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16. Abstract

The Advanced Traffic Management System (ATMS) from the Texas Department of Transportation (TxDOT) has been used in multiple Intelligent Transportation System (ITS) deployments across the state. ATMS utilizes a physical communications infrastructure that provides connections to field devices, provides video streams, and enables information flow to other centers, the media and/or the public. Several trends have an impact on the design and operation of this physical infrastructure, including:

- development of the next generation software interfaces for ATMS,
- development of a core technology architecture for TxDOT,
- communication of industry trends, and
- needs of information providers.

This project documented the current state of ATMS deployments, analyzed the impacts of the above trends, and developed a conceptual model for an ATMS network architecture to be used in future ITS deployments. This architecture is discussed in terms of services, security, and areas of responsibility.

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COMMUNICATIONS TRENDS AND THEIR IMPACT ON TXDOT ITS DEPLOYMENTS

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The researcher in charge was Robert E. Brydia

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INTRODUCTION

The Texas Department of Transportation (TxDOT) has made a significant investment in Intelligent Transportation Systems (ITS). The TxDOT Glossary defines ITS as "an integrated system that uses video and other electronic detection devices to monitor traffic flows on major freeways"*(1)*. Simply put, ITS is the use of software, information, and technology to increase the safety and efficiency of the roadways.

One component of TxDOT's ITS strategy is the use of an Advanced Traffic Management System (ATMS). In TxDOT nomenclature, ATMS used to refer to a specific software product that was developed in-house and provided basic Traffic Management Center (TMC) services, such as data communication with field devices, closed circuit television (CCTV) control, and some analysis of field data to determine the operating conditions of the roadway. ATMS was deployed at several TMCs around the state and was developed and supported in-house.

Several years ago, TxDOT undertook a new approach in developing the next generation of software to support ITS deployments. The Department selected a statewide integrator and began a multi-year software development program to re-engineer ATMS from the ground up. For all practical purposes, the only commonality between the previous and current products is the name. Today, ATMS refers to a suite of advanced software components for ITS deployments that have been developed with support for the latest standards and techniques for information exchange.

ATMS utilizes a communications infrastructure that provides for data flows to/from field devices, provides video information, and enables information flows to other centers, agencies, the media, and/or the public. As technology continues to change, the design requirements of ATMS installations have changed to keep pace with industry solutions. ATMS deployments today can look markedly different from deployments of even a few years ago. In addition, policy decisions can have a considerable impact on the design of communication systems, necessitating an additional level of requirements beyond the purely technical needs. While TxDOT strives to provide robust, scalable, cost efficient ITS services, the rapidly changing environment for ITS in general, and TxDOT ATMS deployments in particular, pose significant challenges.

In order to document the various technical and policy requirements that can impact ATMS installations, the project team developed a six-step work plan to examine the critical areas that impact ATMS installations. These steps were:

1. Evaluate Current ATMS Installations.
2. Assess Future Directions for ATMS.
3. Assess Impacts of Other Communication Directions.
4. Assess Communication Needs for External Partners.
5. Develop Framework for Evaluating ATMS Communication Options.
6. Prepare Project Documentation.

As the project took place, it became apparent that a significant number of decision points that would affect communication options have already been determined, either through the support of industry standards, or via decisions made within the information technology hierarchy of TxDOT or other date agencies. The Task 5 focus therefore shifted to provide a conceptual layout for typical ITS deployments and to document the various areas of responsibility and interaction within deployments.

The overall goal of the project is to discover and document the numerous issues that affect the design, deployment, operation, and interaction with ATMS deployments. Although the needs, constraints, and requirements of each deployment may be vastly different, TxDOT would like to build ITS solutions that provide robust, scalable, efficient, and cost-effective services.

UNDERSTANDING CURRENT ATMS DEPLOYMENTS

For this aspect of the project, researchers documented the existing communication environments at various TxDOT ATMS installations in the state. The task focused on understanding the high-level communications data flows, especially from the viewpoint of the physical infrastructure. In addition, the task sought to understand the decisions or policy that resulted in the infrastructure or data flow needs. In other words, the focus of the task was not simply on the physical environment, but also on understanding the history of the decisions or needs that resulted in the current physical environment.

As defined in the research proposal, the goals of Task 1 were to:

- Identify existing ATMS communication environments.
- Identify common practices in ATMS installations.
- Identify the presence of wholly owned or leased services in ATMS installations.
- Identify typical constraints (time, manpower, communication options, cost, etc).

QUESTIONNAIRE AND PHONE INTERVIEW

Researchers developed a questionnaire to determine the communication architecture being deployed at various TxDOT ATMS installations. The questionnaire targeted information relating to both the existing infrastructure, as well as inquired about future plans or improvements. The questionnaire sought to determine not only the specifications of the ATMS infrastructure, but also the business or policy decisions that influenced the design and deployment decisions. The questionnaire was divided into nine sections:

1. Overview of existing communication setup
2. Inventory of existing communication setup
3. Overview of near-term (already planned) expansion of communication setup
4. Near-term (already planned) expansion of communication setup
5. Project planning and control information
6. Video streams and live feeds of roadway conditions
7. Existing connections with external agencies
8. Planned connections with external agencies
9. Lessons learned and past experience

Appendix A contains a blank version of the questionnaire used in Task 1. TxDOT approved the questionnaire prior to its use.

Researchers worked with the Traffic Operations Division (TRF) at TxDOT headquarters in Austin to identify the appropriate ATMS installations within the state to include in this process. The questionnaires were completed mainly by an interview process between a project team member and the contact person within a TxDOT district. In all cases, the TxDOT respondent was supplied with the questionnaire prior to the telephone interview. In some districts, due to time constraints, the TxDOT contact completed the questionnaire prior to the telephone interview, which was then used to discuss any questions or issues that arose from reading the written response. Table 1 shows the seven locations that were a part of the Task 1 questionnaire process.

Table 1. TMCs and TxDOT Districts Contacted for Questionnaire.

Traffic Management Center	TxDOT District	Contact Person
-	Bryan	Michael Jedlicka
CTECC (Combined Transportation, Emergency, & Communication Center)	Austin	Brian Burk
TEXOMA VISION	Wichita Falls	Molli Choate
NETRIS	Tyler	Juanita Daniels-West
TRANSVISTA	El Paso	Victor De La Garza
TRANSVISION	Fort Worth	Billy Manning
STRATIS	Laredo	Albert Aldape

EXISTING ATMS COMMUNICATIONS ENVIRONMENT

Table 2 provides an overview of the communication environment at each TMC that was included in the questionnaire. The communications environments consist of private systems, leased components, private wireless, and services from telecommunication providers.

As an overall summary, the questionnaire revealed that ATMS installations in traffic management centers (TMC) across the state are significantly different. This diversity highlights a strength of ATMS because it is flexible enough to fit into a number of different communication scenarios. However, this same diversity can also be looked upon as a weakness since there is little to no consistency to the various deployments in use across the state. This makes it more difficult to achieve any degree of uniformity and consistent application. The lack of consistency also creates significant difficulties for supporting ATMS installations since each environment is unique, and both issues and solutions may not be broad-based. This was evident from the questionnaire responses, which indicated that each TMC has been experiencing unique problems.

Table 2. Overview of Communication Environment.

TMC (TxDOT District)	Overview of Communication Environment
- *(Bryan)*	Contractors currently installing ITS devices on freeway segment. Initial focus is on video surveillance and DMS for special event and incident management.
CTECC (Austin)	Well established traffic management center, does employ TxDOT ATMS, but employs customized system, communication media (Dial-up, private T1, private SONET OC-3)
TEXOMA VISION (Wichita Falls)	Traffic management center with limited capabilities and few ITS field devices, employs TxDOT ATMS, communication media (Dial-up, T1, and wireless)
NETRIS (Tyler)	TMC is in infant stage, employs TxDOT ATMS, communication media (ISDN connection for DMS and CCTV)
TRANSVISTA (El Paso)	Mature TMC, employs TxDOT ATMS, communication media (T1, SONET, Dial-up)
TRANSVISION (Fort Worth)	Mature TMC, employs TxDOT ATMS, communication media Wireless ENET, 900 MHz, RS232, T1 Drop Insert, ISDN
STRATIS (Laredo)	TMC in infant stage, shared fiber network with the City of Laredo (T1 and Ethernet with dial-up)

Most of the TMCs do not have a long-range ITS communications plan. Most of the current short-range ITS plans were developed as part of individual projects and connected into the overall infrastructure in a piecemeal (albeit consistent) fashion. The respondents felt that development of a long-range infrastructure plan is difficult due to dynamic and ever-changing communication medium.

One of the main issues faced by TxDOT's ATMS is the diversity of field devices and the changing marketplace over time. Table 3 tabulates the number of sensors of various types in use across the TMCs contacted for this questionnaire.

When TxDOT first develop the ATMS system, communication was often performed by serial multi-drop connections. In today's marketplace, Ethernet connectivity has been extensively embraced, which leaves ATMS spanning a significant range of communication options and requirements. Table 3 shows that a wide variety of communication protocols and solutions are in place today and that across the TMCs, different communication options are used for the same devices, further straining the diversity issue experienced by TxDOT for ATMS installations.

ATMS must continue to support the legacy solutions and provide an appropriate migration path to current technologies. As an example, more and more traffic management centers, especially smaller or infant ones, are employing wireless connections over fiber due to the capital cost and a shortage of trained personnel.

Vehicle sensors are one area where the change in marketplace technology is evident. The older, more established TMCs generally have some significant infrastructure outfitted with loop detectors using serial communications. However, current TMCs are deploying numerous options in place of loops, such as microwave, radar, or video imaging. These sensors require different communication solutions, different protocol support, and varying levels of expertise for their overall design, deployment, and maintenance.

Table 3. Inventory of Current ITS Deployment.

TMC (TxDOT District)	Vehicle Sensors	Dynamic Message Signs	Lane Control Signals	CCTV Cameras
- (Bryan District)				
Number of Devices	0	0	0	0
Communication Media	-	-	-	-
Communication Protocol	-	-	-	-
CTECC (Austin District)				
Number of Devices	3463*	16	261	74
Communication Media	T1, Fiber	T1, Dial-up	T1, Fiber	T1, ISDN, Fiber
Communication Protocol	RS232, SONET	RS232, SONET	RS232, SONET	RS232, SONET
TEXOMA VISION (Wichita Falls District)				
Number of Devices	0	4	0	9
Communication Media	-	Dial-up	-	T1, Dialup
Communication Protocol		TCP/IP		RS232
NETRIS (Tyler District)				
Number of Devices	0	2	0	1
Communication Media	-	Dial-up	-	Wireless
Communication Protocol	-	TCP/IP		Ethernet
TRANSVISTA (El Paso District)				
Number of Devices	72**	45	179	90
Communication Media	Fiber, Wireless	T1, Fiber	T1, Fiber	T1, Fiber

Communication Protocol	RS232	RS232	RS232	RS232
TRANSVISION (Fort Worth District)				
Number of Devices	150	68	200	170
Communication Media	T1, ISDN, Fiber, Wireless	T1, ISDN, Dial-up, Fiber, Wireless	T1, ISDN, Dial-up, Fiber	T1, ISDN, Dial-up, Fiber, Wireless
Communication Protocol	RS232,TCP/IP, ATM, Ethernet	RS232,TCP/IP, ATM, Ethernet	RS232,TCP/IP, ATM, Ethernet	RS232,TCP/IP, ATM, Ethernet
STRATIS (Laredo District)				
Number of Devices	12	13	12	18
Communication Media	T1	T1	T1	Fiber
Communication Protocol	RS232	RS232	RS232	-

Note: * mostly loop detectors ** mostly microwave vehicle detection system

FUTURE DEPLOYMENTS IN EXISTING ATMS ENVIRONMENTS

In addition to the inventory of existing devices (Table 3), Table 4 shows the deployments the respondents have planned for the future. Shown in parentheses is the timeframe of these deployments. For example, CTECC plans an expansion to approximately 14,000 vehicle sensors (from a current deployment of 3,463) within 10 years. TransVista expects to grow from a current deployment of 72 to a deployment of 110 vehicle sensors within the next year.

Table 4 also shows the communications method that respondents are planning to use for these deployments. It is perhaps significant to note that every respondent indicated some future use of wireless technologies. The questionnaire did not probe the specifics of each communication choice, so the standards, frequencies, and other implementation information are not known. However, it is evident that many respondents are looking to extend their deployments, particularly in the last mile, through the use of wireless infrastructure. As time progresses and the wired deployment grows, the locations of the wireless connections may migrate further out to the edge, providing a renewable resource for connecting additional infrastructure.

Table 4. Inventory of Planned ITS Deployment.

TMC (TxDOT District)	Vehicle Sensors	Dynamic Message Signs	Lane Control Signals	CCTV Cameras
- (Bryan District)				
Number of Devices	0	0	0	0
Communication Media	-	Wireless	-	Fiber
Communication Protocol	-	-	-	-
CTECC (Austin District)				
Number of Devices	14000 (10 Years)	261 (10 Years)	888 (10 Years)	600 (10 Years)
Communication Media	Wireless, Fiber	Dial-up, Fiber	Wireless, Fiber	Wireless, Fiber
Communication Protocol	RS232, TCP/IP, SONET, ETHERNET	RS232, TCP/IP, SONET, ETHERNET	RS232, TCP/IP, SONET, ETHERNET	RS232, TCP/IP, SONET, ETHERNET
TEXOMA VISION (Wichita Falls District)				
Number of Devices	0	0	0	0
Communication Media	-	-	-	-
Communication Protocol	-	-	-	-
NETRIS (Tyler District)				
Number of Devices	0	3 (2 Yrs)	0	3 (1 Yrs)
Communication Media	-	Dial-up	-	Wireless
Communication Protocol	-	Not Planned Yet		Not Planned Yet
TRANSVISTA (El Paso District)				
Number of Devices	110 (1 Yrs)	10 (3 Yrs)	6 (2 Yrs)	20 (5 Yrs)
Communication Media	Fiber, Wireless	Fiber	Fiber	Fiber
Communication Protocol	RS232	RS232	RS232	RS232
TRANSVISION (Fort Worth District)				
Number of Devices	20 (3 Yrs)	10 (3 Yrs)	0	20 (3 Yrs)
Communication Media	T1, ISDN, Fiber, Wireless	T1, ISDN, Dialup, Fiber, Wireless	T1, ISDN, Dial-up, Fiber	T1, ISDN, Dialup, Fiber, Wireless
Communication Protocol	RS232,TCP/IP, ATM, Ethernet	RS232,TCP/IP, ATM, Ethernet	RS232,TCP/IP, ATM, Ethernet	RS232,TCP/IP, ATM, Ethernet

STRATIS (Laredo District)				
Number of Devices	0	2	0	5
Communication Media	-	Wireless	-	Wireless
Communication Protocol	-	Ethernet	-	Ethernet

ITS PROJECT PLANNING AND CONTROL

The questionnaire revealed that most of the traffic management centers did not have a long range communication plan for ITS deployments. Respondents indicated that the selection of technology options and design factors for a particular communication installation was driven by the ease of integration with the existing system and lowered maintenance costs. Table 5 summarizes the responses pertaining to the development of a master ITS communications plan and the selection of any particular technology

Table 5. ITS Communications Plan and Technology Selections.

TMC (TxDOT District)	Do you have a long range communication plan?	Reasons for selecting a technology option?	Design factors?
- *(Bryan)*	No	-	-
CTECC (Austin)	Yes	Ability to integrate with existing systems, maintainability and expertise required to plan, design, construct, operate and maintain	-
TEXOMA VISION (Wichita Falls)	No	-	-
NETRIS (Tyler)	A project will be let to develop a telecommunication plan as a prerequisite to developing PTZ camera design	-	Installation and maintenance are primary issues
TRANSVISTA (El Paso)	No	-	-
TRANSVISION (Dallas-Fort Worth)	No	-	-

STRATIS (Laredo)	Yes	Easier to interface and equipment options	Network tools, partnerships (integration)

The respondents also had varying reasons for selecting a particular vendor, even though smaller districts indicated that the design of a communication plan as well as the selection of vendors is typically decided by TRF. The ability to integrate with the existing system and cost seem to be the strongest issues to consider when selecting a vendor. Table 6 highlights the reasons presented by the respondents for the selection of a particular vendor and indicates how any conflicts are resolved.

Table 6. Vendor Selection Criteria.

TMC (TxDOT District)	On what basis do you select vendor/s?	Do you often experience conflict between your communication design and vendor's proposal?	How do you resolve the conflict?
- *(Bryan)*	-	-	
CTECC (Austin)	Support, documentation, expertise, ability to integrate with existing system	Occasionally, not often. Conflict often arises within TxDOT.	Explain system requirements clearly.
TEXOMA VISION (Wichita Falls)	Vendors are selected based on cost and expansion capabilities	No	
NETRIS (Tyler)	Expertise and past experience	No	-
TRANSVISTA (El Paso)	Expertise, cost, and ability to integrate with existing system	No	-
TRANSVISION (Dallas-Fort Worth)	Available funds, cost, blanket order, low bid, test performance	No	Let vendor figure out how to play with us. Offer suggestions on how to get there. They are the ones making money, not us.

STRATIS (Laredo)	Detailed specification	No	-

VIDEO STREAMS OF ROADWAY CONDITIONS

All of the traffic management centers that participated in the study have closed circuit television cameras in the field to monitor traffic flow and traffic-related incidents. The ability to monitor the traffic has become one of the core functions of most centers. External agencies, mostly first responders, value the ability to monitor the traffic flow and traffic-related incidents. Hence, there is growing demand to share the video data between traffic management centers and external agencies tasked as first responders during traffic-related incidents.

There are a number of models for sharing video information. Some centers, such as CTECC, have a number of first responders co-located within the physical premises of the TMC, and sharing is accomplished through the use of large-screen projection systems, as well as video distribution networks. Other centers share video to external agencies, even though they are not co-located. A number of centers share some level of video with the local media and external information sources, such as web sites. A general trend that respondents related was that the number of video sharing requests continues to increase.

Table 7 shows the respondents' expected growth in camera deployments over the next 5–10 years. A number of TMCs such as STRATIS and TRANSVISTA expect a significant growth of CCTV cameras to monitor traffic flow as their roadway coverage is expanded. The respondents also related their expectations that much of the growth in camera deployment will take place at outlying areas where wireless solutions would be more prevalent for at least the initial deployment.

Table 7. Inventory of Current and Planned Video Data.

TMC (TxDOT District)	Current Use of Video Data	Video and Other Data in Common Line	Expected Growth of CCTV (0-5yrs)	Expected Growth of CCTV (5-10yrs)
- *(Bryan)*	-	-	-	-
CTECC (Austin)	Yes	Yes	>30	>30
TEXOMA VISION (Wichita Falls)	Yes	Yes	1-10	Unknown

NETRIS (Tyler)	Yes	Yes	1-10	Unknown
TRANSVISTA (El Paso)	Yes	Yes	10-20	Unknown
TRANSVISION (Fort Worth)	Yes	Yes	20-30	Unknown
STRATIS (Laredo)	Yes	Yes, but not yet	10-20	20-30

TRENDS IN INFORMATION SHARING

As the previous section showed, sharing information is a critical task in most TMCs. The number of TMCs with connections to external agencies is growing rapidly. In many cases, local agencies, such as city government and emergency response, have become aware of the roadway surveillance capability that TxDOT TMCs possess and would like to use that capability to improve response time, incident clearance, responder safety, and public information (to name just a few). Table 8 shows the existing connections that respondents have with external agencies, while Table 9 shows those connections that are planned for the future. Table 9 also shows that a wireless connection is planned for many of these external connections, highlighting the growing importance of that medium for expanding the ITS capabilities within a region.

Table 8. Existing Connections with External Agencies.

TMC (TxDOT District)	Existing Connection with External Agencies	Purpose	Connection Medium
- *(Bryan)*	-	-	-
CTECC (Austin)	City of Austin, City of Austin Traffic Signals and EOC, Local Television Stations	Incident Data, Roadway Status, Video Data	Fiber (Video Stream), Leased ISDN (Command and Control)
TEXOMA VISION (Wichita Falls)	Police Department	Video Data and PTZ Control	T1
NETRIS (Tyler)	City of Tyler, Police Department, Emergency Management Service	Voice Communication	Radio
TRANSVISTA (El Paso)	City of El Paso Traffic, City of El Paso 911 Center, Local TV Stations	Video Data and PTZ Control	Fiber
TRANSVISION (Fort Worth)	Local TV Stations, NTCOG, Fort Worth, Grand Prairie	Video Data	Fiber
STRATIS	City of Laredo, DPS, Police	Video Data	Fiber

(Laredo)	Department		

Note:
EOC = Emergency Operation Center, NTCOG = North Texas Council of Governments
DPS = Department of Public Safety, PTZ = Pan Tilt Zoom

Table 9. Planned Connections with External Agencies.

TMC (TxDOT District)	Planned Connection with External Agencies	Purpose	Connection Medium
- *(Bryan)*	City of Bryan, City of College Station, Texas Transportation Institute	Local Integration	Fiber
CTECC (Austin)	Williamson County Computer Aided Dispatch (CAD), Round Rock CAD, San Marcos CAD, Hays County CAD, City of San Marcos, City of Austin Emergency Operations Center (EOC)	Incident Data, Video Data, Emergency Response Data	Optical Fiber, Leased Line, Wireless
TEXOMA VISION (Wichita Falls)	Local Media	Video Data	Wireless
NETRIS (Tyler)	-	-	-
TRANSVISTA (El Paso)	DPS, Fire Department, Texas Transportation Institute	Video Data, PTZ Control	Fiber, Wireless
TRANSVISION (Fort Worth)	Grand Prairie, Arlington, Fort Worth, Local TV Stations, Traffic Service	Video and Roadway Data, C2C Control, Video Switching	Fiber, Web
STRATIS (Laredo)	Fire Department	Video Data, PTZ Control	Wireless

Video is by far the largest component of the bandwidth used by TMCs. In many cases, data and video components are on different networks or communication systems. These systems may be physically separate, or they may be on separate bandwidth allocated from a common backbone. In general, across the nation, one constraint related to meeting external video requests that is often seen in TMCs is the external "pipe," or shared bandwidth, leaving the TMC. Table 10 shows that the TxDOT TMCs are not seeing this problem, which is a testament to the TMC communications design, and the forward thinking and planning of working with external agencies. The table also shows that many TMCs are monitoring the bandwidth in use for external connections, which should prevent surprises in the future.

Table 10. Bandwidth Monitoring for Existing and Future Connections.

TMC (TxDOT District)	Monitor Bandwidth	Adequate Bandwidth	Accommodate Bandwidth
- *(Bryan)*	-	-	-
CTECC (Austin)	No	Yes	By increasing optical carrier equipment capacity
TEXOMA VISION (Wichita Falls)	Yes	Yes	By increasing wireless capabilities
NETRIS (Tyler)	Yes	Yes	Not decided yet
TRANSVISTA (El Paso)	Yes	Yes	System is only using fraction of available bandwidth
TRANSVISION (Fort Worth)	Yes	Yes	System is only using fraction of available bandwidth
STRATIS (Laredo)	No	Yes	-

LESSONS LEARNED

The questionnaire asked respondents to provide a frank assessment of their concerns or issues with their ITS deployments. As shown in Table 11, maintenance of the existing communication equipment and field devices appeared to be the most significant issue. Districts are focusing on careful planning and execution of projects and designs to reduce maintenance concerns and hopefully avoid significant maintenance costs. It is, however, recognized by all that, typically, the more equipment that is deployed, the higher the maintenance costs. Included in the maintenance issue is the manpower required to performance maintenance and the technical knowledge necessary to perform those tasks.

Table 11. Maintenance, Installation, and Cost-Related Experiences.

TMC (TxDOT District)	Maintenance	New Installation	Cost
- *(Bryan)*	-	-	-
CTECC (Austin)	- Expensive if not carefully planned	- Plans and specifications must clearly explain expectation	- Installation cost compared to operation and maintenance

TEXOMA VISION (Wichita Falls)	- Some pending issue with telecom company regarding the availability of T1 bandwidth	- Get ISD and local IT dept involved from the start helps	- No funding issue, but would like to reduce monthly costs
NETRIS (Tyler)	- Hardware problem with DMS due to power supply - Modems burn out every week—temporarily fixed - Plan to let a project to fix the problem	- Nothing significant	- Funding for new ITS equipment is an issue due to unavailability of external funds
TRANSVISTA (El Paso)			
TRANSVISION (Fort Worth)	- Mostly related to connections	- Keep it simple	- Keep it as low as possible -Blanket order
STRATIS (Laredo)	- Long distance modem problems	- Getting away from T1	- Ethernet products cost effective

Some maintenance issues can be difficult to solve and may wind up in finger pointing. One TxDOT district has an ongoing issue related to T1 bandwidth, where the communication line provider says that the disturbance in the existing T1 connection is due to the video data, while the district disagrees. If there is little available technical expertise and no alternative communication solutions, these issues can cause a great deal of frustration, time, and added expense, which ultimately affects the traveling public.

The questionnaire also asked respondents to gauge their level of system reliability and available support, from the standpoint of both in-house expertise and utilizing the traffic operations division personnel. The results summarized in Table 12 show that most TMCs feel they have good reliability across the board, although wireless may be suspect considering the relative lack of experience in ITS deployments.

Table 12. Reliability, In-House Expertise, and TRF Support-Related Experiences.

TMC (TxDOT District)	Reliability	In-House Expertise	TRF Support
- *(Bryan)*			
CTECC (Austin)	- More of an issue as data passed to	- Required to manage consultants and	- Desired but not always reliable or

	emergency services to make life safety decision support	contractors effectively	consistent
TEXOMA VISION (Wichita Falls)	- Good reliability with all devices, but not sure about wireless capabilities - TxDOT has not been good at communicating what other TMCs are doing, especially with wireless	- Great local information resource - New expert in radio communication	- Very helpful/current setup would not have been possible without their support - Perform remote access for tech support
NETRIS (Tyler)	- Incompatible DMS applications, even though DMS came from the same manufacturer - Integration of two DMS to be able to access from one application would cost $12,000	- Signal staff is responsible for maintenance, but not fully trained	- Adequate support from TRF - Attended specialized workshops organized by TRF
TRANSVISTA (El Paso)			
TRANSVISION (Fort Worth)	- Radio manufacturers are not real stable	- Adequate	- Some support
STRATIS (Laredo)	- No significant issues	- More expertise in Ethernet than T1	- Helpful but solved own problems

In terms of support issues, as deployments take place, TMCs are developing in-house or local expertise. TRF appears to be performing a credible job in the difficult task of supporting varied deployments across the entire state. This task could get easier in the future if substantial standardization of items such as system design, hardware and software, and external connections are employed to reduce complexity and cost.

FUTURE DIRECTIONS

BACKGROUND

From its early beginnings as a Freeway Traffic Management (FTM) software package through present day, ATMS has a rich history of providing access to roadway information (video and data), allowing operators to make command decisions, and communicating those decisions back to roadway infrastructure to effect changes in the driving environment.

Over time, ATMS has transitioned from being an in-house programming effort to a contracted software project with rigorous documentation and interface requirements. The early versions of ATMS provided interfaces for inductive loop detectors and ramp metering and used a loop occupancy algorithm to determine incident conditions. As a result of more than a decade of ongoing development, ATMS has built upon that base by adding services such as camera control and video management, support for dynamic message signs (DMS), and data logging, as well as by embracing increased industry standardization through efforts such as the National Transportation Communications for ITS Protocol (NTCIP). ATMS is a critical data provider to Center-to-Center (C2C) Communications, which allows for the exchange of information between management centers. During the past decade, programming tools have also undergone a significant change, not only in the programming languages, but also with a move to distributed client/server and web-based architectures.

While ATMS is a software package, it utilizes information technology to communicate data to and from centers and field devices. The field of information technology has also experienced significant changes in the past decade. Communication devices have become smaller, faster, more affordable, hardened for field solutions, and support more capabilities than ever before. Perhaps now more than ever, it is important for ITS deployments to utilize industry standard solutions to achieve significant efficiencies and capabilities as they capitalize on past developments.

Within TxDOT, the Information Services Division (ISD) is responsible for supporting the business operations of TxDOT with innovative information technology and strategic information resource planning. Through the publication of TxDOT's Core Technology Architecture, planning for ITS deployments within the architecture and operations of ISD is now an essential task prior to providing ITS services.

As should be obvious, since its creation, ATMS has been affected on several fronts, including software, hardware, and communication architectures and solutions. Although changes are expected in any large scale development effort, the pace of these changes has led to wholesale changes in the way ATMS and, indeed, ITS services are designed and deployed within TxDOT. The purpose of this technical memorandum is to document the current hardware and software practices that impact ATMS and future ITS deployments.

TXDOT CORE TECHNOLOGY ARCHITECTURE

The TxDOT Core Technology Architecture document defines network architectures and corresponding requirements in a living document *(2)* that is meant to be updated periodically. The document defines the enterprise-wide technology architecture. Overall, the document discusses data, processes, applications, standards, policies, and implementations. Specific areas of discussion include items such as operating systems, relational databases, hardware requirements, remote access, security, fault tolerance, and more.

This document is publicly available and is also meant to provide some level of information to individuals and organizations outside of TxDOT that need access to transportation-related information throughout the organization.

With regard to ITS, it is important to note that the core technology document makes explicit reference to ITS projects. In particular, the following information is conveyed:

- Legacy projects, including Intelligent Transportation Systems projects are under the purview of the core technology architecture.
- These projects include transportation management centers, freeway traffic management systems, high occupancy vehicle lane traffic management systems, arterial traffic management systems, closed loop traffic systems, ITS, and traffic management related research and development projects.
- Existing ITS projects are exempt from the core technology architecture requirements for information technology presently in place.
- Existing ITS projects where information technology is being replaced or enhanced are subject to the core technology architecture requirements.
- All ITS projects in the planning stage are subject to the core technology architecture requirements.

ITS components are specifically called out in several diagrams within the document, recognizing the potential interaction of ITS systems with the rest of the TxDOT information technology enterprise.

SUMMARY OF CORE TECHNOLOGY ARCHITECTURE REQUIREMENTS

The core technology document contains numerous decisions pertinent to ITS deployments and future development of ATMS. These include:

- Transmission Control Protocol / Internet Protocol (TCP/IP) should be the single TCP/IP on the TxDOT topology.
- Ethernet is recommended as the media of choice for all local connectivity.
- Redundant connections should be used, when possible, to provide fault tolerance and successful implementation of client/server technologies.
- The TxDOT network shall consist of standard switched infrastructure, including switches, routers, firewalls, monitoring devices, and IP video.
- Wireless LAN capabilities will be used to connect to ITS devices and to provide point-to-point connections for off-site TxDOT buildings.
- Windows XP Professional and Windows 2000 Server are the recommended operating systems.
- Sybase Adaptive Server will be used for maintenance of legacy database applications.
- Microsoft SQL Server will be used for enterprise and workgroup database applications.
- Minimum hardware requirements for servers and workstations will be specified to promote uniformity..

Several of the bullets above represent a major departure from previous ITS deployments. However, the core technology architecture document recognizes the changing face of the information technology industry and seeks to unify TxDOT business practices from several standpoints, including procurement, costs, support, stability, and security.

Folding ITS deployments under this umbrella actually provides significant advantages to ITS projects. Perhaps most important is that adhering to the standards of the core technology document provides a data and video communications mechanism that has previously been the individual responsibility of each deployment. Under this architecture, those pathways are now the responsibility of ISD to provide and maintain. This allows TxDOT traffic operations to focus on implementing the best solutions for ITS while having an enterprise network available for data transport. Task 5 of this project will discuss in more detail the segments of the networks used for data transfer between the field and the TMC, as well as to other areas, such as the public or external partners.

ATMS SUBSYSTEMS

With the initiation of the statewide integrator program, TxDOT has redesigned ATMS from the ground up. At the core, the system is a series of modular software applications that can exchange data using common formats, protocols, and message sets. All of the core functionality pertaining to a specific need, such as support for Dynamic Message Signs, is contained within each module. Modules, or subsystems, can be deployed as needed in support of any ITS deployment. Modules are essentially "plug and play" components and can be added into a deployment at a later time with some minimal configuration.

Within each module, a sophisticated information exchange concept was developed based on standards development within the transportation and information technology communities. The core communications protocol used within ATMS is TCP/IP. Utilization of this family of protocols allows ATMS to take advantage of all of the services that are available to TCP/IP and provides a significant cost advantage over developing a new communications protocol. The accumulation of all of the command and control aspects of a particular subsystem defines the protocol for that subsystem.

Within a particular protocol defined for a subsystem, like DMS, the Extensible Markup Language (XML) is used to convey information. XML is a language of choice for many similar efforts, since it allows for the creation and transmission of user-defined information. This is critically important to efforts like ATMS since TxDOT can create department-wide information sets pertaining to a particular area, such as dynamic message signs, traffic sensors, weather systems, etc. Within the TxDOT subsystems, these message sets are defined as an interface. The interface contains definitions for all of the specific information necessary for the operation of a particular subsystem, such as raw data components, smoothed data components, calculated data components, location data, event data, etc.

Figure 1 illustrates a typical software component within ATMS. The Traffic Sensor Subsystem (TSS) has a stated goal of "…acquiring the traffic flow information, analyzing and reduced the collected data and maintaining the equipment location and configuration information…"*(3)*.

There are several important concepts to understand in Figure 1. A primary aspect to understand is that the subsystems were designed to be device independent and to support multiple vendors. Devices from multiple vendors can live side-by-side and be supported simultaneously.

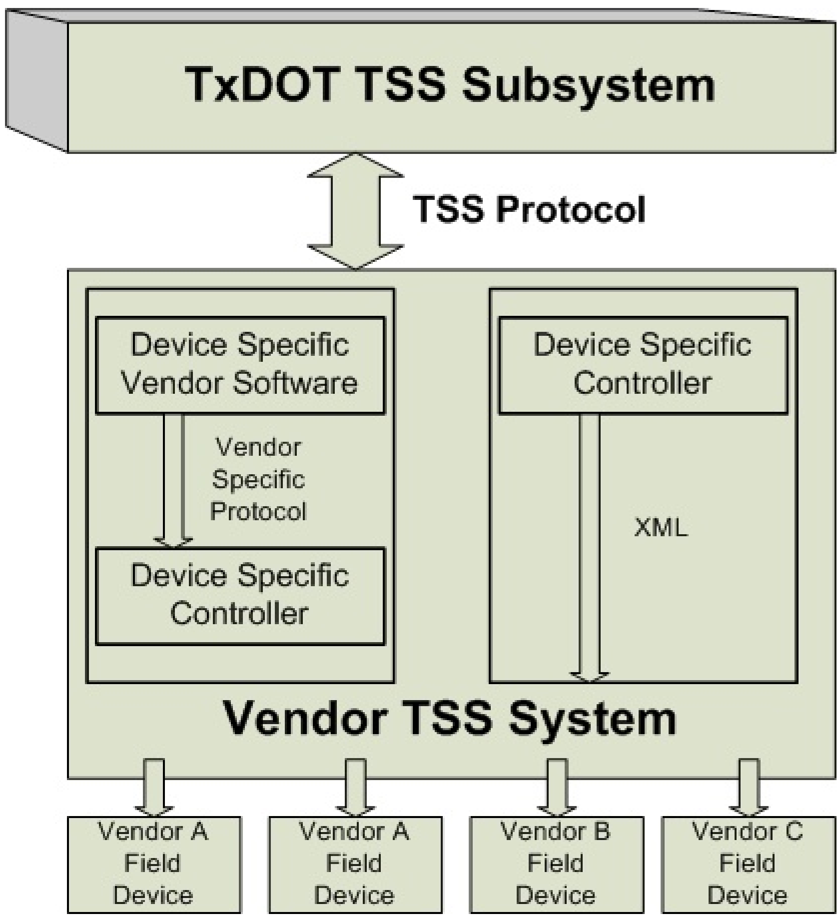

Figure 1. Example of a Typical Subsystem in TxDOT ATMS (Adapted from Figure 1, Reference 3).

Additionally, it is important to understand that the design of the subsystem allows for two distinct communication paths from field devices. The first path allows for a field device from any particular vendor to be incorporated without speaking the same protocol or language as the TxDOT subsystem. The vendor is responsible for translating their proprietary information to the interface defined for TSS. The second pathway allows for the common message set and XML protocol to be supported all the way to the field device. The support for multiple methods of data communications allows TxDOT to support multiple vendor devices. The only requirement is that the vendor software must supply the TSS with the defined information in the appropriate format, at the appropriate times, and in response to the appropriate queries.

An important component of ATMS development has been the creation of rigorous documentation supporting each subsystem. Typically, each set of documentation consists of the following:

- Concept of Operations — a document providing a high-level overview of how each subsystem will work, as well as the specific operations it must perform in order to accomplish the desired tasks.
- Software Requirement Specification — a document detailing the functional requirements for each aspect of the subsystem, such as interfaces to other components, data acquisition, data smoothing, etc.
- Subsystem Protocol — a document describing the components of the subsystem protocol and the XML schema and message set information.

ATMS DEPLOYMENT

As described previously, the various subsystems of ATMSare modular by design and can be implemented in any particular ITS deployment to provide a particular service. Figure 2 shows a number of subsystems assembled together and interfacing to a common command and status distribution (CSD) subsystem. The CSD subsystem is essentially the communications manager of the deployment and supports all communication activities across all modules. The CSD can also interface to other deployment activities, such as databases for data archiving and communication to other centers.

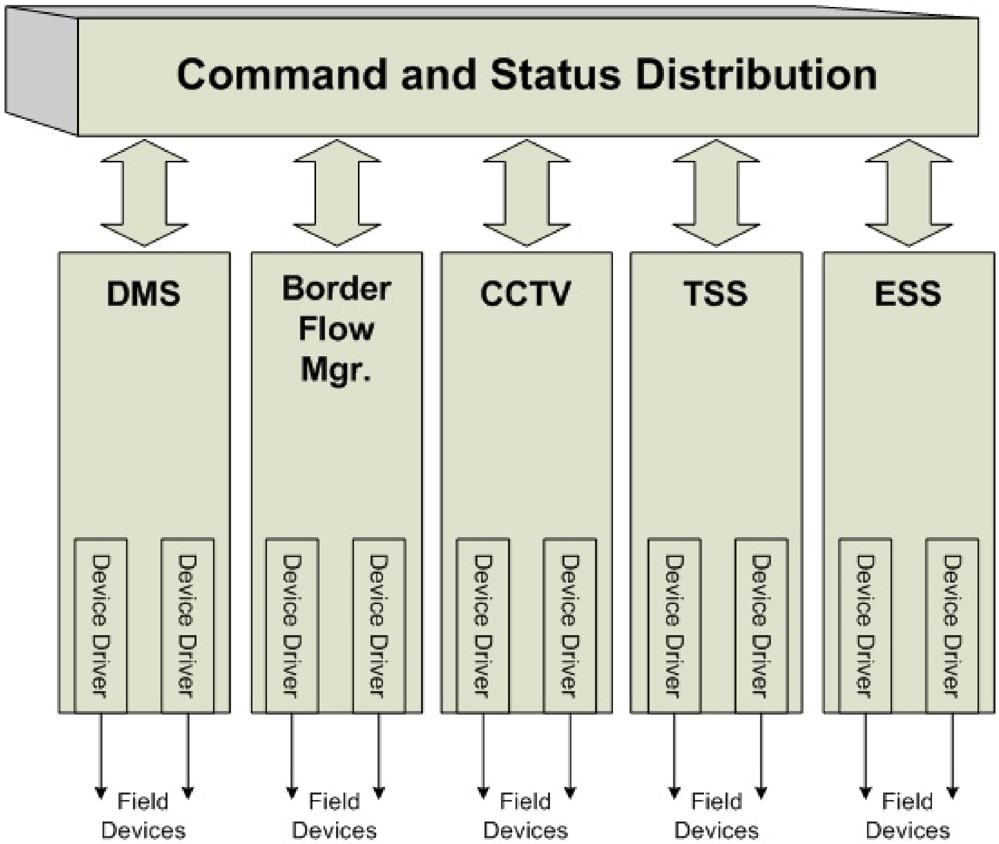

Figure 2. Illustration of Subsystems Assembled to Support ATMS Deployments (Adapted from Figure 1, Reference 4).

The current ATMS subsystems that exist include:

- DMS — (Dynamic Message Sign) — interfaces to dynamic message signs to provide messages to motorists.
- Flow Manager — interfaces to flow devices (traffic lights, etc.) at Border Safety Inspection Facilities.
- CCTV — (Closed Circuit Television) — interfaces to CCTV cameras for video surveillance.
- TSS — (Traffic Sensor Subsystem) — interfaces to field traffic data collection devices.
- ESS — (Environment Sensor Subsystem) — interfaces to field sensors to provide environmental data, such as temperature, humidity, etc.

- CVM — (Commercial Vehicle Management) — used within Border Safety Inspection Facilities to interface to vehicle compliance equipment such as Weigh-In-Motion, static scales, etc.

CENTER-TO-CENTER (C2C)

Perhaps one of the most significant aspects of TxDOT's ATMS development has been the forethought to provide for information exchange at the highest levels, i.e., between deployments or traffic management centers. The C2C concept provides an infrastructure for information exchange between centers. It should not be confused with a data archiving system because it does not permanently store any information. Centers can "publish" information to other centers, as well as "subscribe" to information being published from other centers. In essence, C2C is a transient, real-time, "cloud" of traffic-related information. Centers can choose what information they publish to the "cloud." The real-time aspect is critical since it supports a number of applications that would not be possible with a data-archiving or storage approach.

A typical use might entail two bordering cities, each of which has its own TMC and field devices. Subscribing to information from the other center might alert operators to an imminent problem or provide them the opportunity to take proactive steps during developing traffic situations. Another use might be to obtain a regional or statewide view of traffic conditions and then use that information to populate an Internet based map for motorists.

An example deployment that utilizes C2C is illustrated in Figure 3. The subsystem lives on the other side of the command and status distribution subsystem, and has several goals, including: *(4,5)*

- supporting data exchange between dissimilar systems,
- sharing ITS information in real-time,
- providing capabilities to allow agencies to share command/control of ITS equipment, and
- utilizing national ITS standards for implementation.

Note that the C2C subsystem does not interface directly to field devices or each individual subsystem. It exchanges all information through the CSD subsystem.

Within the C2C infrastructure, there are several components.

- Data Provider — receives data from an ITS system.

- Data Collector — receives data from multiple sources and stores data in local memory.
- Data Extractor — receives data from data collectors.

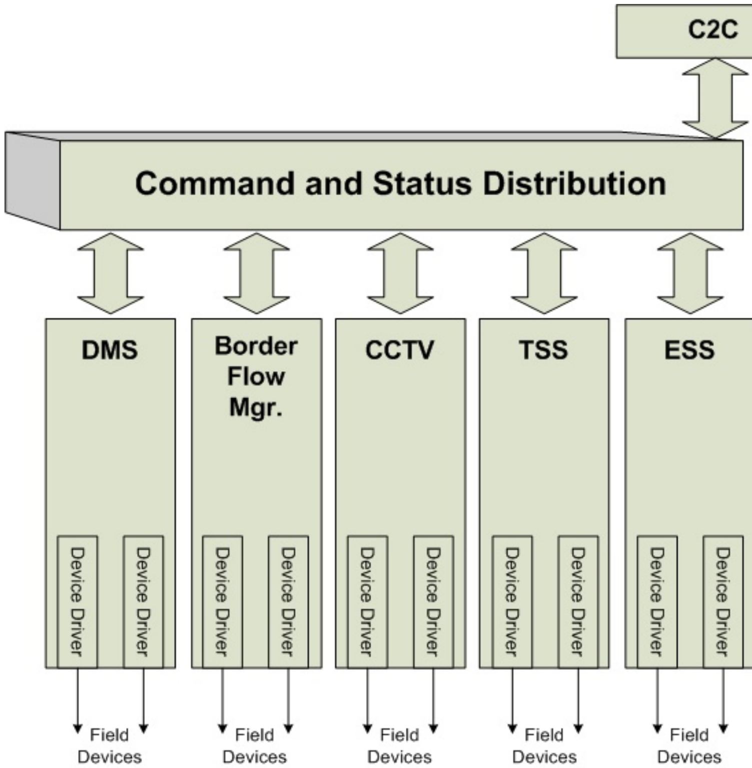

Figure 3. Typical ATMS Deployment with C2C Subsystem.

The use of these components is illustrated in Figure 4. The "cloud" is established with data collectors, which store the information in local memory. Information is fed to and from the cloud via the use of data providers and extractors. More than one data provider can be providing information into the C2C cloud. Essentially, the growth of the cloud is only limited by the hardware and communications infrastructure. Conceptually, the cloud could encompass the entire state.

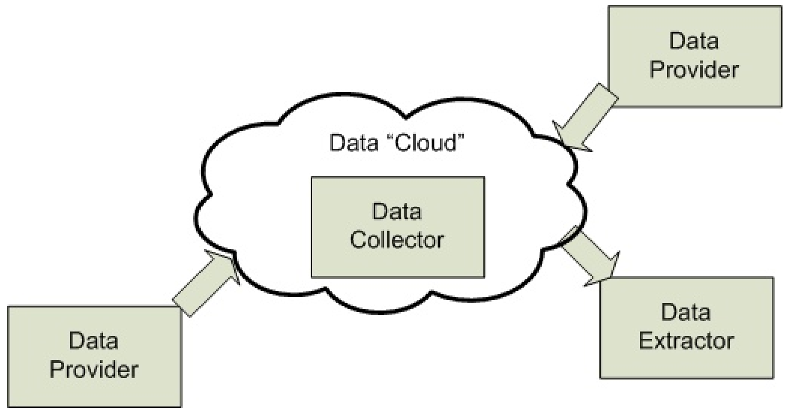

Figure 4. Illustration of C2C Components.

In addition to the C2C components illustrated in Figure 4, the C2C infrastructure provides for two other components. These are a Command/Control Sender and a Command/Control Receiver. As their names indicate, these paired components allow for ITS field devices to be by an external entity without opening up the system itself to outside access.

IMPACTS OF OTHER COMMUNICATION DIRECTIONS

The results of the ATMS deployment survey conducted in Task 1 documented the current diversity of ATMS installations across the state. In many cases, the existing deployments have substantially different communication solutions and utilize different hardware. It is a testament to the strength of the previous in-house software development effort that the package supports as many different deployments as it does.

Task 2 showed, however, that significant changes are taking place in the ATMS arena. These include a wholesale redesign of the software architecture and techniques for transmission of data. Another significant change is the involvement of the TxDOT Information Services Division, which means that ITS deployments are subject to many of the same hardware, security, and policy considerations that are in place for other core services. In fact, ITS deployments are now mainstream applications within the TxDOT communications system and are specifically mentioned within the TxDOT Core Technology Architecture.

As the number and sophistication of ITS deployments have grown across the state, the ATMS effort has also focused on sharing information between these deployments to serve the motorist regardless of political jurisdictions. The creation of the Center-to-Center (C2C) infrastructure is a critical step in evolving ITS deployments beyond the local area and into a more far-reaching, integrated system.

Despite the significant progress to date, it is always a continuing challenge to respond to market and industry changes. Market evolution, particularly in the hardware arena, can occur at lightning speeds. TxDOT is most often in a reactive state to these types of changes, since they are not in a position to significantly influence hardware development. Changes in how software is developed and written typically occur at a more moderate pace, but again leave TxDOT in a reactionary mode. TxDOT can, however, be more proactive in their support for, and use of, standards within the ATMS arena. TxDOT can also make proactive decisions to develop and support new capabilities within ATMS to expand the core services that are provided by ITS deployments. The purpose of this technical memorandum is to examine notable trends in the communications and transportation arenas and discuss their potential impact on ATMS.

NATIONAL STANDARDS

With the redesign of ATMs into a modular software platform, TxDOT has embraced standards at every level. This will continue to be a critical component of the ATMS strategy going forward.

There are many different types of standards defining how ITS deployments can exchange information and interact to deliver services. The National Transportation Communications for ITS Protocol (NTCIP) is one well-known family of standards employed within the ITS arena. However, the ITS standards web site maintained by the United States Department of Transportation (USDOT), currently has information on over 100 standards in various stages of development or publication *(6)*.

These standards establish "rules" for how communications take place, i.e., how connections are made, how data are exchanged, and what data are exchanged. Standards are independent of products and, in fact, promote interoperability between all products. This allows agencies such as TxDOT to focus on defining and delivering a core set of functionality, yet also allows vendors to provide valued-added products with enhanced feature sets beyond the root functionality.

In addition to the national ITS standards, TxDOT has also developed standardized interfaces within ATMS by defining standard data elements, sets of data, and exchange points between various components or ATMS modules. TxDOT employs these standards at numerous levels, such as field device support and data transfer and information exchanges between ITS deployments.

Impacts on TxDOT ATMS and Communications

The ongoing development and publication of these standard interfaces will continue to be a benefit for TxDOT and ATMS development. By continuing to embrace standards-based ITS development and deployment, TxDOT can increase the capabilities of their ITS infrastructure. In particular, the advantages can accrue across the state and multiple deployments, as opposed to a single location.

COMMUNICATIONS INDUSTRY TRENDS

For many years, the communications industry has been consolidating data communications with the Transmission Control Protocol / Internet Protocol. TCP/IP is a low-level networking protocol used by computers and other hardware to communicate across networks. In reality, TCP and IP are two separate protocols that are part of a large number of Internet protocols. TCP/IP has, however, become known in the industry to stand for the family of common Internet protocols. The protocols stem from a Defense Advanced Research Projects Agency (DARPA) project dealing with the interconnection of networks in the late 1970s. By 1983, it was mandated for all U.S. defense long-haul networks. Over time, TCP/IP became accepted throughout the world and is now an internationally known and supported protocol.

A significant industry trend has been seen in the last several years whereby virtually all new devices support the TCP/IP communication protocol. Generally, these devices also interface to an Ethernet based networking system. From traffic signal controllers to video codecs, virtually the entire hardware side of the transportation industry has embraced the common use of the TCP/IP protocol for data communications. This common use lowers cost, provides increased functionality, and moves towards "plug and play" hardware capabilities.

Impacts on TxDOT ATMS and Communications

Because TCP/IP has become so universally accepted, it is supported in virtually any data communications and networking environment. TxDOT standardized on TCP/IP as the communications protocol of choice when designing the software architecture of ATMS. This is in keeping with industry trends and allows TxDOT to take advantage of improvements in data communications over time without having to re-engineer the ATMS product.

Another distinct advantage to the use of TCP/IP is the fact that because it is support across disparate networks, it provides an ideal and standard mechanism for information exchange, even to systems where other communication protocols may be in use. This is a particular advantage, considering that previous ITS deployments across the state did not use a consistent network architecture or design. In fact, in some of the larger ITS deployments, while the software applications are completely different, the use of TCP/IP will allow them to participate in statewide information sharing concepts like C2C.

VEHICLE-INFRASTRUCTURE INTEGRATION (VII)

Nationally, more than 43,000 fatalities occurred in 2005, up 1.4% from 2004. The fatality rate per 100 million vehicle miles traveled was 1.47 in 2005, up from 1.45 in 2004 *(7)*. These numbers are above the USDOT's goal of 1.0 fatalities per 100 million vehicle miles and moving in the wrong direction, despite vehicle design improvements, such as crumple zones, and increased use of seat belts and airbags.

Accordingly, the USDOT has sought other avenues for increasing safety and reducing fatalities. Vehicle-Infrastructure Integration (VII) is one of the USDOT's current research initiatives to explore methods of reducing the fatality rate. VII's goal is to create a new paradigm for increased safety, efficiency, and convenience on the nation's roadways. The VII concept centers on wireless mobile communication between vehicles and between vehicles and the roadside. These data conduits will provide information never before available and will support applications such as in-vehicle safety warnings, free flow electronic payment, work zone warnings, and vehicles as probes. Many potential applications have already been identified.

The VII concept includes both vehicle-to-vehicle (V2V) communication and vehicle-to-infrastructure (V2I) communication. To illustrate the potential value of V2V, consider the fact that 60% of highway fatalities occur in roadway departure crashes. These crashes may be reduced in the future via mechanisms such as cooperative collision warnings, emergency brake light warnings, blind spot warnings, blind merge warnings, lane change warnings, wrong way driver warnings, and other similar applications. Data will be exchanged among nearby vehicles in real time for many of these projected safety and mobility applications.

V2I enables applications such as signalized and stop sign protected intersection violation warnings, sharp curve / rollover warnings, emergency vehicle warnings, and pedestrian crossing warnings. These applications emphasize safety in a localized area. Network oriented applications incorporate resources beyond the local scene. These include vehicles as data probes for traffic, weather and road surface conditions, electronic payment of tolls and other purchases (fuel, parking, etc.), commercial vehicle data (electronic manifests, weights, cargo tracking, etc.), fleet maintenance, road condition warnings, traffic information (incidents, travel time, construction, etc.), and enhanced route guidance and navigation.

Current Activity

Based on the USDOT VII initiative status report published in January 2007 *(8)*, the development of both a high-level and detailed VII network architecture is well underway. Construction of a laboratory test environment in Detroit, Michigan, is also in progress. This real-life laboratory will cover approximately 20 square miles and serve as a proof-of-concept environment to test more than 20 prototype VII applications. Additionally, development of a cost-benefit model for the VII system is ongoing.

In a parallel effort, the auto industry is undertaking its own efforts to investigate the viability of VII by examining suitable business models, privacy policies, deployment strategies, and management models for a national system. Prototype applications, some originally conceptualized in the DOT's Vehicle Safety Communications project, have already been demonstrated to the public. These demonstrations include extended electronic brake light, traffic signal violation warning, hazard warning, wireless map update, probe data collection, in-vehicle signing, lane-change and blind-spot warning, and forward collision avoidance and warning.

In 2004, the Cooperative Intersection Collision Avoidance Systems (CICAS) program partnership was initiated between the United States. Department of Transportation (USDOT), automobile manufacturers, and state and local departments of transportation. CICAS will use VII technologies to address intersection crash problems related to stop sign violations, traffic signal violations, stop sign movements, and unprotected, signalized left turn movements.

There are three operational concepts for CICAS:

- CICAS–Violation (CICAS-V): a system that warns the driver via an in-vehicle device when it appears likely that the driver will violate a traffic signal or stop sign.
- CICAS–Stop Sign Assist (CICAS-SSA): a system that uses a DMS to tell drivers on the minor road when it is unsafe to enter the intersection due to insufficient gaps in traffic on the main road.
- CICAS–Signalized Left Turn Assist (CICAS-SLTA): a system that uses a DMS or in-vehicle sign to tell drivers when it is unsafe to make an unprotected left turn at a signalized intersection.

All of the above systems are under development in partnership with major manufacturers, research agencies, and some state Departments of Transportation. The primary objectives of these partnerships are to develop system designs for prototyping and field operational testing.

Architecture

The VII architecture as currently published *(9)* is organized into four general categories or layers: vehicles, roadside, centers, and external users, as shown in Figure 5.

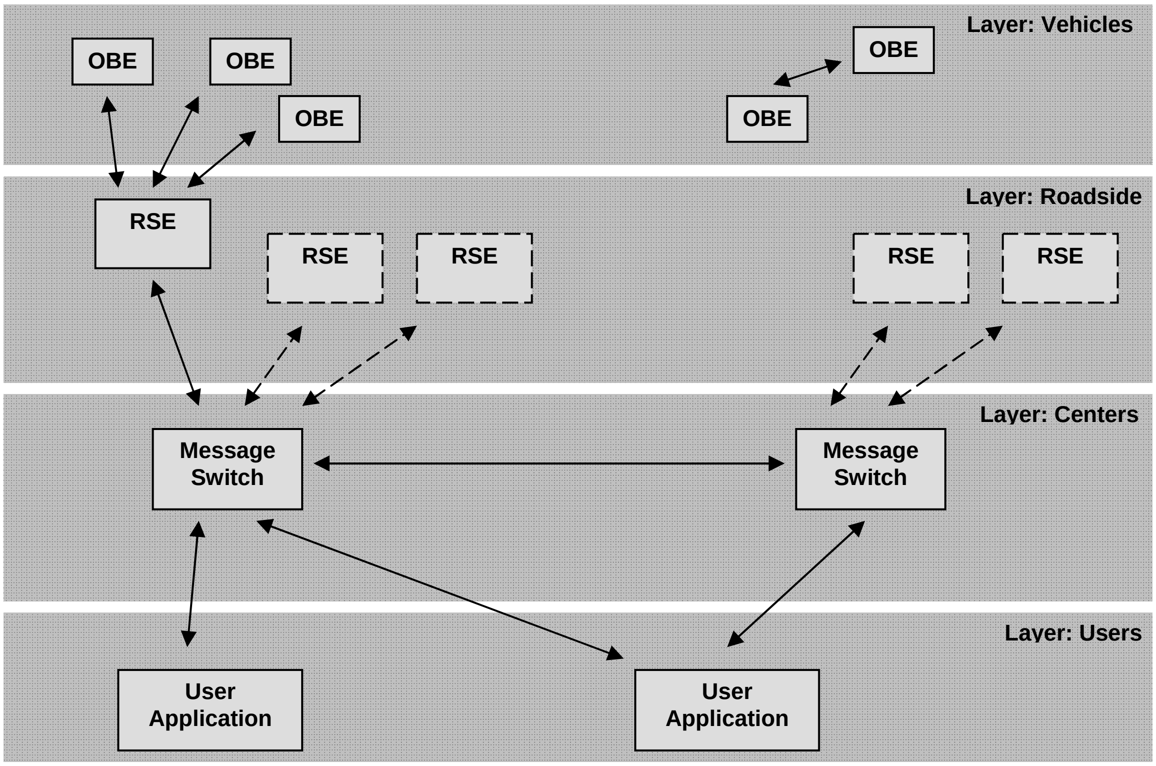

Figure 5. Current VII Architecture.

Vehicles will receive Onboard Equipment (OBE) that accesses data throughout the vehicle (GPS, vehicle status, and other communication devices) and provides an applications processor and display for the driver. The OBE package includes a wireless interface that will use the emerging Dedicated Short Range Communications (DSRC) standards such as 802.11p, commonly called Wireless Access the Vehicular Environment (WAVE). WAVE is part of the 1609.x family of standards for wireless access to communicate with other vehicles and the roadside from the Institute of Electrical and Electronics Engineers (IEEE)

Each vehicle will create and store "snapshots" of the vehicle's status (e.g. timestamp, location, speed, heading, temperature, brake application, wipers, etc.) periodically and upon exception. The wireless protocol will support fast association with other VII entities to enable latency sensitive safety applications. Vehicle created data will not have any unique identifiers and will thus protect the anonymity of the provider.

The roadside category uses Roadside Equipment (RSE), which include a DSRC wireless receiver to communicate with vehicles, as well as a GPS receiver (to provide location identification and timing), an interface to a local safety processor, and a message router. The local safety processor interfaces to devices such as a traffic signal controller or a ramp meter. The RSEs would be deployed along the national roadway network at places such as signalized intersections.

The rural interstate highway system will likely be equipped at less frequent intervals, possibly only at locations such as interchanges or major ramps. RSEs are not required to be permanent installations and may be portable (although it must be stationary during operation) for applications such as work zone and special event support. As vehicles come into range of the RSE, they upload their snapshots and create a dialog for any associated safety applications at the individual RSE site. The RSE is currently designed as an information pass through to the next layer up (centers); thus, there is no information aggregation function at this level. There will be large numbers of RSEs deployed on the transportation system. It has been speculated that 500,000 RSEs may be deployed in a fully operational system *(10)*. It is clear the VII system will create a large amount of data to be managed and also require a large network to support the data transfer.

VII Message Switches are defined as the ”centers” layer. Each VII Message Switch (MS) will connect to numerous RSEs (potentially several thousand) and other MSs. The RSEs register with the Message Switch and send their data to the associated MS using a publish/subscribe model. The MS channels incoming data from many RSEs to specific output ports (users). Currently, the MS is not designed to perform any data aggregation or management other than routing specific input data elements to subscribed users. The potentially overwhelming amount of data this conceptual design will create has been questioned *(10)*.

Finally, the consumers of all this data are as external users. By definition, the VII network is designed to support the needs of the public sector and the original equipment manufactures (OEMs). Data between other commercial RSEs, such as tolls or fueling stations, are not supported by the VII network. External users might be traffic management centers at a local, regional, state, or even nationwide scope. The vehicle OEMs are also classified as external users. The external users will maintain applications that publish and subscribe with MSs to access inbound data and to push messages outward to vehicles. Public sector users send broadcast messages received by all vehicles within range of the target RSE. Conversely, private sector users send only messages targeted to an individual vehicle.

Although slightly different abbreviations are used, Figure 6 shows another illustration of the first three layers of the VII infrastructure. In this diagram, the on-board units (OBU) are equivalent to the OBE, while the Road Side Unit (RSU) equates to the RSE shown in Figure 5. Figure 6 also shows some additional components of the OBU and RSU, as well as illustrating that communication is via a wireless mechanism. Communication between the RSU and the TMC components is shown as a fiber connection, although any type of broadband backhaul that is available would suffice.

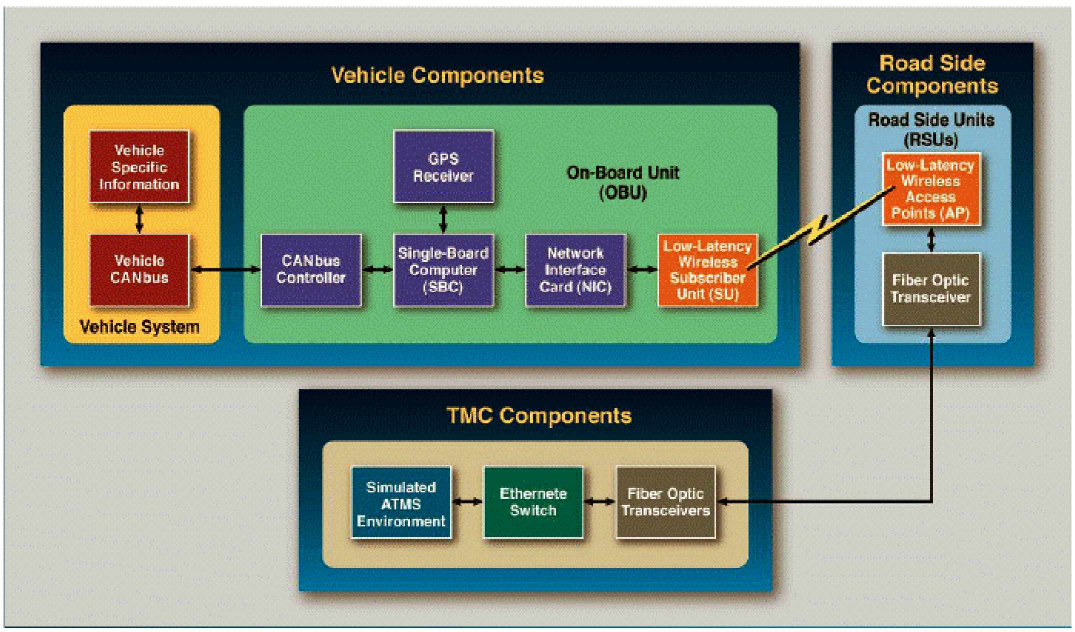

Figure 6. Example VII Infrastructure Showing Vehicle, Roadside, and TMC Components (Source: Reference 11).

Roadside

Much of the communication network design and operation has yet to appear in VII published documents. As stated in the architecture and functional requirements, there will be a significant number of deployed RSEs along the roadway system. The RSEs embody two different types of communication: local and network. The local component links directly with vehicles via DSRC. All local safety-oriented communication occurs over this medium that is optimized for the safety task (e.g., low latency transmissions, high message volume, fast association with RSEs, etc.), which is the main focus of the VII system. The second communication “style” is a link to an associated VII Message Switch. The current documents indicate the RSEs will receive IPv6 addressing, thus pointing toward an IP network connection at the RSE.

Vehicle snapshot messages should dominate the upstream traffic to the MS. Current documentation indicates the snapshot data will likely have a lower limit of approximately 50 bytes, and the vehicle will have a snapshot buffer that will fill while the vehicle is outside of RSE coverage. The size of the snapshot buffer is also undefined, but the requirements documentation mentions a buffer size of 20 snapshots. When a connection with an RSE is made, the snapshots will be uploaded to RSE and forwarded upstream to the assigned MS.

Using the suggested message and buffer size, a single automobile will have approximately 1000 bytes of data (protocol overhead is not included here but will obviously add to the byte count) to upload to the RSE. Assuming a peak traffic flow of 2000 vehicles/lane/hour, 10 lanes of traffic, and all vehicles on the roadway equipped with OBEs, an aggregate of 50 kilobits per second of network bandwidth will be required to support the RSE. The above simple calculation does not take into account all traffic that will move over the link (message to vehicles, security messages, etc.) and does not include any equipment related traffic for management of devices, status and heartbeat, etc. The calculation is intended solely to illustrate the minimum requirement neighborhood for the network communication link. Several current communication options can support the 50 kilobit per second bandwidth including:

- copper wireline service (dial-up, ISDN, DSL, etc.),
- cellular data providers,
- private wireless (wireless LAN, wireless point-to-point, etc.), and
- fiber (Ethernet, T1, SONET, ATM, etc.).

In general, the addition of an RSE to a field location will not require an expensive, broadband communication link.

The VII network will be managed centrally from a number of geographically distributed VII Operations Centers that will include the VII Message Switches and other network equipment. An unidentified ”VII Network Operations Entity” will be responsible for the design, implementation, expansion, operations, and maintenance of the VII Network. It is unclear just what the role of state DOTs will be in the installation, operations, and maintenance side of the VII system. It is possible that the system will be managed and operated by the private sector under contract. It also is unclear if all the communication links required by the VII system will be installed as new infrastructure and managed independently from any current roadside ITS systems.

Traffic Management Centers

Public agency TMCs are data users in the VII hierarchy. The TMCs will host applications that subscribe to VII Message Switches to receive data from the vehicles (through the RSEs). The current VII system requirements' documents do not identify a point in the system where traffic data is aggregated; therefore, applications will subscribe to MSs and receive all the snapshot data from the vehicle in the application's region of interest. Obviously, a large volume of data will be routed from the MSs to applications. TMCs will need to have a broadband link into the VII Network to participate. This data link has been defined as being an IP based network using the most current version of the protocol available at design time.

The volume of data moving to a TMC user can be quite large. Using the same example as before, (50 kilobits per second upload from a single RSE) and requesting data from potentially thousands of RSEs in a region, the inbound data bandwidth could be on the order of 50 megabits per second of data and upwards of 100 megabits per second from the VII Message switches. Network links for this level of service would likely be fiber supporting Gigabit Ethernet or Ethernet over ATM. Application will have to be designed to manage this flood of data, and hardware will have to be purchased to support the software.

It may be advantageous for an operating agency to establish a single center with the communications and computational hardware to provide the traffic data analysis services for regional TMCs where it would be cost prohibitive to locate such resources in different locations. This regional network operations center could aggregate data coming from the RSEs and provide tailored datasets to individual TMCs over lower bandwidth networks. The network operations center concept would also allow easy access to local, regional, and statewide data from a single source. This concept could fit well into the State of Texas's mission to centralize information technology operations and to gain extra use from the Center-to-Center subsystem within the statewide integrator's traffic management software package.

Impacts on TxDOT ATMS and Communications

Public operating agencies will interact (at the communications level) with the VII in potentially two areas. First, RSEs will be deployed at the roadside. The RSEs will require a communication link. Second, the public agency will need a path to send and receive information into the VII system. The user level (i.e., a traffic management center) does not link directly to the field but through an intermediary, the VII Message Switch (MS). The two communication links (RSE to MS, and MS to TMCs) will be reviewed individually. Significant issues still remain to be resolved pertaining to the mechanism of accomplishing VII information transfers, the method of providing the data to external applications, and the amount of data that will be in a data stream. While bandwidth will be one concern, other issues, such as privacy and security, will be significant challenges that will also have to be resolved. With ATMS evolving to an open-interface system, TxDOT should be positioned for entry into VII applications and infrastructure in the future.

COMMUNICATION NEEDS FOR EXTERNAL PARTNERS

In today's ITS environment, information sharing is an important component of providing ITS servers. A traditional outlet for information sharing has been the motoring public. Both Houston TranStar and San Antonio TransGuide have been recognized by the Federal Highway Administration (FHWA) as the best Internet destinations providing travelers with real-time information.

It is important to understand that most ITS applications are not legislatively imposed on travelers; they are market driven. If ITS works for individuals and is cost effective, it is likely to produce meaningful mobility results. ITS-related traffic information on web sites has been shown to be wildly popular in terms of the number of views of information and the repeat visitors.

While in the past many Texas ITS deployments have provided their own web presence, the on-going consolidation of information resources across the state may establish different communications requirements for the provision of traffic-related information from the state.

In addition to the public, information has been shared with other agencies, such as the media. Media is most often interested in TMC resources, such as Closed Circuit Television cameras. The media often has requirements for the quality of the video, which relates directly back to the technical aspects of acquiring and providing the video and the communications bandwidth necessary to provide video feeds to the media.

Third-party information service providers (ISPs) are also a consumer of ITS data. ISPs often repackage this information, adding value and features for their subscriber base, and resell it on a feed basis to travelers, media outlets and other private customers. In general, TxDOT does not charge for furnishing such information to the ISPs. Customers, however, buy a service from a business entity for personal consumption and in return receive a benefit or value for their purchase.

The purpose of this chapter is to provide an overview of known practices and discuss the impacts of providing ITS data (including video) to external partners, particularly with respect to the communications necessary for the exchange of the information.

CURRENT PRACTICES FOR TXDOT TMC INFORMATION SHARING

Information Service Providers

Public sector agencies provide ITS data to provide user services, by installing and maintaining equipment using public funds. On the other hand, the ISPs mostly purchase ITS data from public sector providers, add value and features to the data, customize it, and provide it to private users based on subscription fees.

To date, many of the TxDOT TMCs have been successful in providing traffic-related data to ISPs free of charge. TxDOT does not charge for furnishing such information to the ISPs, but there may be an opportunity to do so and generate additional revenue for TxDOT. Currently, only Houston and Dallas provide real-time data (speed) to private ISPs. Both have signed agreements with two ISPs for transmittal of speed data. Earlier research performed by TTI found that while there is no standard agreement, the agreements are similar in their wording and most were developed according to previous agreements *(12,13)*.

Media

Many ITS deployments share information with the local media, as they are a valued partner in getting information to the traveling public. Data shared are primary video. Many deployments have expanded their information sharing over time to incorporate additional information, such as construction activities. Below are three short examples, abstracted from prior research *(13)*, that highlight the type of information sharing taking place with the media in the districts.

Austin District

Austin District shares video data directly with four media stations in Austin. The media have pan/tilt/zoom capabilities, but their use of the feature has been limited. TxDOT and the media participants held a meeting to agree upon mutually acceptable camera angles to prevent excessive independent camera movement, particularly in the morning peak traffic period.

In addition to the video, speed, volume, and classification, detector occupancy data are typically provided as a comma delimited file in a CD format. A more desirable exchange medium is a website format, with data files regularly posted to an Internet File Transfer Protocol (FTP) site. Interested parties could download the desired data without making a formal request to TxDOT. Traffic monitoring data is provided by request or on an as needed basis; data is not actively distributed by the TxDOT Austin District.

Requests have been received by individuals who want the video/CCTV feed directed to their home. These requests were denied and resulted in TxDOT's informal policy to only provide the video data to entities who will further disseminate the information (i.e., not for personal use). Initially, TxDOT was asked to provide exclusive rights to the video data for a single media outlet. TxDOT instead opted to make the video widely available for dissemination with no exclusive rights.

Houston District

Houston provides real-time access to the Houston TranStar cameras to TV stations. The media does not have any control over the cameras but can view and broadcast the video. The Texas Transportation Institute (TTI) offices in Houston perform the analysis of Automatic Vehicle Identification (AVI) data, which are provided to TxDOT in electronic format and hardcopies as needed. These data are the source for speed related information on the Houston real-time traffic map. Data is also provided to others on the TranStar web site; some of these are of a historical nature, while others are in “real-time” mode. ISPs have access to a password-protected data set that they are free to use according to their respective agreements.

Prior surveys *(13)* of Texas TMCs found that the only major concern is how ISPs may be using the data in terms of a company “selling” the Houston data to other companies; this would be a violation of their agreement. The companies are also required to provide credit to TxDOT/Houston TranStar when using the data; some of these companies may not be doing this as well as they probably could.

TranStar can no longer authorize data agreements TxDOT headquarters in Austin will now review all agreements for data sharing. The Leadership Team and Executive Committee must approve the amount of compensation. There are some exceptions, such as the government office of emergency management or police agencies. Exclusive agreements where an outside entity “owns” the data will not be signed.

San Antonio District

TransGuide stores speed, volume, and occupancy data in text flat files and those files are available to researchers and others through an FTP site. San Antonio personnel update these data on a non-scheduled basis. TransGuide also shares video with the local media. Local TV stations provided the equipment (external access video switch) necessary to supply 20 camera views to each of the stations. Each station can then control which image they display to their viewers. ISPs wanting to share TransGuide's video data must enter into a written agreement; however, there is no agreement required for anyone to use TransGuide images on web sites. Users (e.g., researchers) of data on the ftp site are not required to enter into an agreement. However, private firms that will market TransGuide data are required to have an agreement.

TransGuide also archives "scenario" data, which includes an incident's start time, end time, DMS message, and the lane control signal display. However, TransGuide does not provide access to archived information regarding how TxDOT responds to incidents (e.g., DMS messages, travel times, etc.).

External Agencies

In addition to the ISPs and the media, ITS deployments often share information with other agencies. These may be city or state entities, and the information may be video or data. Video is probably the most often requested information. Generally, information sharing between agencies requires some level of agreement, which may speak to the uses of the information, the access mechanism, the maintenance of the communications equipment, or any exchange of other resources in exchange for the information. The primary information requested is generally video. Any sharing agreement should also address camera control and priority issues, as well as archiving. TxDOT can also be on the receiving end of such agreements, as other agencies, such as cities, can provide video from local traffic signals or arterial surveillance cameras.

THE FUTURE OF EXTERNAL INFORMATION SHARING

To date, most of the information sharing practices among TxDOT TMCs appear to have developed somewhat in isolation of other areas. Although many of the practices and solutions are similar, there have been no formal policies in place to establish similar practices in all districts. Recent research *(13)* may change that approach by establishing consistent agreements and approaches across the state.

Outside of the agreements, establishing the communications necessary to support the external transfer of information (data or video) is a critical task. The mechanisms to accomplish various levels of information sharing are detailed below.

General Public

By and large, the general public gets information from TxDOT TMCs via web sites run by the district. Currently, many districts develop and feed information to a local district web site. Information may include speeds, incidents, camera snapshots, video, travel times, dynamic messages sign information, and more. The state of Texas has recently made moves to consolidate data traffic to a statewide data center. In the future, public Internet access to traffic information will be via this state data center. The assumed model is that districts will run a service within ATMS that feeds information to the statewide data center, such as speed, incidents, and camera snapshots. A statewide "view" known as the Highway Condition Reporting System (HCRS) can be seen at http://www.dot.state.tx.us/GIS/HCRS_main/viewer.htm. The communications impact on TxDOT TMCs is such that general public traffic / bandwidth to local web sites would cease to be necessary, while bandwidth would have to be provided to the statewide data center to supply the traffic information to update the statewide web site.

Media

Media operations require a different level of video for public broadcast than the general public receives on a web site. Media generally requires full-motion broadcast quality video. To date, each of the districts has developed markedly different solutions for this need. In the future, it is likely that the convergence of information technology to TCP/IP will have more of an effect on the ultimate solutions put in place than TxDOT policies. TxDOT policies will support a consistent approach and agreements for information sharing, but are unlikely to spell out a consistent technique for establishing communications to media. That will be left to individual districts to handle on a best-fit-within-their-technology basis.

Information Service Providers

The use of traffic data by ISPs is not expected to stop in the future. It may, in fact, increase as more companies seek to develop services based on a rich stream of available data.

Guidelines may be developed in the future to establish a more consistent approach to sharing this data and, potentially, to charging a fee for access. The access mechanism itself will likely be the public Internet, probably with the use of a dedicated server with appropriate access controls within the district or TMC. If this practice increases significantly, the communications bandwidth that is necessary at the TMC might be impacted.

In some cases, (e.g., Houston TranStar), ISPs are present on the floor of the center itself. Such an arrangement is not thought to have a significant impact on the actual communications necessary to support ISP information sharing, as information must still leave the TMC, regardless of a local or external presence.

Other Agencies

Information sharing from ITS deployments with other agencies is likely to be a significant future growth point for TxDOT. This will be particularly true in a statewide 511 system, since traffic information from across the state must be assembled and fed into other systems. TxDOT has a blueprint for information sharing in place with the C2C infrastructure supported within ATMS. While the concept of C2C providing information to support external uses and applications is certainly valid, it remains to be seen how the system could scale to a statewide level and how well other agencies could interface with the infrastructure. These communication needs could take place through direct links or extensions of the TxDOT network to local agencies, or, more likely, through the public Internet, with appropriate use of security practices to protect the information.

A CONCEPTUAL NETWORK MODEL FOR ITS DEPLOYMENTS

In the original concept for this research, Task 5 was to develop and summarize a methodology for evaluating communication options for ATMS deployments. As the research progressed, it became apparent that industry convergence, support for standards, and the influence of statewide policies and procedures would all have a significant effect towards curtailing the design independence of future deployments.

At the mid-year (April 23, 2007) meeting for the project, Task 5 was re-focus on developing a conceptual layout for future deployments, as well as documenting the various areas of responsibility and interaction within deployments. In essence, the Task 5 information serves as a roadmap to "discover" ATMS, understand the core networking areas of ITS deployments, and understand the interactions of ITS deployments with other areas of TxDOT, other agencies, and external partners.

ITS WITHIN THE TXDOT CORE TECHNOLOGY ARCHITECTURE

TxDOT Information Services Division has stated their core network architecture will deploy TCP/IP as the foundation protocol and Ethernet media as the topology to support TxDOT's information technology needs in districts throughout the state. All state offices are served by the TEXAN2000 network, which delivers 3Mbps to 5Mbps circuits to all divisions and districts. The network shall consist of a standardized switched network infrastructure including routers, firewalls, and switches. ISD is responsible for determining the network equipment on the Wide Area Network (WAN). TxDOT ISD established the base architecture in the Core Technology Architecture document, Version 5.3.1, June 2006 *(2)*. A more detailed discussion of the TxDOT core architecture was presented in the technical memorandum for Task 2 of this project

Figure 7 shows a high level view of the TxDOT information network architecture. Of particular note is the District Office block. Within this block, ISD includes a block named "ITS Site." The ITS Site is a branch off the main district switch behind the district router.

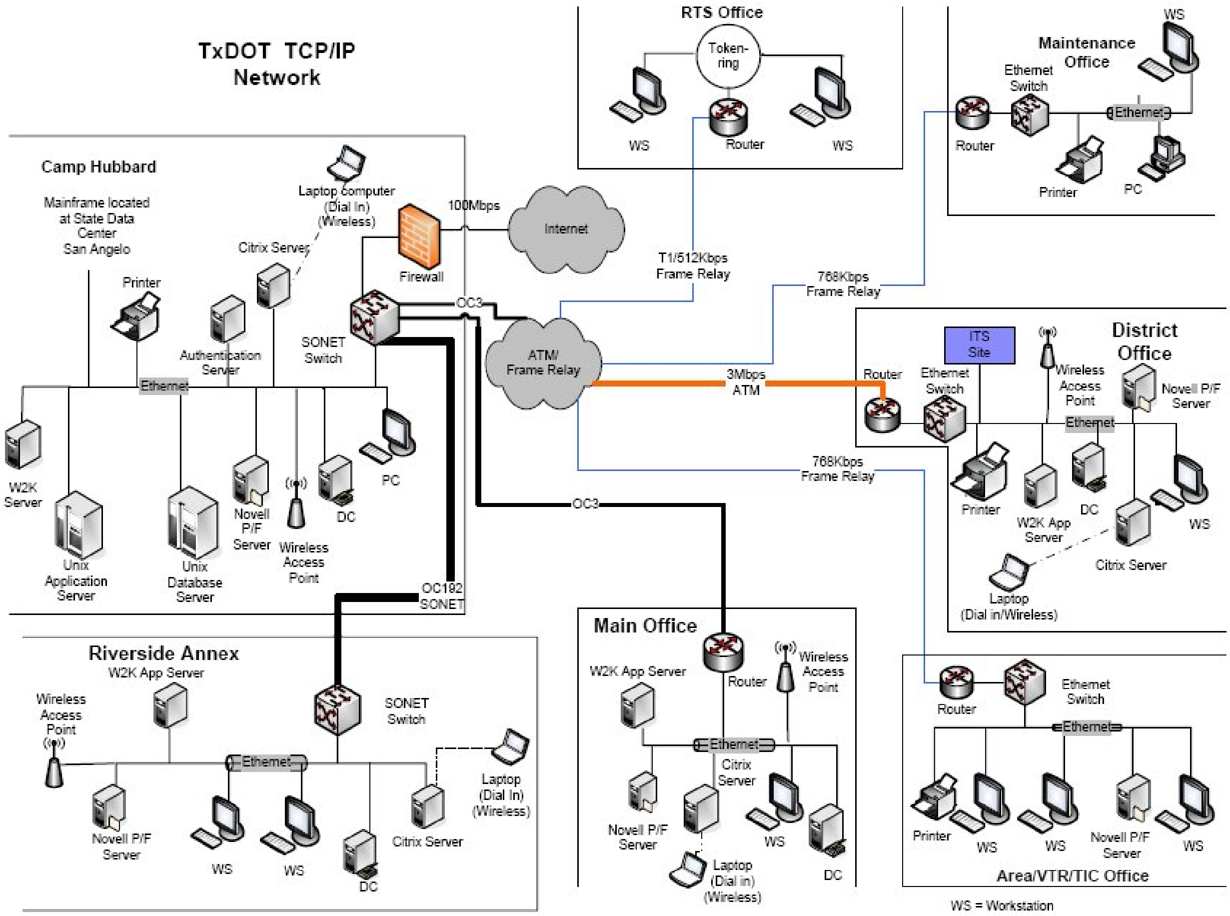

Figure 7. TxDOT Network Architecture (Adapted from Figure 1, Reference 2).

ISD recognizes ITS as an important component of the data network at the district level and has incorporated it into their overall network architecture. However, significant additional detail is necessary to explore what comprises an “ITS Site,” as illustrated in Figure 7.

CONCEPTUAL MODEL FOR ITS DEPLOYMENTS

A conceptual network view of ITS deployments was developed from the results of the ATMS deployment survey, as well as from an understanding of the core technology requirements, future ATMS development, and industry directions and communication needs for external partners. This conceptual model is a view into the ITS deployment at a district level and serves to provide significant detail and explanation from the box labeled “ITS Site” in Figure 7. The conceptual model, shown in Figure 8, illustrates that an ITS deployment is typically made up of several unique networks.

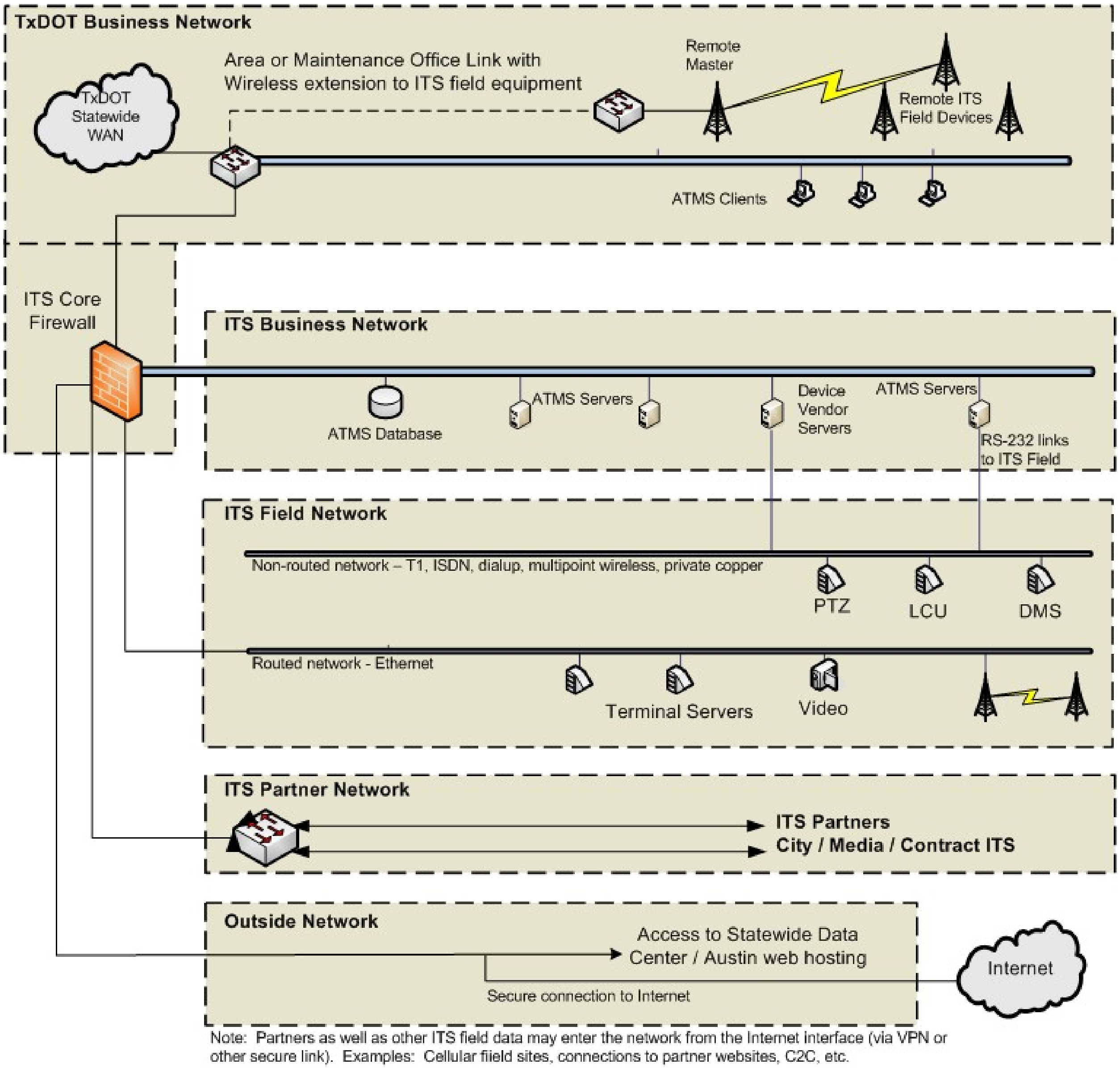

Figure 8. A Conceptual Model for an ITS Deployment Network Architecture.

Figure 8 identifies five different networks, including:

- the TxDOT Business Network,
- the ITS Business Network,
- the ITS Field Network,
- the ITS Partner Network, and
- the Outside Network.

Each network above has a distinct purpose and is an integral link in providing ITS services. Each individual network layer is discussed below, using concepts such as common activities, areas of responsibility, security, etc.

TxDOT Business Network

The topmost network in the diagram is the TxDOT Business Network. This network carries all the day-to-day activities and transactions for the district. In the model, the statewide TEXAN2000 WAN provides connectivity to other districts and organizations inside TxDOT. The WAN link connects to a district router and subsequently to a core district network switch. Links off this core district switch support workstations, printers, and other application servers. Transactions and activities conducted by these servers include email, calendar, task management, scheduling, file transfers, network file storage, access to network applications, and many more. A core firewall provides network links to the ITS networks. ISD is solely responsible for network design, equipment definition (network equipment, as well as servers and workstations), and network support for the TxDOT Business Network. ISD is also responsible for all security aspects of this network.

Currently, ITS deployments are served at this level of the network by ATMS client workstations residing among the other normal TxDOT business workstations on the network. TMC operators use these ATMS workstations to interact with the regional ITS system which lies on the various underlying ITS network components. Operators access processed traffic and situational data from the ATMS system and send commands to operate field devices such as DMS) and CCTV cameras. The ATMS workstations reside on the Business Network to give operators access to the ITS system, as well as critical TxDOT business applications on a single workstation. Example business applications would include email and network file access.

The district business network extends to area offices and maintenance offices. Moving forward, these facilities are envisioned to become network access points for ITS field data. This concept is alluded to in the Core Technology Architecture. As illustrated by the dashed line in the TxDOT Business Network layer in Figure 8, the concept would establish a network extension from the field office to ITS equipment at the roadside. The network extensions might be fiber segments to ITS devices or a private broadband wireless system deployed in the region near the area office.

Early deployments would likely experiment with low bandwidth devices such as DMS signs, snapshot cameras, and/or traffic detectors as the field ITS devices. An obvious concern would be the amount of network traffic generated by the ITS equipment. If significant, this could gravely impact the area or maintenance office business network and WAN link. A case by case analysis would likely be required to insure the ITS equipment would not negatively impact the data network operation at the field office level. Network security would also be a significant concern for a wireless extension of the network and must be addressed. The core technology architecture specifies minimum security requirements for wireless links. Other typical solutions include strict firewall rules or the use of wireless equipment operating in the restricted public safety spectrum (5.9 GHz) *(14)*.

A security aspect of the TxDOT Business Network is the provision of a router to all lower level networks supporting ITS deployments. This router is shown in Figure 8 and labeled as "ITS Core Firewall." The purpose of this router is to pass or isolate traffic between networks based on security rules. As a basic security feature protecting the TxDOT Business Network, this router would typically be specified, installed, configured and operated by ISD. TRF would provide specific requests pertaining to data flows necessary to support ITS deployments.

ITS Business Network

The ITS Business Network is a leg off the TxDOT Business Network and is typically implemented as a network stub off of the core firewall. The ITS Business Network can be viewed as the 'back office' network for the district's ITS system. This network is what would typically be considered the TMC, although the ATMS clients on the TxDOT Business Network are also a part of the TMC.

In general, the ITS Business Network hosts equipment that exchanges raw data with field devices and produces processed data for use by client applications and operators. The network hosts the numerous servers and databases required to manage an ITS deployment. Servers referenced here are typically Windows PCs running custom software created by TRF, the Statewide Integrator, or ITS vendor software. These servers include the ATMS System Server, the ATMS Database, and all the server products in the Statewide ATMS suite (e.g., CCTV server, DMS server, C2C server, ITS data archiving system server/database/system, etc.).

ISD is responsible for defining the hardware requirements of the network devices (Ethernet switches) and the server machines (PCs). TRF and ITS product vendors supply software to run on the servers. TRF and local district ITS staff are responsible for managing the ITS specific software, including installation, setup, configuration, ongoing backup, and maintenance.

ITS Field Network

The ITS Field Network supports direct communication between the TMC and ITS field devices, such as DMS, CCTV, traffic detectors, Highway Advisory Radio (HAR), etc. The physical network begins in the TMC "back office" and extends to all devices installed along the roadway. The network is typically a mixture of several technologies and has evolved over the life of the region's ITS system.

Legacy systems will likely have deployed T1 circuits and dial-up services to reach field devices. These network solutions create many RS-232 point-to-point and multi-drop circuits between the TMC and the field. The network is classified as a non-routed solution and thus does not directly touch any of the other Ethernet networks in the architecture. Legacy technologies do not normally employ TCP/IP protocols and thus are somewhat orphaned from the emerging TxDOT networking standards. Figure 8 shows the connections from legacy technologies as vertical lines crossing both the ITS Business Network and the ITS Field Network without routing traffic through the ITS Core Firewall.

For non-legacy technologies, the ITS Field Network diagram shows a line connecting the network to the core firewall. This link will exist if there is an Ethernet component to the ITS Field Network. This path will be the path that raw sensor data and commands take to pass between the ITS Business Network and the ITS Field Network. ITS server applications may use virtual communication ports to replace the traditional hardware RS-232 port. It is anticipated that Ethernet systems for field data communication will be the direction to go in the future, with ISD offering equipment specifications and/or recommendations, thus ensuring that the field network conforms to statewide networking specifications.

A core function of most TMCs is utilizing video in support of daily operations and incident management. Video, however, presents a challenging network problem. Generated mainly within the ITS Field Network, video consumes large amounts of bandwidth and demands high quality networking resources when transferred digitally. Today, the "last mile" of many video deployments is accomplished via analog transfer between the ITS Field Network and the ITS Business Network. In the future, for many deployments, the video requirements are expected to be a significant driving force behind the ITS Field Network design. Digitally encoded video will likely use TCP/IP as the transport protocol and either Gigabit Ethernet or Asynchronous Transfer Mode (ATM) as the media of choice. Due to the high bandwidth and network resources needed to transport video, it is unlikely video will be spread outside the ITS Field Network, with the exception of the ITS Partner Network discussed below. Live video will likely terminate within the ITS Field Network, with only video snapshots or low bandwidth streaming moving outside the ITS Field Network.

In ITS deployments where significant fiber exists, an alternative to digitally encoded video over TCP/IP is to analog multiplex multiple video (and camera control data) streams onto a single fiber. This solution would pull the high bandwidth video feeds off the switched data network. The advantage of this is that it reduces the network traffic, but it creates an additional network specifically for video that must be managed and maintained.

ITS Partner Network

The ITS Partner Network is a network space where partnering agencies can directly link into the ITS system without using an open public network (Internet). The private network access scheme can enhance security by eliminating many of the risks found on the public Internet (hackers, denial of service attacks, spoofing, etc.) while providing higher network bandwidth than an agency can support to the Internet. Partner agencies can be data providers or consumers to the regional ITS system. The latter is a more prevalent arrangement.

Typical agencies participating on this network might, for example, include police, fire, city traffic management, emergency management, transit agencies, the Department of Public Safety, and the Border Patrol. It is possible that different media outlets, including traffic information services, might also be a part of this network. Partners may be given authority to view ITS video, to move roadway CCTV cameras, to directly receive traffic statistics, or to access ITS historical data. Partner agencies may provide traffic data and statistics, such as toll road information, arterial traffic speeds and travel times, border crossing delays, and traffic incidents and closures on roadways managed by the agency (e.g., city or county), from devices they manage themselves.

Access to ITS video is likely the most common use of the ITS Partner Network. Fiber resources might be extended to a partner agency, such as a local media outlet, to receive broadcast quality video. An Ethernet or ATM solution can be employed for digital video transfer or analog multiplexing for a non-digital solution. This network will only be used for ITS purposes and thus will likely be jointly managed by ISD and the local ITS staff, with ISD responsible for the design and equipment specification.

The proposed national Vehicle-Infrastructure Integration system may be another entity that would enter the TMC over the ITS Partner Network. The VII system creates a national data network between roadside equipment, VII Message Switches, and TMCs. At this time, details of the proposed national network have not been published, but it is clear that the system will require a significant bandwidth link at the TMC level to transmit and receive data from the VII network infrastructure.

Outside Network

The Outside Network comprises links to outside network bandwidth and resources. Examples include Capnet and the public Internet. Capnet is a statewide network with links to all TxDOT facilities, including the state data center(s). Capnet will provide the network link to enterprise class web servers located at state data center(s). The web servers host travel information for public viewing and will likely be the public's interface to district level travel information in the future. Web servers located in large scale data centers will relieve district personnel of web management at the district level and provide a degree of load balancing during times of high web page use. Initially, this concept is being implemented with the transfer of traffic camera snapshots from TMCs around the state. The statewide web page is accessible at: http://www.dot.state.tx.us/travel/traffic_cameras.htm

ITS field sites that utilize a cellular data service would likely be routed into the system via a Virtual Private Network (VPN) established with the cellular provider. An example of this the hurricane evacuation network deployed in 2006 in the Houston and surrounding districts. Remote ITS devices are equipped with a cellular data modem from a single service provider.

The provider then establishes a private network into Houston TranStar, thus providing added security over a normal Internet connection.

The concept of a contract ITS deployment is also underway in the Waco district, where a vendor deployed traditional ITS devices (CCTV, DMS, and traffic detectors) to a section of interstate that is undergoing long term construction. The contractor maintains the field equipment and produces a website for interaction with the ITS system. An integrated solution where the contractor provides the data to a TMC for use in their regional ITS system is an obvious next step. This data flow would likely move to the TMC via a secure Internet connection.

CASE STUDY — EL PASO DISTRICT

The project team undertook a case study to corroborate the conceptual architecture and ensure that a somewhat mature ITS system can be mapped into the network structure put forth in this research. The El Paso district was chosen as the example case because, although their ITS system can be considered mature, it continues to grow and evolve technologically.

The El Paso system includes many of the elements previously discussed. It should be noted that the network model presented above is not a totally rigid, rule-based model. Individual ITS deployments will undoubtedly have some characteristics that do not easily fit into a definition box and are handled using approaches unique to their particular situation.

While there are several unique features in the TxDOT El Paso District ITS architecture, the most important finding is that the case study affirms the conceptual model presented for ITS deployments at the district level. The El Paso district ITS deployment is easily discernible into the five networks in the conceptual model (TxDOT Business Network, ITS Business Network, ITS Field Network, ITS Partner Network and Outside Network). In addition, the deployment follows a significant amount of the core technology architecture requirements from ISD and is well prepared to continue to evolve to support industry trends and partner needs. Each section or network within the ITS deployment in the El Paso District of TxDOT is described below.

EL PASO DISTRICT BUSINESS NETWORK

The TxDOT Business Network carries all the everyday activities and transactions for the district and hosts workstations, printers, and other application servers including ATMS workstations. Figure 9 illustrates El Paso District's Business Network. The network begins with a link from the TEXAN2000 system to the district router. The router connects to the main district core Ethernet switch (Cisco 3550-12G).

Fiber optic broadband links off this switch extend Gigabit Ethernet to area offices, other district switches (automation switches), and a dedicated switch that supports the district's ATMS operator workstations. A leg off the district core switch goes to the core firewall (Cisco PIX 525E). The district business network currently extends to area offices (Alpine, East Area, and West Area). At present, area and maintenance offices do not have network extensions to ITS equipment at the roadside, with the exception being area offices, which have access to CCTV cameras.

The Business Network is defined, designed, and maintained by ISD staff both in Austin and in El Paso. Equipment choice and configuration, both networking infrastructure and server machines, should follow the statewide architecture.

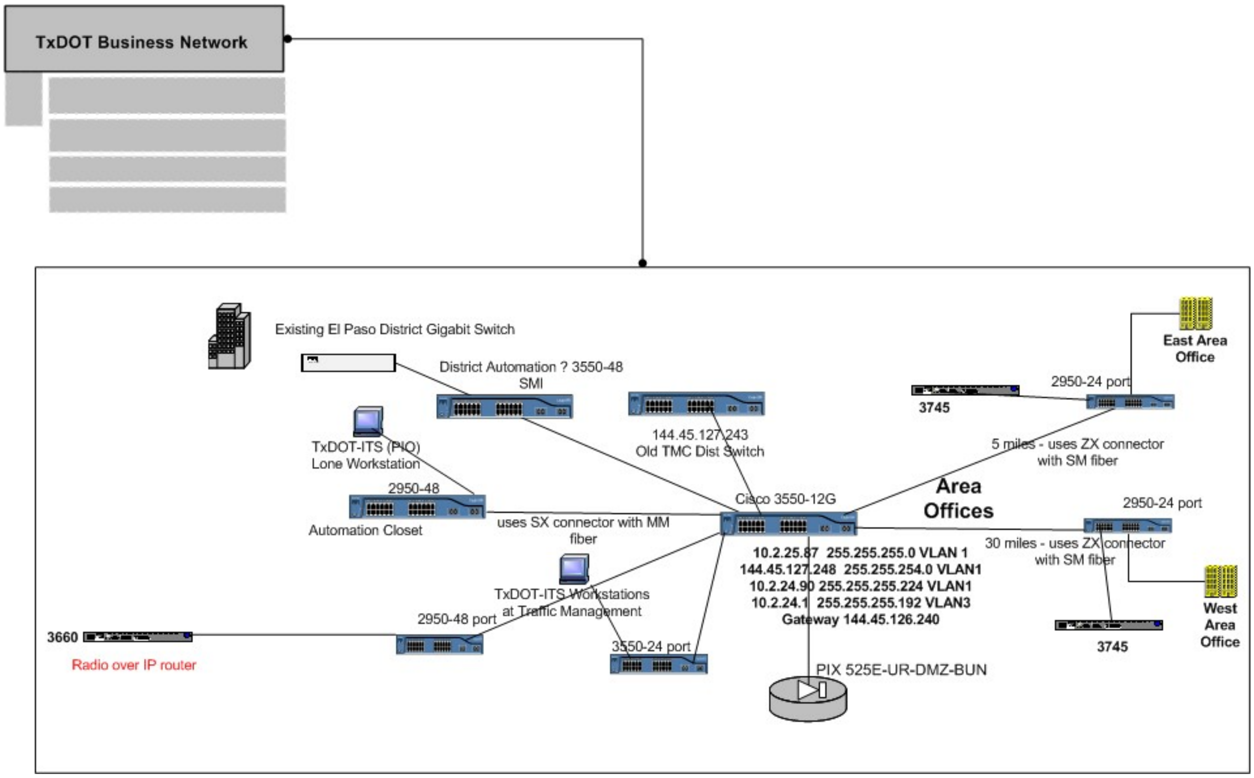

Figure 9. El Paso District Business Network.

EL PASO DISTRICT ITS BUSINESS NETWORK

The ITS Business Network is implemented as a network stub off the district core firewall. A Cisco WS-3550 Ethernet switch is placed on the link from the firewall. The switch supports the district's ITS servers and databases, essentially the heart of the ITS system. El Paso is a user of the TxDOT TRF ATMS software package, and thus a database application, (Elp-its-db), is employed to maintain and manage the ITS system configuration.

The main application server (Elp-its-atms) runs the core ATMS software application. This application receives and sends user commands and data to the ATMS operator workstations in the Business Network, as well as accesses raw ITS system data through its linkage to the ITS Field Network.

Video system management is the purpose for the "Quic and Quest" server. The Digiport Server provides the ATMS system server (Elp-its-atms) multiple RS-232 communication ports to be directly connected to the ITS Field Network. The Digiport Server machine replaces the legacy solution of multiple RS-232 port PC cards installed in the ATMS server.

The HAR server manages El Paso's HAR's, which will be the first ITS field equipment to exchange data over a TCP/IP protocol Ethernet connection for the El Paso district. This data link will be a wireless Ethernet system deployed as an extension of El Paso's extensive fiber T1 network. The El Paso ITS Business Network is shown in Figure 10.

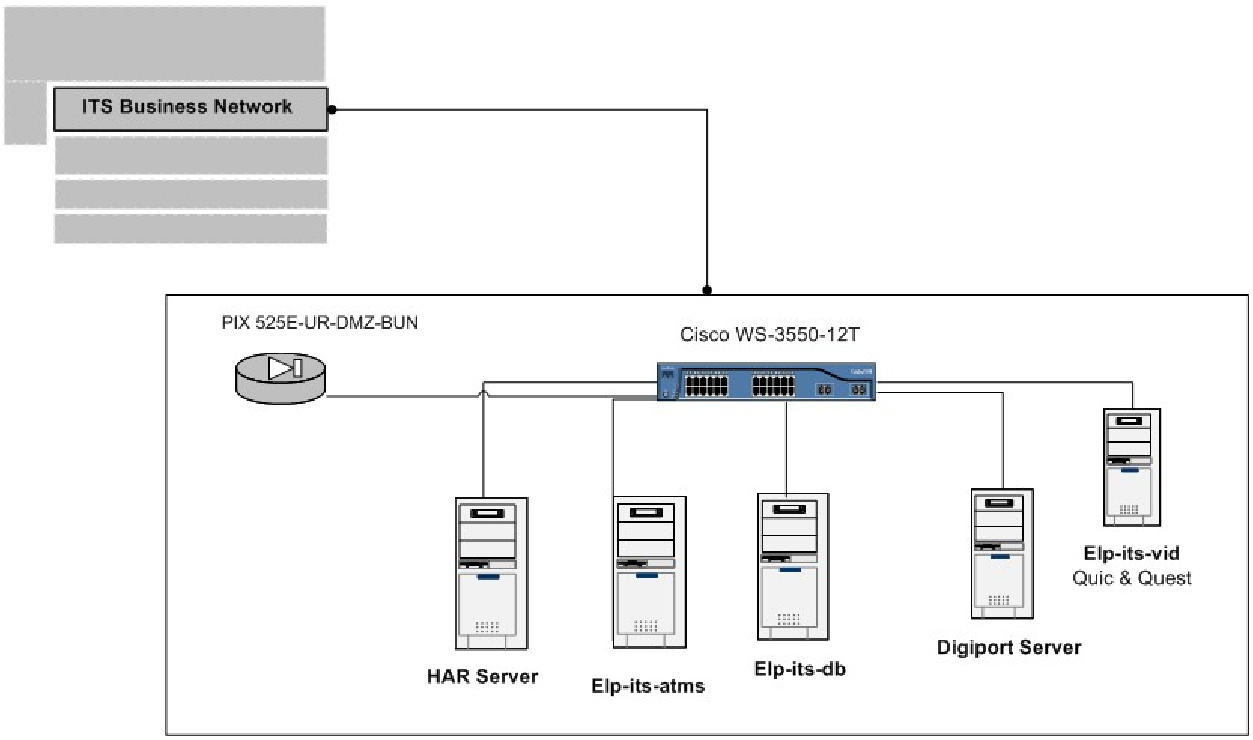

Figure 10. El Paso District ITS Business Network.

EL PASO DISTRICT ITS FIELD NETWORK

The ITS Field Network supports direct communication between TRANSVISTA and ITS field devices, such as DMS, CCTV, vehicle detectors, HAR, LCS, etc. The district has deployed numerous ITS field devices (as shown in Figure 11) and has plans to deploy additional ITS devices in the future. The physical network begins in the TRANSVISTA "back office" and extends to all devices installed along the roadway.

The El Paso Field Network is based on an extensive fiber optic T1 deployment along IH-10 and other state highways in the metropolitan area. The T1 system deploys add/drop multiplexers in hubs located along the fiber run. These multiplexers break out channels of RS-

232 for direct or multi-drop connection to ITS field equipment or for conversion to RS-422 for longer distance runs to field equipment using a Limited Distance Modem (LDM).

The RS-232 channels or circuits are routed back to TRANSVISTA, where they are broken out and fed directly to the Digiport Server. These RS-232 circuits have no interaction with any other piece of the TCP/IP network. These are non-routed communication channels.

El Paso has begun to use TCP/IP and Ethernet for their field network through the use of an emerging fiber and wireless Ethernet network. A secondary fiber Ethernet field network is being established to move TCP/IP traffic from the TMC to field hubs. This network is implemented as a leg off the district core firewall. Wireless Ethernet extends the current fiber infrastructure to ITS devices at the very edge of the ITS Field Network. Currently, HAR is the only ITS device utilizing the Ethernet field network.

The district uses a separate system for transporting video from the field. All digital data is moved using either the fiber T1 system or the emerging wireless Ethernet. Video is transported by analog multiplexing, stacking several camera feeds onto a single fiber at field hub sites. This group video is then sent optically to the TMC, where it is broken back out into individual video feeds for insertion into the analog video switch.

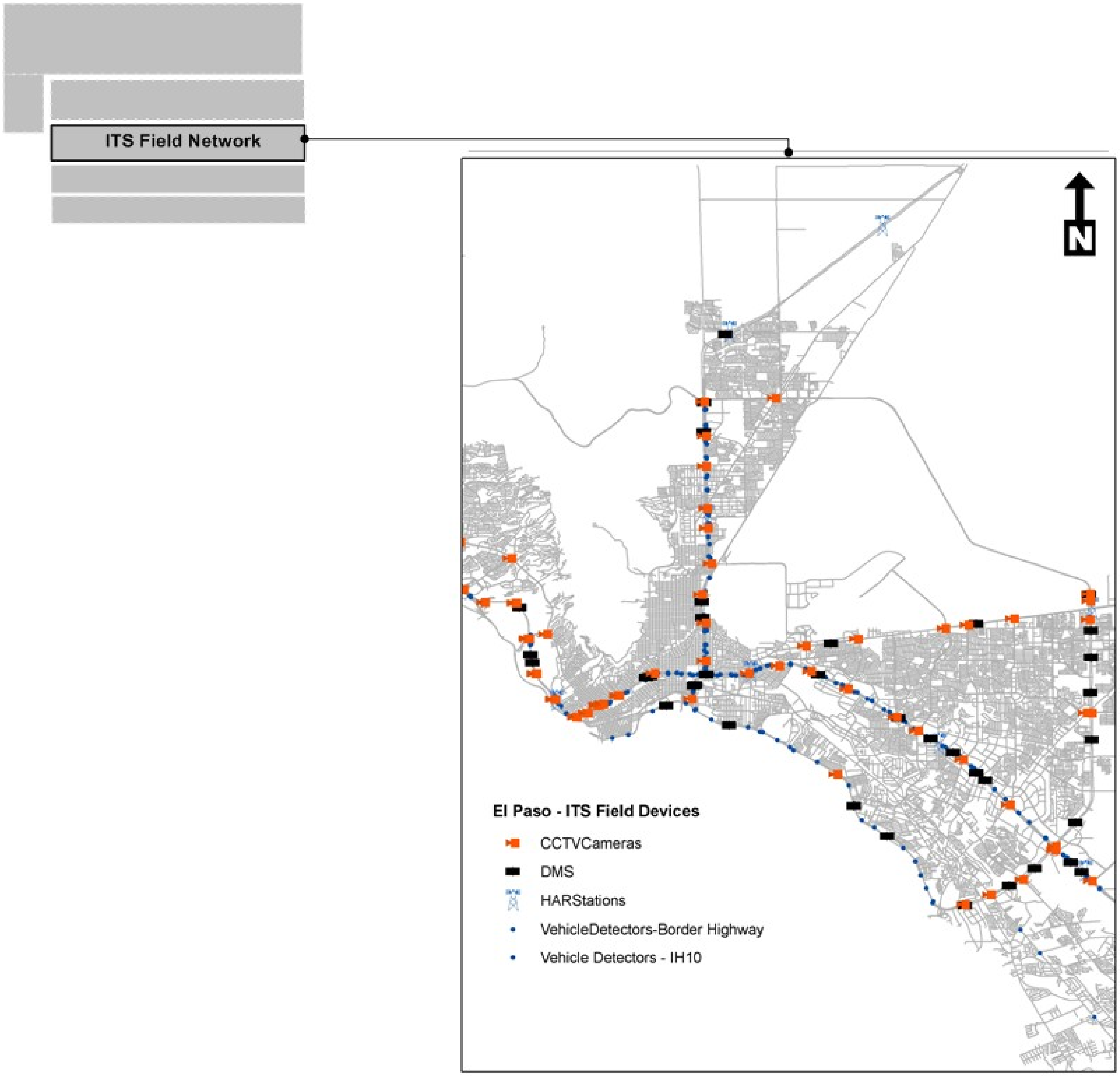

Figure 11. El Paso District ITS Field Network.

EL PASO DISTRICT ITS PARTNER NETWORK

The ITS Partner Network is defined as a network space where partnering agencies can directly link into the ITS system without using an open public network (Internet). El Paso's ITS partners can be categorized into two groups, local government and local media, and Figure 12 shows the breakdown. The partners are:

- the El Paso Police Department,
- the El Paso Fire Department,
- the City of El Paso Traffic Management Center,
- the El Paso Municipal Service, and
- the local broadcast media outlets.

Live video is the shared asset among the partners. Local government entities are granted access to camera control (PTZ) though an ATMS workstation located at their respective facilities. Local media is not granted camera control and can only receive live video. Analog video is delivered on a dedicated fiber, and data access (camera control – ATMS workstation) is delivered on another fiber. TRANSVISTA's ATMS system maintains a set of priorities to manage multiple user access to camera control, with TRANSVISTA operators at the highest level, followed by the El Paso police and fire departments.

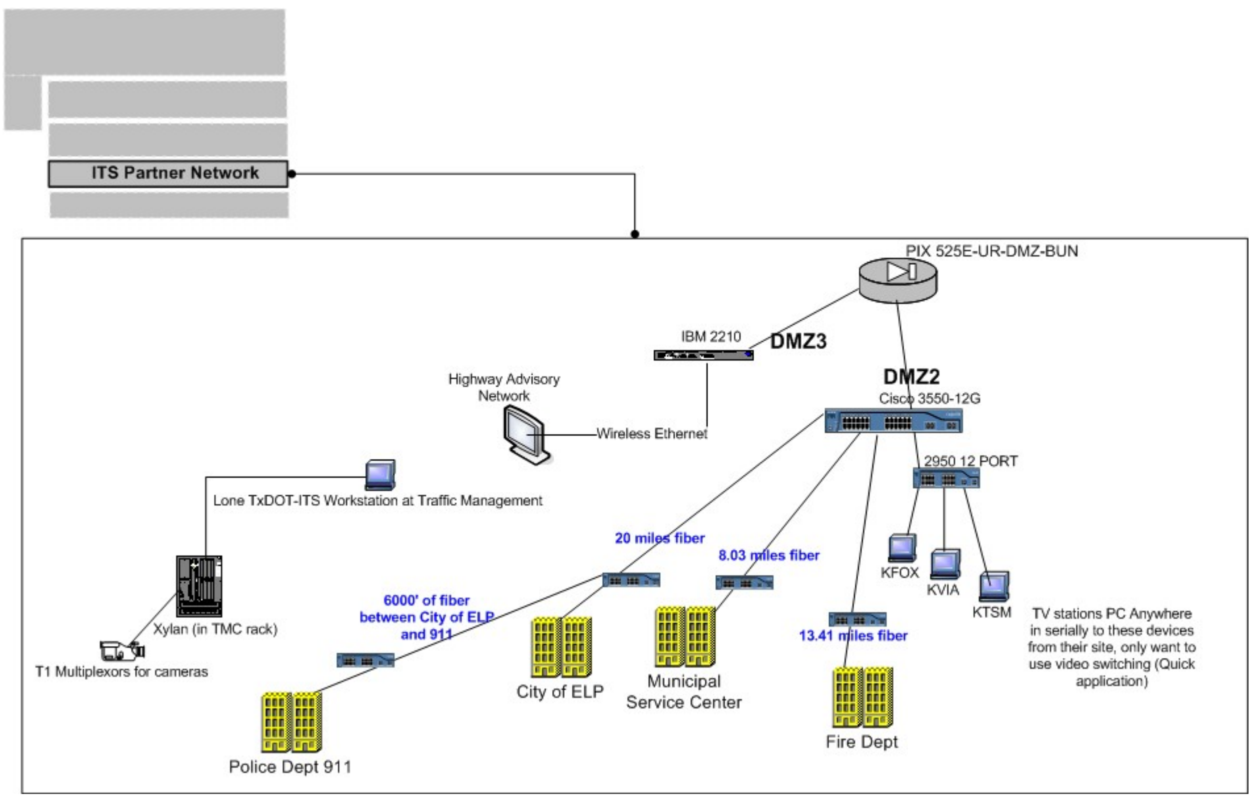

Figure 12. El Paso District ITS Partner Network.

The ITS Partner Network is implemented on a leg off the main district firewall that connects to a broadband Ethernet switch (Cisco 3550-12G). This switch supports fiber Gigabit

Ethernet links to individual partner agencies over a significant distance. For example, the City of El Paso site is a 20 mile run from TRANSVISTA.

EL PASO DISTRICT ITS OUTSIDE NETWORK

Figure 13 shows the outside connection network for the El Paso district ITS deployment. The Outside Network provides El Paso's ITS system with its connection to the Internet. The district uses the Internet to serve up local travel information and camera snapshots to the public. The Internet is also used to access the Public Alert and Incident Notification System at the following site: http://www.ci.el-paso.tx.us/traffic/. The city-maintained web site displays a real-time list of traffic incidents being worked by the El Paso Police Department.

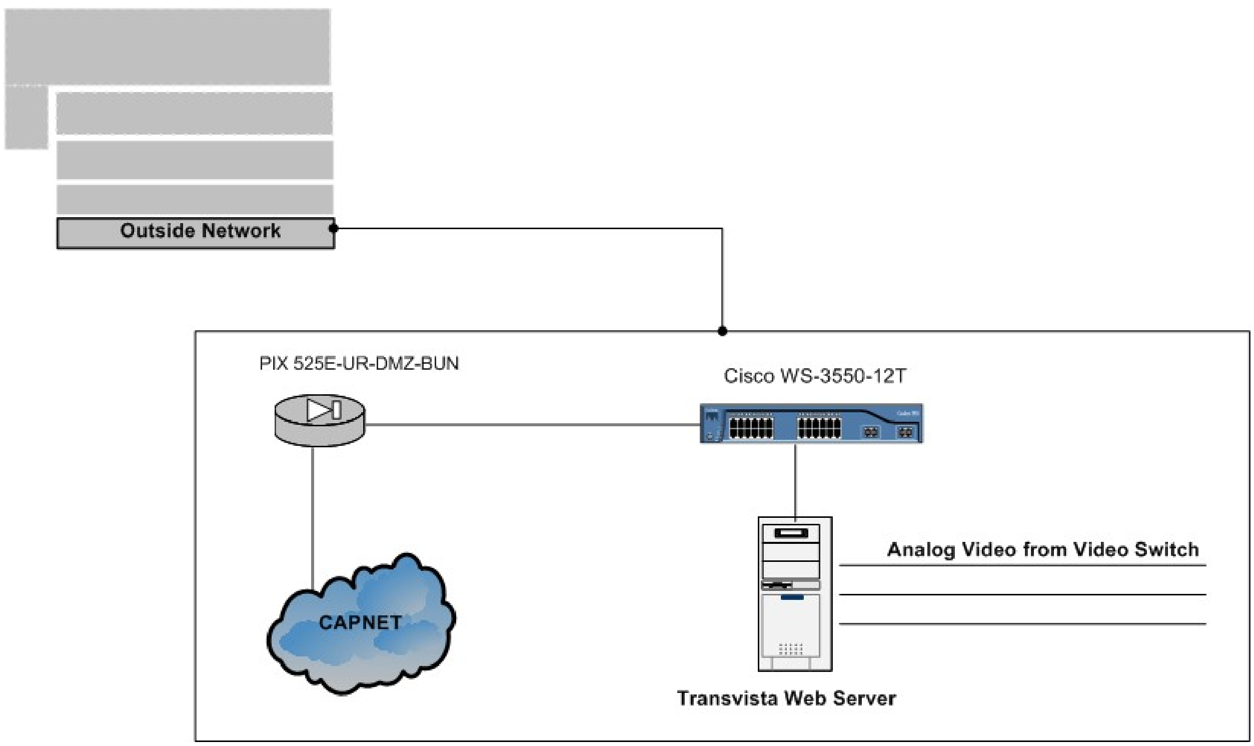

Figure 13. El Paso District Outside Connection Network.

The Outside Network is implemented as a leg off the district core firewall that links to the statewide CapNet and to a small network containing the district's ITS webserver. In the near future, this solution will be migrated to the statewide architecture, where individual district webservers will be mirrored in Austin, with all public content serving being done in Austin instead of individual district installations. At that time, the district's ITS webserver will likely migrate from the Outside Network to the ITS Business Network. It is anticipated that the link to ISD Austin will travel over the TEXAN2000 WAN.

SUMMARY AND CONCLUSIONS

PROJECT REVIEW

Through the traffic operations division (TRF), TxDOT has been deploying ITS solutions for a number of years in various districts across the state. TxDOT has constructed these deployments with a software system known as ATMS. Developed in-house to deliver a core set of services, both the software and the supporting physical infrastructure are legacy systems that are not amenable to expansion, either in terms of additional services, or current technologies and/or products for supplying data from the roadside.

Several years ago, TxDOT recognized the need to update their deployments to systems that are based on standards and open interface solutions. This allows for potentially unlimited expansion to providing other services, as well as supporting standards based information exchanges with partners in ITS deployments. Through the use of a statewide integrator, TxDOT has developed new software platforms to support not only a core set of ITS services, but also to be open to future expansion and addition integration. While the name ATMS remains the same, the current product development represents a sophisticated software offering utilizing network communications and a distributed physical infrastructure. This positions TxDOT well for future ITS deployments across the state.

At the same time that TRF was updating their ATMS platform, significant strides were made in the information technology areas of the agency. TxDOT has developed and published a core technology architecture document that identifies critical standards and networking capabilities supported and used within the TxDOT network. This living document recognizes ITS services as a core component within the network and outlines requirements and responsibilities for ITS deployments.

Another element to consider in the provision of ITS services is the needs and trends external to TxDOT. Overall, the communications industry has embraced Ethernet as the predominant networking topology of choice and has made significant strides in adapting the technology to dozens of new markets, including ITS. Vendors are supplying ITS equipment with Ethernet interfaces, and TxDOT partners want to receive data using the TCP/IP protocol.

However, the missing piece in all of the above is a conceptual plan for how ITS services should be provided in the future, considering all of these developments and the increasing needs to be interoperable with other networks and agencies.

CONCEPTUAL MODEL

Through the use of an extensive review of current deployments, industry trends, external agency needs, the core technology architecture, round-table discussions with TxDOT, and the researcher teams' extensive experience with communication technologies, a conceptual model was developed for future ITS deployments.

Illustrated in Figure 14, the conceptual model presents a hierarchical five-layer network model to provide ITS services, utilizing layers of:

- the TxDOT Business Network,
- the ITS Business Network,
- the ITS Field Network,
- the ITS Partner Network, and
- the Outside Network.

The conceptual model has several features that are worth noting; for instance, the model:

- uses a distributed physical system recognizing the strengths of network communications;
- supports legacy environments in terms of both communications and equipment without compromising security;
- supports the next generation ATMs products that require network connectivity and the TCP/IP protocol;
- fits within the TxDOT Core Technology Architecture;
- recognizes security as a critical issue and segments off various networks as a means of controlling security;
- adapts to future network developments, such as wireless connections to external sites or offices;
- provides a defined pathway for communication to/from external partners, including data providers;

- supports future ITS efforts, such as VII or contracted ITS services; and
- recognizes and provides for the consolidation of ITS information services to the public through the statewide data center.

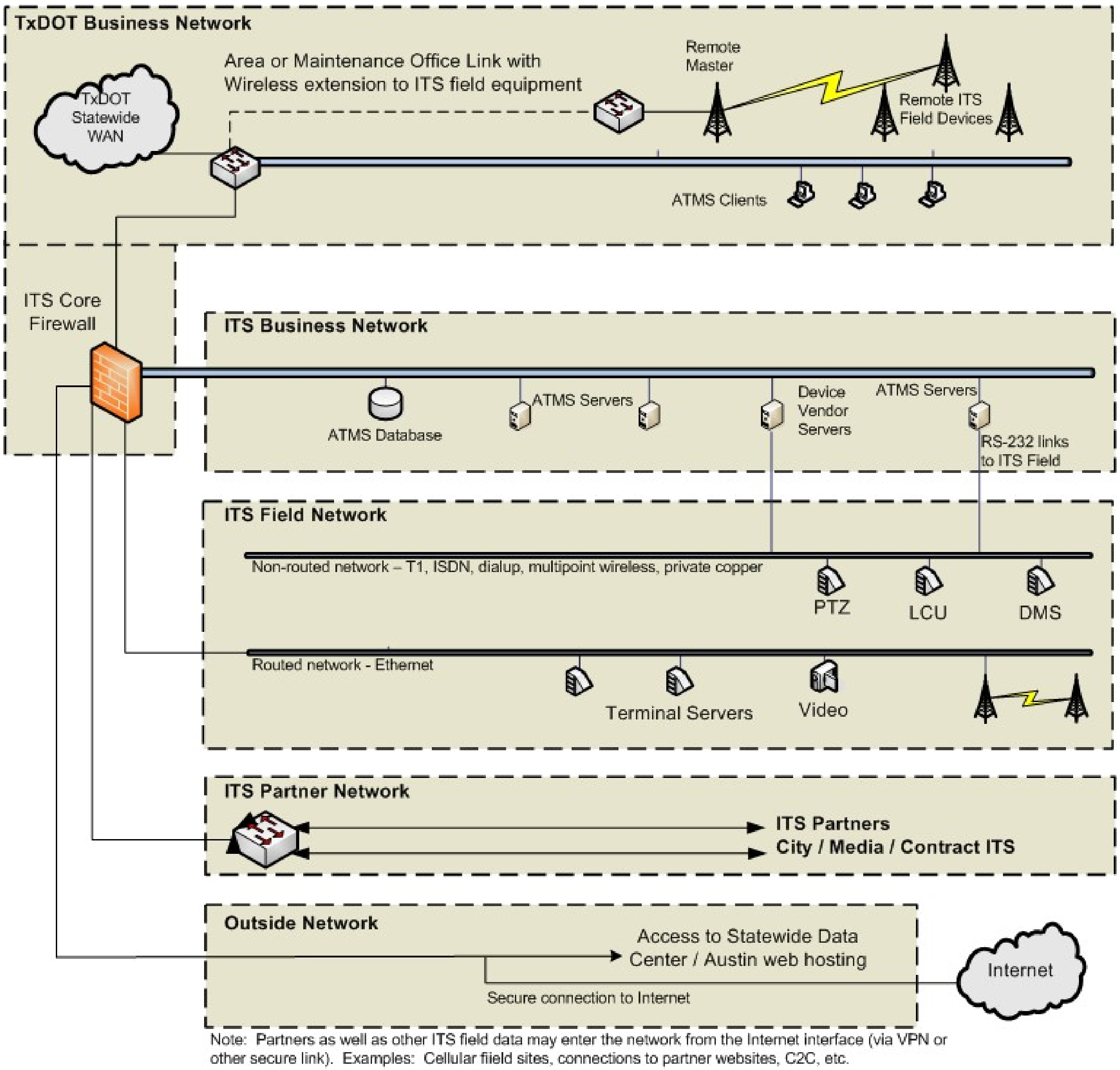

Figure 14. A Conceptual Model for Future ITS Deployments.

The model was examined with respect to areas of responsibility in order to better understand the critical aspects of who is involved at what levels for ITS deployments. Figure 15 overlays the network diagram from Figure 14 with shaded boxes identifying the areas of responsibility.

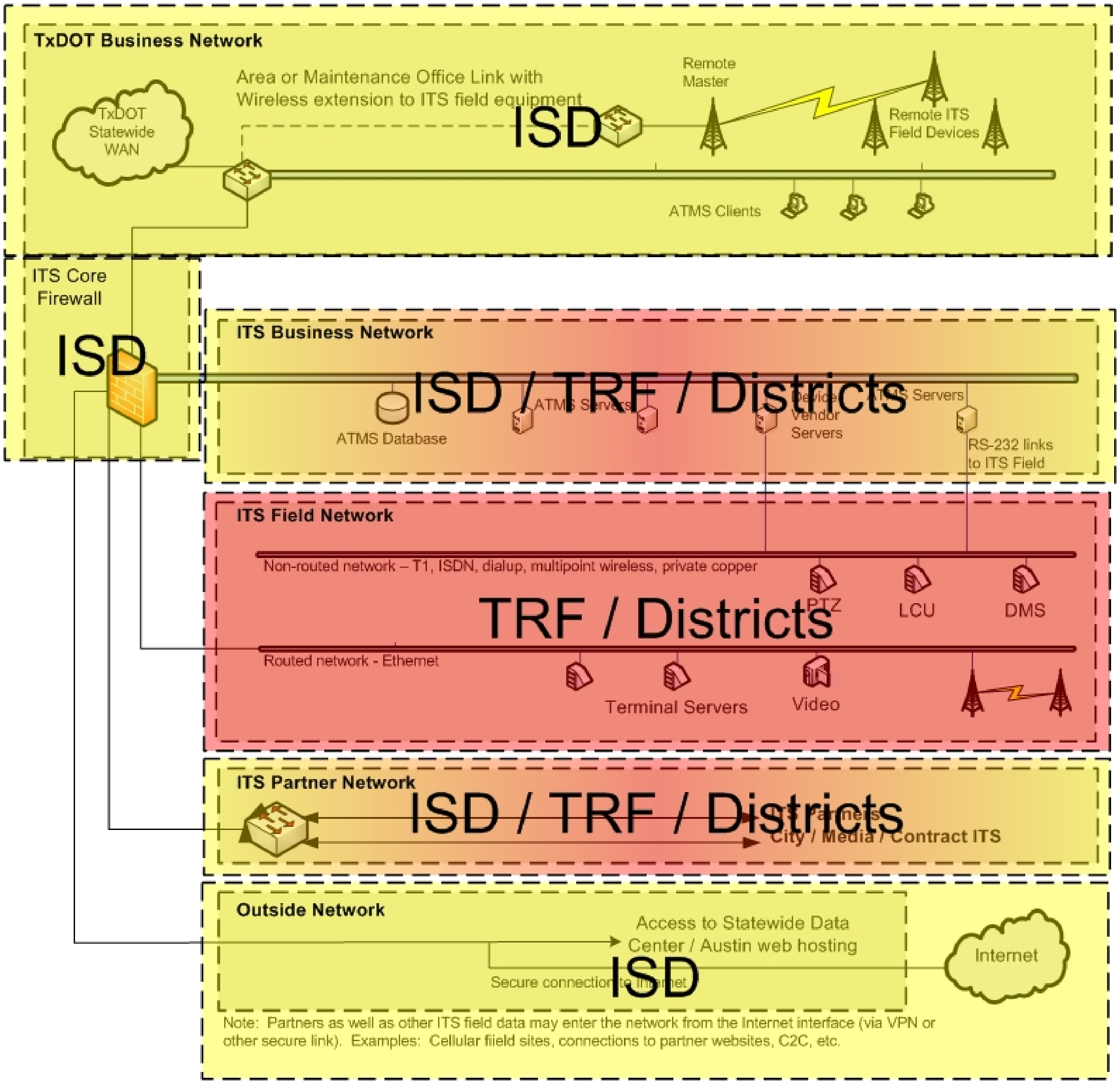

Figure 15. Areas of Responsibility for ITS Deployments.

The areas of responsibility identified in Figure 15 are a global summation of all aspects of responsibility, including equipment specification, configuration, maintenance, and operation. Many of the concerns and one-of-a-kind solutions from previous deployments can be removed or at least minimized by adherence to the core technology architecture and the cooperative design and deployment of ITS service between TRF and ISD.

Finally, Figure 16 provides a brief summary of the essential elements contained within each of the networks discussed in the conceptual model for ITS deployments.

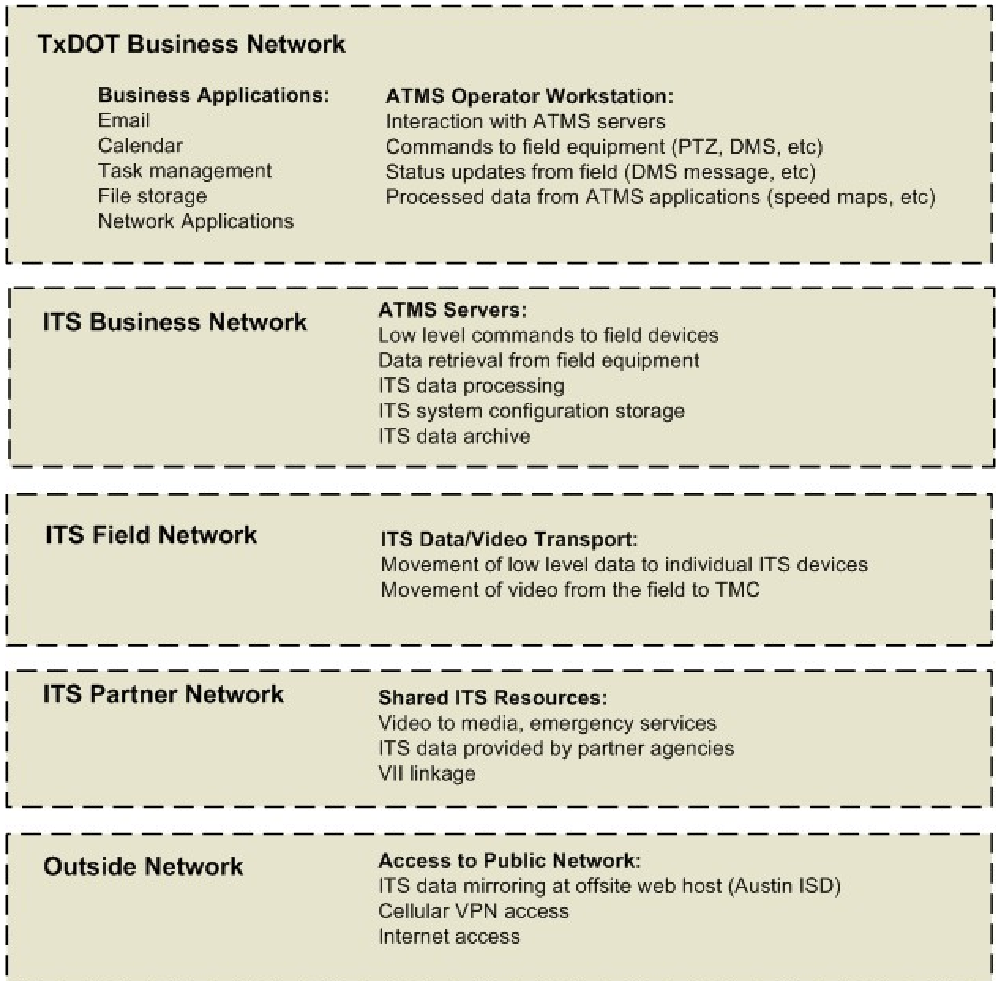

Figure 16. ITS Networks Summary.

APPLICATION OF CONCEPTUAL MODEL TO CASE STUDY

While the TxDOT Core Technology Architecture document recognizes an “ITS Site” as a component of the statewide network, it does not provide additional detail as to how these services should be planned and deployed. The conceptual model for ITS deployments developed in this project was applied to the El Paso district (TRANSVISTA) as a case study. TRANSVISTA was shown to conform nicely to the conceptual network model, although it was not without its own unique properties and implementations, such as how TxDOT extended its network to regional partners.

CONCLUSIONS

The conceptual model developed in this project accomplishes the goals of providing significant detail and guidance to planning future ITS deployments. It adheres to the TxDOT core technology while providing an extensible architecture for future services. It is recommended that this conceptual model be included in the TxDOT Core Technology Architecture as a means of documenting, explaining, and providing for future ITS deployments. There are several steps this process should take.

- Undertake an internal consensus approach to review the ITS conceptual communications architecture developed in this project.
- When complete, incorporate the conceptual architecture into the TxDOT core technology architecture to cover ITS deployments.
- Develop internal training documentation for ITS deployment architectures (districts, new hires, etc)

When this information is included in the Core Technology Architecture, TxDOT districts can map their existing deployments to this model, and use the results as an aid for future migrations or additions

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APPENDIX:

QUESTIONNAIRE ON
EXISTING ATMS DEPLOYMENTS

Project 0-5586
Next Generation Communication Architecture for TxDOT ATMS
COMMUNICATIONS ARCHITECTURE SURVEY

The Texas Transportation Institute (TTI) is conducting a research study for the Texas Department of Transportation (TxDOT) to evaluate existing communications technology deployed by traffic management centers and analyze the future communication options. One of the tasks of the project is to identify communication mechanisms and technology being deployed by TxDOT traffic management centers throughout the state of Texas. Another task of the project is to identify short-term and long-term investments planned by the traffic management centers to enhance their communication. This will assist the researchers to identify new communication technologies that can be implemented in TxDOT ATMs. Hence, your participation to complete the survey is crucial in the overall success of the project. If you have any question regarding the survey, please feel free to contact either Robert Brydia (r-brydia@tamu.edu) or Rajat Rajbhandari (rajat@tamu.edu).

Person completing the survey:

Name:	
Phone:	
Email:	
TMC Name:	

1. Overview of Existing Communication Setup

1.1 Please provide a general overview of the communication setup of your TMC, including network arrangement and coverage.

2. Inventory of Existing Communication Setup

Field Device	Number of devices being used	Type of communication media	Type of communication protocol (e.g., TCP/IP)	Type of communication topology (e.g., P-P)
2.1 Vehicle Sensors		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media	Example: RTMS are connected to nearest camera pole using wireless, and the pole is connected to the nearest hub bldg using fiber.			
2.2 Dynamic Message Sign		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of				

Field Device	Number of devices being used	Type of communication media	Type of communication protocol (e.g., TCP/IP)	Type of communication topology (e.g., P-P)
communication media				
2.3 Lane Control Sign		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				
2.4 Ramp Meters		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				
2.5 PTZ Cameras		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				
2.6 AVI Tag Readers		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				
2.7 Weather Stations	-	☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				
2.8 Traffic Controllers		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				

2.9 HAR		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				
2.10 Barrier Gates		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				
2.11 Pumping Stations		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				
2.12 Other		☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media				

3. Overview of Near-Term (Already Planned) Expansion of Communication Setup

3.1 Do you have a near-term plan for an expansion of communication setup for your TMC? If yes please provide a general overview of the expansion plan.
Example: in process to upgrade the entire network from T1 to SONET

4. Near-Term (Already Planned) Expansion of Communication Setup

Field Device	Additional devices being planned	Will be installed within xx number of years	If different media than above, please specify	If different protocol than above, please specify	If different topology than above, please specify
4.1 Vehicle Sensors			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.2 Dynamic Message Sign			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.3 Lane Control Sign			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.4 Ramp Metering			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.5 PTZ Cameras			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					

4.6 AVI Tag Readers			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.7 Weather Stations			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.8 Traffic Controllers			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.9 Barrier Gates			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.10 HAR			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					
4.11 Other			☐ T1 ☐ ISDN ☐ DSL ☐ DIALUP ☐ WIRELESS ☐ FIBER	☐ RS232 ☐ DSL ☐ TCP/IP ☐ ATM ☐ SONET ☐ ETHERNET	
Description of communication media					

5. Project Planning and Control Information

5.1 Project Planning: Do you have a long-range communication plan for the TMC?

If YES, does it have plans for specific projects?

If YES, please describe the plan:

Reasons for selecting the technology option:

Design factors:

5.2 Project Control:

On what basis do you select vendor/s for supply and installation of communication devices?

Do you often experience conflict between your communication design and vendor's proposal?

If YES, please describe:

If YES, how do you resolve the conflict?

6. Video streams and live feeds of roadway conditions

6.1 Are video streams and live feeds currently used?			YES	NO
6.2 Do you have enough bandwidth?			YES	NO
6.3 Do you monitor bandwidth?			YES	NO
6.4 Do you have bandwidth management tools?			YES	NO
6.5 Are video streams and data being transmitted together over the same communication system?			YES	NO
6.6 Expected to grow within 0-5 years	1-10 cameras	10-20 cameras	20-30 cameras	> 30 cameras
6.7 If expected to grow, how do you plan to accommodate the bandwidth?				
6.8 Expected to grow within 5-10 years	1-10 cameras	10-20 cameras	20-30 cameras	> 30 cameras
6.9 If expected to grow, how do you plan to accommodate the bandwidth?				

7. Existing Connections with External Agencies

External Agency	Existing Connection Medium	Purpose	Type of Control	Data being Transferred

Description of communication setup:

Description of communication setup:

Description of communication setup:

Description of communication setup:

Description of communication setup:

Description of communication setup:

8. Planned Connections with External Agencies

Agency	Planned Connection Medium	Purpose	Type of Control	Data being Transferred

Do you have a connection plan?
If yes, please describe the plan:

Do you have a connection plan?
If yes, please describe the plan:

Do you have a connection plan?
If yes, please describe the plan:

Agency	Planned Connection Medium	Purpose	Type of Control	Data being Transferred
Do you have a connection plan? If yes, please describe the plan:				
Do you have a connection plan? If yes, please describe the plan:				
Do you have a connection plan? If yes, please describe the plan:				
Do you have a connection plan? If yes, please describe the plan:				

9. Lessons Learned and Past Experience

Please describe lessons learned and experiences regarding the following:	
9.1 Maintenance	
9.2 New Installation	
9.3 Cost Concern	
9.4 Reliability	
9.5 In-house Expertise	
9.6 TRF Support	
9.7 Others	