffic management center.

4.4.2 Objective: Assess the human factors issues

HYPOTHESIS: 99.5% of IRV operators can perform the required data collection.

No statistical experiments were available to analyze this hypothesis, although the IRV performance documented has shown satisfactory results. While it is reasonable to assume that the data collection for relevant decisions can be accomplished even under time limitations, it is not known at the present if the IRV operators will be able to collect the required data (and hence, make correct decisions) 99.5% of the time. Additional experiments have to be designed for this evaluation.

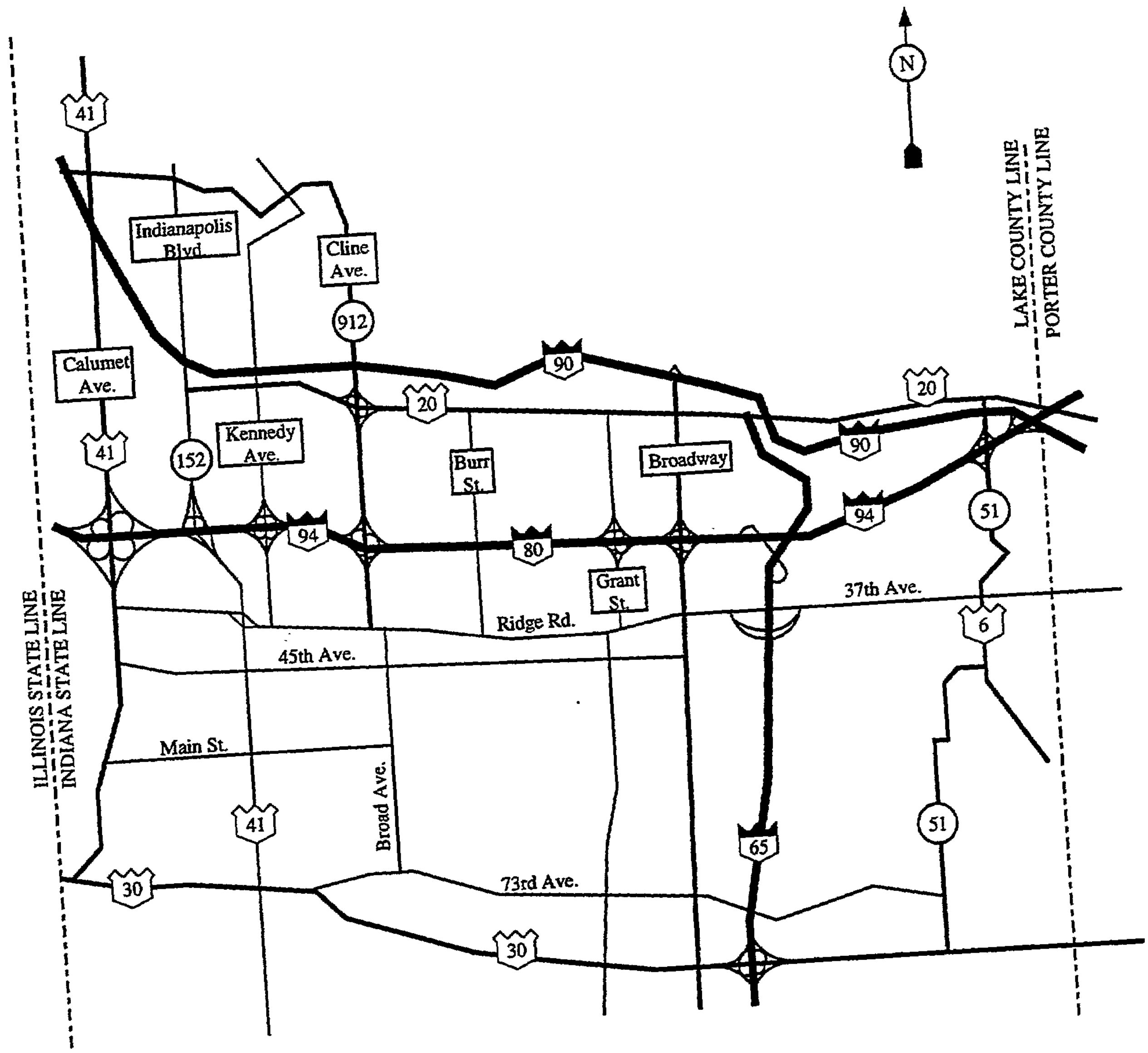


Figure 13: Borman Expressway Evaluation Network.

4.5 Goal: Evaluate the Institutional Issues

4.5.1 Objective: Assess the capability of the system to integrate with the existing local infrastructure and emergency response services

In order to evaluate how the proposed system will be integrated in the existing infrastructure and emergency services, all civil divisions, police stations, ambulance services, hospitals, as well as towing services along the **Borman** corridor were identified as presented in Appendix 5. **A** randomly selected number of these agencies and establishments were contacted to determine their level of preparedness in terms of personnel and equipment to adopt to the **ATMS** technologies.

HYPOTHESIS: It is likely that local wrecker, police, fire, and ambulance services will be equipped to respond to the planned coordination.

None of the agencies and establishments contacted has any advanced equipment to receive information from either the IRV or the TMC. Even if the IRV has the capability of transmitting video taped information about an incident to any of the emergency response services, there are no existing facilities at the receiving end. All existing services operate using traditional means using telephones and manual records. Any automated system of transmitting incident information to the emergency response delivery services must consider the need for equipping these services with proper facilities.

Recommendation: A system should be developed for communicating incident information to emergency services in the corridor. Such a system should be geocoded for easy and uniform referencing among **INDOT** and all emergency services. The system should be developed through a coordinating team comprising representatives of all public and private agencies (police, fire, towing, ambulance, and hospital) services in the corridor.

HYPOTHESIS: Local authorities are willing to cooperate with INDOT.

No organized effort has so far been made to involve local authorities in the planning of the Borman ATMS. The evaluation team considers this issue to be a major omission. However, there is no indication that the local authorities will offer less than full cooperation.

Recommendation: An important element of successful implementation of Borman ATMS is the coordination of INDOT efforts with the transportation planning and operation activities of the adjoining local authorities. It is suggested that a planning committee be set up consisting of transportation planning and/or operating units of adjoining local authorities and INDOT representatives to plan, coordinate, and implement the Borman ATMS in order to enhance transportation services along the Borman corridor.

4.52 Objective: Assess the communication system requirements for effective interagency communication

HYPOTHESIS: The communication system requirements are consistent with the capability of the local emergency services.

All local emergency services use traditional telephone system for communications. In this sense, there is built-in compatibility. However, many local emergency services organizations do not yet have FAX capability and this deficiency should be considered.

HYPOTHESIS: The planned communication architecture will support additional ***communication links.***

This hypothesis has been verified as outlined in the previous sections.

4.5.3 Objective: Assess the issues associated with radio frequency utilization

The Borman design team has done a good job of achieving a reasonable spectral efficiency given the design constraints imposed by the radio designs. Design guidelines for packet radio system suggest the way to get capacity in a spread spectrum system is to use sectorization, frequency planning, processing gain, and power control. The radio design fixes the processing gain so the Borman designers could use processing gain when available but not modify it. In general, the processing gain of the radios is moderate (i.e., 15-20 dB) so large interferers cannot be rejected completely with processing gain. The Borman designers have efficiently used sectorization (with directional antennas) and have done a good frequency plan (e.g., co-located sites to not use identical spectrum).

Recommendation: The only design technique that has not been used is power control. The Borman designers might want **to** keep this in mind as they expand the system. Power control is often used in spread spectrum communications systems to combat the so-called near-far problem where the signal received at the base station from a distant transmitter is swamped by the signal from a nearby transmitter due to propagation loss over a long distance. Power control is used to reduce the power of the nearby transmission in order that the distant transmission may also be received.

HYPOTHESIS: The proposed spectrum is sufficient at this time.

Phase I has demonstrated the feasibility of using the ISM and Part 15 spectrum for this ATMS application.

HYPOTHESIS: The proposed spectrum will be sufficient for future expansion.

The amount of video that is deemed necessary by the operators of the ATMS will determine whether enough spectrum is available. The study team feels that if 10 or more video images are required in the TMC from a large number of potential sources then the spectrum will be hard pressed to support the operation. If 5 or fewer images are sufficient then the current spectrum is adequate. Certainly, if high performance low bit rate video compression algorithms become available then the number of video image transmissions supported on this spectrum could drastically increase. Also as more sensor sites are added to the Borman ATMS the frequency planning and antenna positioning will become tougher as a larger number of constraints are enforced. While this will make the designer's job more difficult and iterative it is not likely that it will limit the capacity that one can squeeze out of the available spectrum.

5 Conclusions

The overall conclusion of this evaluation is that the Phase I Borman ATMS has demonstrated the feasibility of the basic ATMS design. It is the opinion of the evaluation team that a cost effective Phase II ATMS can be developed using the basic Phase I architecture. However, experience with the Phase I system suggests certain issues must be addressed as the Phase

II ATMS is planned. These issues are:

1. A careful study of the. communication bandwidth requirements must be performed as regards the necessity for video transmission and its impact on the required radio spectrum. Consideration should be given to other options including fiber optic links and the 220 MHz ITS spectral allocations.

2. The failure of the sensor subsystem to meet both performance and reliability goals must be addressed.

3. Procedures must be developed early in the Phase II design to ensure the effective inclusion of other authorities and agencies.

A Emergency Services Information for Borman Vicinity

Local Civil Divisions Adjoining the Borman Expressway:

- Chesterton
- Crown Point (S)
- Dyer
- East Chicago
- Griffith
- Hammond
- Hobart
- Lakes of the Four Seasons (S)
- Lake Station
- Leroy (S)
- Merrillville
- Munster

- Portage
- Schererville
- Valparaiso (S)
- Wheeler
- Whiting

Note: The civil divisions with "S" marking are close to but not adjoining the Borman Expressway.

Ambulance Services:

- Air Ambulance By Air Response
  800-631-6565

- East Chicago
  Prompt Medical Transfer Ambulance Service
  398-3406

- Gary
  Procare Ambulance Service Inc.
  4890 Harrison
  884-2344

- Highland
  Fagen-Miller Ambulance Service
  2831 Jewett St.

- Hobart
  Emergency: 911

- Lake Station
  Emergency: 911
  Non-Emergency:
  4325 Riverpool Road
  962-4689

- Portage
  Emergency: 911
  Non-Emergency:
  6070 Central Ave.
  763-2455

- Valparaiso
  Emergency: 911
  Non-Emergency: 464-9663

Fire Stations:

- Chesterton
  Emergency: 911
  Non-Emergency: 926-7162

- Crown Point (S)
  Emergency: 911
  Non-Emergency: 662-3248

- Dyer
  Emergency: 911

- East Chicago
  Emergency: 911
  Non-Emergency: 391-8472

- Gary
  Emergency: 911
  Non-Emergency: 886-1313

- Griffith
  Emergency: 911

- Hammond
  Emergency: 911
  Non-Emergency: 853-6550

- Hobart
  Emergency: 911
  Non-Emergency: 947-1888

- Lake Station
  Emergency: 911

- Merrillville
  Emergency: 911
  Non-Emergency: 769-0004

- Munster
  Emergency: 911

- Portage
  Emergency: 911
  Non-Emergency: 762-7404

- Schererville
  Emergency: 911
  Non-Emergency:
  Fire Chief: 322-2599
  Fire Station No. 2:865-5510

- Valparaiso
  Emergency: 911
  Non-Emergency: 462-8325

- Wheeler
  Emergency: 911
  Non-Emergency: 759-3321

- Whiting
  Emergency: 911
  Non-Emergency: 659-1069

Hospitals:

- Crown Point
  St. Anthony Medical Center
  1210 S. Main St.
  663-8120

- Dyer
  St. Margaret Mercy Health Care Center
  24 Joliet (US-30)
  865-2141

- East Chicago.
  St. Catherine Hospital
  392-1700
  Emergency Department: 392-7200

- Gary

  1. The Methodist Hospitals
     600 Grant St.

886-4000
Emergency Services: 886-4710

2. Northwest Family Hospital
   501 Family Plaza (5th Ave. & Tyler St.)
   882-9411
   Emergency Services: 881-8200

3. St. Martin Medical Center
   5041 Broadway
   884-3000

- Hammond
  St. Margaret Mercy Health Care Center
  5454 Hohman Ave.
  932-2300

- Hobart
  St. Mary Medical Center
  1500 S. Lake Park Ave.
  942-0551
  Emergency Department: 947-6200

- Merrillville

1. The Methodist Hospitals
   8701 Broadway
   738-5500
   Emergency Services: 738-5510

2. St. Anthony Medical Center
   739-2100

3. Home Health Care Center
   769-1065

- Portage
  Portage Medical Surgical Center
  3630 Willowcreek Road
  759-3414

- Valparaiso

1. Porter Memorial Hospital
   814 La Porte Ave.
   465-4900
2. Valparaiso Physician & Surgery Center
   1700 Pointe Dr.
   531-5000

Police:

- Chesterton
  Emergency: 911
- Crown Point
  Emergency: 911
  Non-Emergency: 663-2131
- Dyer
  Emergency: 911
  Non-Emergency:
  230 Schulte
  865-1163
- East Chicago
  Emergency: 911
- Gary
  Emergency: 911
  Non-Emergency: 886-1313
- Griffith
  Emergency: 911
  Non-Emergency:
  115 N. Broadway
  924-7503
- Hammond
  Emergency: 911
  Non-Emergency: 853-6544
  Robertsdale Station: 659-2161
- Hobart
  Emergency: 911
  Non-Emergency: 947-1888

- Highland
  Emergency: 911
  Non-Emergency: 838-3184

- Lake Station
  Emergency: 911
  Non-Emergency: 962-1186

- Merrillville
  Emergency: 911
  Non-Emergency: 769-3531
  Administrative Call:
  13 W. 73rd
  769-3722

- Munster
  Emergency: 911

- Portage
  Emergency: 911
  Non-Emergency: 762-3122

- Schererville
  Emergency: 911
  Non-Emergency: 322-5000

- Valparaiso (S)
  Emergency: 911
  Non-Emergency: 462-0717

- Whiting
  Emergency: 911
  Non-Emergency: 659-2131

Towing Services:

- Chesterton

  1. CLW Towing (24 hr.)
     1350 Broadway
     926-5525

2. Gaston's Towing & Auto Repair (24 hr.)
   1051 Wabash Ave.
   926-5411
3. Joe's Towing Inc.
   111 Waverly Road
   926-7460
4. Shoreline Towing
   800-807-2944

- Gary

1. Andy's Towing Service
   3801 Vermont
   884-1590
2. Central Auto Wrecking
   1008 Virginia
   882-7278
3. Generic Towing (24 hr.)
   8848844
4. Giden Towing Service
   701 W. 9th
   885-9067
5. Great Lakes Enterprises (24 hr.)
   1300 W. Ridge Road
   887-1900
6. Hugh's Towing Service
   1148 Colfax
   944-2301
7. James Towing & Salvage
   4821 W. 26th Ave.
   944-7397
8. Mako's Towing
   260 E. 40th Ave.
   8840377
   887-8770
9. Mason's Wrecks Inc.
   1216 W. Ridge Road
   980-1900

10. Perry's Towing (24 hr.)
    31 W. 8th Ave.
    883-7361
    882-8430
11. Republic Frame & Axle (24 hr.)
    7500 E. Melton Road
    938-7040
12. Simon's Complete Auto Service (24 hr.)
    4495 Cleveland (45th Ave. at Cleveland)

- Hammond

1. Bert's Towing Service (24 hr.)
   173rd & Kennedy
   844-0552
2. Oldenberg & Sons Inc.
   2319 Cline Ave.
   845-5440

- Hobart

1. Balash Towing (24 hr.)
   1849 E. Hwy 130
   942-2186
2. Warren's Service Station
   800 W. Ridge Road
   947-4045
3. Steve's Towing
   4716 W. 61st
   942-4959

- Lake Station
  Lake Station Service
  2000 Central Ave.
  800-217-7644
  962-7644

- Merrillville

1. A-VIP Towing (24 hr.)
   5970 Broadway
   980-5088
2. Steve's Towing & Associated Inc.
   6499 Broadway
   980-2895

- Portage

1. Charlie's Towing
   6653 Melton Road
   762-0274
2. Jerry's Shell Service (24 hr.)
   6259 Melton Road
   762-4810
3. Jim's AMOCO Service (24 hr.)
   6090 Central Ave.
   762-4282
4. Magoo's Sales & Service
   6718 Melton Road
   762-3961
5. Shoreline Towing
   762-3662

- Valparaiso

1. Bubba's Towing (24 hr.)
   205 1/2 Nickle Plate Ave.
   464-9202
2. Bud's Towing (24 hr.)
   765 N. Acadia
   759-5813
3. Discount Towing & Services
   477-6453
4. Green's Towing & Auto Repair (24 hr.)
   458 S. Washington
   4641173

5. Mike & Steve's Auto Repair Center Inc.
252 Morthland Dr.
464-1499

6. Sandberg's Towing Service
1252 W. Lincolnway
462-4622

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