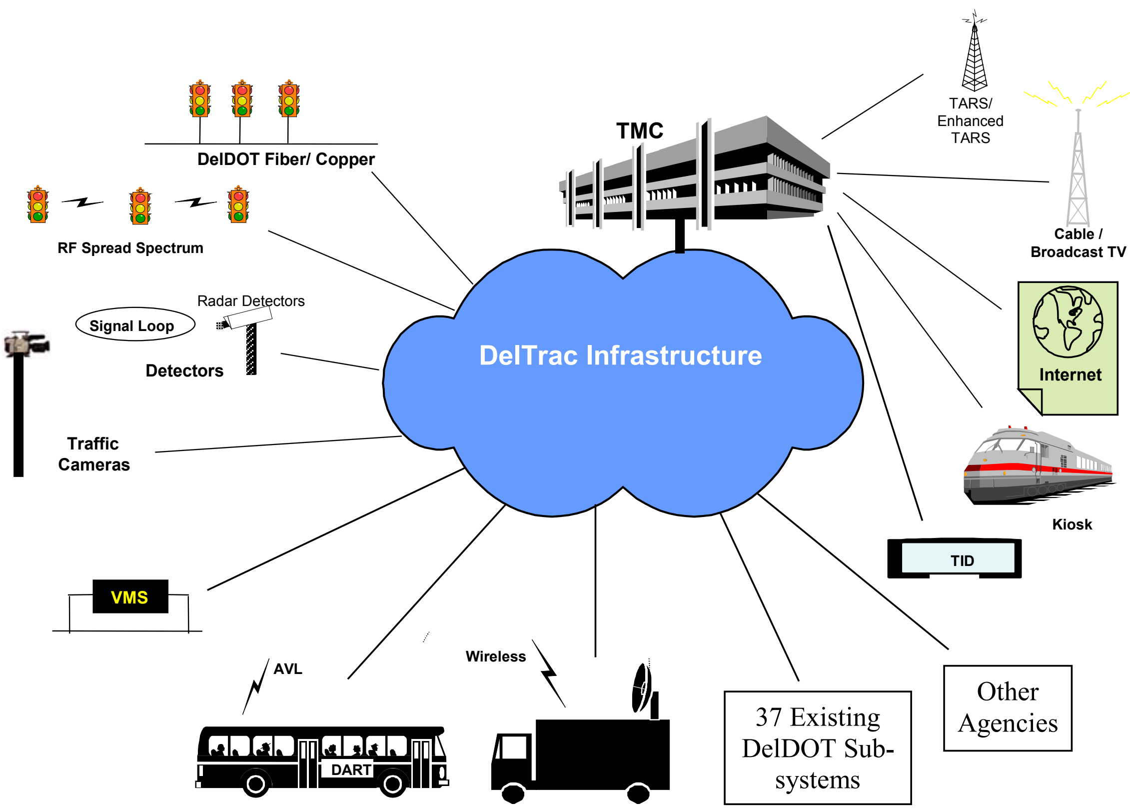
FINAL REPORT

An Evaluation of Delaware's DelTrac Program – Building an Integrated Transportation Management System

June 2004



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Prepared for

U.S. Department of Transportation
Dr. Joseph Peters

Prepared by

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May 2004

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Acronyms and Abbreviations

API	Application Programming Interface
ASN.1	Abstract Syntax Notation One
AVL	Automated Vehicle Location
COM	Component Object Model
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off-the-Shelf
DCOM	Distributed COM
DelDOT	Delaware Department of Transportation
DelTrac	The name used for both DelDOT's ITS program and the Web server application that is intended to establish a common interface for accessing DelDOT ITS applications
DSP	Delaware State Police
DRBA	Delaware River and Bay Authority
DTC	Delaware Transit Corporation
EDEE	Enterprise Data Exchange Engine
EJB	Enterprise Java Beans
GUI	Graphical User Interface
HTML	Hypertext Markup Language
ITMS	Integrated Transportation Management System (now called DelTrac)
ITS	Intelligent Transportation System
JPO	Joint Program Office
J2EE™	Java™ 2 Platform, Enterprise Edition
NESC	National Electric Safety Code
ODBC	Open Database Connectivity
OLE	Object Linking and Embedding
RPC	Remote Procedure Calls
SGML	Special Generalized Markup Language
SQL	Structured Query Language
SOAP	Simple Object Access Protocol
TMC	Traffic Management Center
TMIA	Transportation Management Investment Areas
XML	Extensible Markup Language

Executive Summary

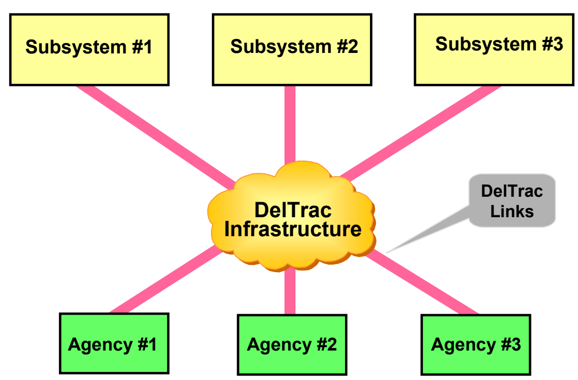
The DelTrac deployment experience included both successes and unmet challenges. Programmatically, the DelTrac approach to managing ITS has been successful at creating a great deal of integration and cooperation between organizations at DelDOT. Stakeholders from across DelDOT have been brought together to help identify opportunities to apply ITS to improve DelDOT operations, and this cooperation with regards to ITS has carried over into other areas. Numerous examples of this increased cooperation are noted throughout this evaluation report, including:

- DTC's purchase of a radio system that was compatible with other organizations within DelDOT.
- Location of the DelDOT TMC at a DEMA facility.
- Sharing data between the DelDOT TMC and the police/fire CAD system.

In these ways, DelTrac has helped bring about considerable organizational integration at DelDOT.

DelTrac has also been successful at deploying a number of ITS technologies. For example, DTC has tested and deployed an automated vehicle location (AVL) system and a bus/rail information system. DelDOT now has an extensive video monitoring system and a new TMC to house operators that monitor this video information and other traffic information. A motorist assistance patrol (MAP) helps respond to traffic events in Delaware, dialing #77 on a cell phone allows callers to report traffic problems, and a CAD/TMC interface shares information between State Police and the TMC. An electronic toll collection system is in place. Traveler information is available via radio, phone, the Web, and kiosks.

On the other hand, the primary focus of this evaluation was on a particular project that was to deploy technology to provide several key elements needed to support technical integration of the various DelTrac subsystems. In particular, this deployment was to provide a data repository that could share and archive DelTrac data and a Web server that could provide a consolidated user interface to the various DelTrac applications. Together, these integration technologies are called the DelTrac Infrastructure in this report, as indicated in the figure at the right. In addition, a new traffic signal control system was being deployed that was to be the test application for the DelTrac Infrastructure. In these regards, DelTrac was not as successful. As of January 2004, neither the traffic signal control system nor the DelTrac data repository and Web interface infrastructure were operational. DelDOT was testing the traffic signal control system and was expecting to receive the DelTrac data repository and Web interface infrastructure after this testing was completed.



This evaluation report documents both the successes of the DelTrac program and the lack of success of the specific ITS project that was to deploy the DelTrac Infrastructure.

The origins of the DelTrac program can be traced to 1997, when DelDOT published a strategic plan that called for the development of an integrated transportation management system in Delaware. This plan identified a number of different individual technologies that should be used to improve transportation management at DelDOT, and also identified the need to integrate these different technologies in order to achieve their full benefits. By 1999, DelDOT had begun projects to deploy many of these technologies and had proposed an approach to integrating these technologies. This integration approach relied on a shared database and messaging system to support interactions between DelTrac applications and a common Web server infrastructure that would support a Web interface to each DelTrac application. One hallmark of the proposed approach was the extensive use of XML to support all DelTrac messaging and data access needs.

In 2000, DelDOT combined ITS Integration Program and other funding to begin developing the DelTrac integration infrastructure. In particular, DelDOT proposed to develop this infrastructure in conjunction with deploying a new traffic signal control system that would be the first DelTrac application to use the integration infrastructure. The proposed project would install a new traffic signal control system and upgrade traffic signal controllers to be compatible with the new system, deploy a DelTrac integration infrastructure, and integrate the new traffic signal control system with the integration infrastructure.

At about the same time, FHWA elected to conduct a case study evaluation of the project in order to meet the following objectives:

- Identify the key technical and institutional steps required to implement and integrate the system
- Document the use of existing technologies to build a seamless transportation management system
- Identify the steps taken to merge freeway, arterial, emergency, and transit management systems together
- Evaluate the integration of legacy systems into a new system
- Describe the use of extensible markup language (XML) to manage and exchange data

Because of the broad scope of some of these objectives, a two-track approach was used in the evaluation. With regards to the first four objectives, the evaluators considered the DelTrac program as a whole. For example, the evaluators considered the key technical and institutional steps required not just to implement the traffic signal control system and the integration infrastructure, but the steps required to create the high level of both technical and organizational integration that are cornerstones of the DelTrac program. With regards to the final objective, the evaluators focused on the specifics of the integration infrastructure that was being deployed. In other words, the evaluators conducted a general review of the entire DelTrac program, which involves both organizational changes within DelDOT and more than twenty planned and existing ITS projects, and a more focused review of one specific project to deploy an infrastructure to merge these different ITS projects into an integrated transportation management system.

On a programmatic level, the evaluators found that DelTrac led to many significant successes for ITS at DelDOT. During interviews, DelTrac management emphasized the importance of creating broad support for DelTrac by integrating ITS into the process of solving Delaware's transportation problems and the benefits of creating organizational as well as technical integration. In this regard, much had been achieved. Representatives from many different DelDOT organizations were involved in the various ITS projects and, through the interactions begun through these ITS projects, these organizations had begun other collaborative efforts.

One interesting example is the relationship between the Delaware Transit Corporation (DTC) and DelTrac. In most states, the level of coordination between transit and other transportation operations is limited, and the same was true in Delaware in the years before DelTrac. DTC reported that the level of coordination began to increase with the purchase of a new transit radio system. The DTC was choosing between a less expensive analog system and a more expensive digital system that would be compatible with the system being used for DelTrac. In the end, both sides compromised with DelTrac management offering funds to offset some of the increased cost. This decision immediately began to pay dividends as transit drivers could report observed traffic problems directly to the transportation management center (TMC) and the TMC could report upcoming traffic problems directly to the transit drivers. This initial success led to increased involvement of DTC in DelDOT's ITS deployment, as well as in other DelDOT operations. For example, DelDOT traffic management and DTC staff regularly meet to plan transportation operations prior to race weekends at Dover International Speedway – a practice that pre-dates DelTrac. As traffic management staff became more aware of the benefits of reliable transit operations in reducing congestion as visitors enter and exit the speedway, the importance of facilitating transit access to the speedway became apparent. This resulted in the construction of a bus-only ramp leading from DE 1 to the speedway that increased the ability of DTC to provide transit services during races. DTC staff suggested that the level of cooperation that led to construction of this ramp did not exist prior to the DelTrac program.

The successes of the DelTrac program led the evaluators to document as lessons learned many of the key features of the program that resulted in these successes. At the same time, the evaluators noted the difficulties that DelDOT encountered in deploying the infrastructure needed to create an integrated transportation management system and documented as lessons learned these difficulties and their causes.

For example, the Evaluation Team felt that the primary reasons for these difficulties were system engineering challenges specific to the DelTrac ITS integration project. A supporting factor was an overly optimistic interpretation of the role of extensible markup language (XML) in facilitating integration. For example, the DelActra technical documentation did not define the interfaces between the DelActra components. Instead, it gave examples of how some of the interfaces could be implemented using XML. The implication seemed to be that the use of XML relieved the designers of the need to clearly define those interfaces. In this sense, the use of XML may have allowed the contractor to take systems engineering shortcuts that might not have been otherwise allowed.

The lessons learned documented in this report are listed in Table ES-1 and are described in more detail in section 9.0 of this report. References to these lessons learned are also called out in the body of the report.

Table ES-1. Summary of Lessons Learned During the DelTrac Evaluation

Lesson Learned	Planning	Design / Engineering	Deployment	Operation / Maintenance
1 – Focus on solving transportation problems, not implementing ITS.	✓	✓		
2 – Include ITS in the long-range plans for the department.	✓			
3 – Try to not do too many things in parallel.		✓	✓	
4 – Plan the program to produce enough wins along the way in order to maintain the momentum of support.		✓		
5 – Be certain to proactively manage personnel issues related to applying ITS technologies.	✓		✓	✓
6 – Avoid proprietary data and closed, proprietary systems.		✓	✓	
7 – Carefully manage the risks of using cutting edge applications.		✓	✓	
8 – XML is not the best approach for all messages.			✓	✓
9 – The design of the message-based interface between subsystems is one of the most important steps in integrating ITS subsystems.		✓	✓	✓
10 – A flexible strategy is necessary to manage potential schedule delays.	✓	✓		

Lesson Learned	Planning	Design / Engineering	Deployment	Operation / Maintenance
11 – The traditional procurement process may not offer the flexibility needed to support ITS procurements.	✓	✓		
12 – The planned budget should account for uncertainties in the design and in the availability of skilled labor.		✓	✓	

On a final note, the evaluators believe that the difficulties encountered in deploying the DelTrac ITS integration project actually serve to highlight the overall strengths of the DelTrac program. From the beginning, the ITS leaders at DelDOT worked to involve stakeholders from throughout DelDOT in the ITS process. The emphasis was not on pushing ITS deployment, but on encouraging DOT employees to help identify how ITS could help solve transportation problems in Delaware. Efforts were also made to secure the support for DelTrac from key DelDOT management and important stakeholders outside of DelDOT.

The difficulties with the project to deploy the DelTrac integration infrastructure, which was expected to be the first project to demonstrate the power of an integrated transportation management system, could have caused DelDOT to question whether integration across DelDOT was feasible, given that integration of a single subsystem was so difficult. However, those with whom the evaluators spoke continued to support the use of ITS at DelDOT. They simply recognized the shortcomings of this deployment, identified how to avoid those shortcomings in the future, and continued to plan for the future of DelTrac.

For example, while the DelTrac traffic signal control integration project failed to demonstrate an integration infrastructure, a separate DelTrac project began to do just that. As part of a project to integrate the State Police dispatch systems with TMC operations, a scaled-back version of a data repository was developed. During final conversations with the evaluators, DelDOT staff were considering whether this system could be used to establish the DelTrac data repository and to begin to integrate DelTrac subsystems. They expect to go online with the DelTrac Data Repository in early 2004.

Perhaps the final word on this evaluation should be simply that the organizational strengths underlying ITS deployment at DelDOT were more than enough to overcome the technical challenges and difficulties they faced in the DelTrac traffic signal control project.

1.0.Introduction and Background

1.1. The Delaware Statewide ITMS Integration Case Study

In 2000, the U.S. Congress earmarked funds for projects that were assessed as supporting the improvements of transportation efficiency, promoting safety, increasing traffic flow, reducing emissions, improving traveler information, enhancing alternative transportation modes, building on existing intelligent transportation systems (ITS), and promoting tourism. A small number of these projects were selected for national evaluation. The Delaware Department of Transportation (DelDOT) Statewide Integrated Transportation Management System (ITMS) Integration project was among the selected projects. (After the ITMS Integration project began, the system was renamed to DelTrac. This name will be used throughout the remainder of this report.)

The DelTrac project was intended to establish one of the cornerstones of DelDOT's ITS program by establishing a data repository for sharing ITS data and a Web server for making ITS functionality available over the Internet. In other words, the purpose of the DelTrac project was to begin the process of integrating DelDOT's ITS applications. Before DelTrac, most DelDOT ITS applications operated as stand-alone systems. For example, the traffic signal control system used traffic signal control loop detectors to provide data to local controllers, which were managed by operators using a traffic signal control application. The goal of the DelTrac project was to integrate ITS applications by (a) providing a data repository that would store data generated by one ITS application that could be shared with other applications and (b) providing a Web-based interface that could be used to access most DelDOT ITS applications. While the DelTrac project would not involve true integration between different ITS applications – only the traffic signal control system would be integrated with the DelTrac data sharing and Web interface infrastructure – it would be a necessary first step towards providing that integration.

The U.S. Department of Transportation (USDOT) ITS Joint Programs Office (JPO) recognized the importance of integrating ITS applications and selected a team led by SAIC to develop and implement a case-study evaluation of DelTrac and the Statewide ITMS Integration project. The Statement of Work for this evaluation noted that:

> *Case study/Lessons Learned studies are to be used as a vehicle to convey unique management strategies, cost allocations, public/private teaming efforts, challenges confronted, and strategies to overcome these challenges. Case Study/Lesson Learned studies should provide qualitative information to others in the ITS arena to help ensure success of their projects. For these projects, it is expected that the contractor will become involved in the project and observe the progression of the project in order to provide information to others responsible for transportation systems.*

This Statement of Work also called out five key objectives for this evaluation. The first step in the evaluation was to identify an evaluation strategy (see the report entitled *Delaware Statewide ITMS Integration – ITS Evaluation Strategy*), which described an approach for fulfilling those objectives. The following paragraphs describe those objectives and approaches.

Identify the key technical and institutional steps required to implement and integrate the system. The Evaluation Strategy called for the use of in-person interviews with follow-up interviews by phone to develop (a) timelines of the steps required to implement and integrate the electronic detection, video monitoring, and traffic signals that were to be part of the deployment and (b) a matrix of institutional responsibilities for the organizations involved in the deployment. As the evaluation proceeded, some changes were required to this approach. First, the planned electronic detection was not implemented, so plans to document this timeline were abandoned. Second, the video monitoring was not innovative, so documenting the steps towards deploying this equipment was not of interest for a national audience. The institutional responsibilities for this specific deployment were also limited, with most of the responsibilities concentrated among those heavily involved in ITS.

On the other hand, the DelTrac program included deployments and deployment plans for a wide variety of ITS technologies. The deployment timelines for the DelTrac program as a whole and the institutional responsibilities for that program might be of interest to a national audience. So, the evaluation documented the key technical and institutional steps required to (a) implement and integrate the traffic signal system, including the related XML-based integration components, and (b) develop and manage the DelTrac program.

Document the use of existing technologies to build a seamless transportation management system. The Evaluation Strategy called for the review of technical documentation and interviews with DelTrac personnel in order to document the system architectures and identify the existing technologies that were used within these architectures. This was done for traffic signal system and the related XML-based integration components.

Describe the use of extensible markup language (XML) to manage and exchange data. The Evaluation Strategy called for identifying how XML messages would be used for DelTrac and providing information about the specific XML messages that were used. In addition, it called for examining the compatibility of these uses with ITS standards, the methods used to ensure security, and tools that were used to facilitate the use of XML. The evaluation succeeded in each of these areas, except for providing information about specific XML messages that were used – the delivery of the DelTrac component that used XML was long delayed and XML messages from a functional DelTrac system were not made available to the evaluators. Review of technical documentation and interviews were used to fulfill these elements of the evaluation.

Identify the steps taken to merge freeway, arterial, emergency, and transit management systems together. The Evaluation Strategy noted that the project that is the basis of this evaluation was to deploy a new traffic signal control system, deploy infrastructure for sharing data and providing a consolidated, Web-based user interface to ITS applications, and integrate the new traffic signal control system with the data sharing and Web-based interface infrastructure. This did not involve a significant merging of freeway, arterial, emergency, and transit management systems. However, other projects were underway at DelDOT that would involve some merging of freeway, arterial, emergency, and transit management systems together. The plans for this element of the evaluation were to use interviews to document lessons learned during these projects about merging freeway, arterial, emergency, and transit management systems together.

Evaluate the integration of legacy systems into a new system. The Evaluation Strategy proposed the use of interviews to (a) identify legacy systems that were integrated into the new system, (b) describe the steps taken by DelDOT to ensure continuity of operations while integrating the legacy system, and (c) identify lessons learned while integrating legacy systems. As it turned out, there was little integration of legacy systems in this project. Legacy traffic signal controllers were upgraded to be compatible with the new traffic signal control system. The remainder of the system (e.g., data sharing and Website interface infrastructure) was new.

In summary, the evaluation focused on DelDOT's use of XML in that project, but also considered other DelTrac projects that were related to this integration. Because this integration was intended to eventually include all ITS subsystems, this included most DelTrac activities that occurred during the period when this evaluation was active, from June 2001 to February 2004. The primary evaluation activities were interviews and reviews of DelDOT technical documentation, as well as review with DelDOT of draft evaluation material produced by the Evaluation Team.

This timeframe constrained the evaluation in two ways. First, the primary purpose of the Statewide ITMS Integration project was to provide the infrastructure to integrate different ITS subsystems, yet the timeframe of the evaluation only covered the initial build of this infrastructure, which was designed to include only one ITS subsystem. This meant that the evaluation only covered the integration of a single subsystem, the traffic signal control system, with the integration infrastructure and did not cover integration between ITS subsystems. Second, deployment difficulties with the Statewide ITMS Integration project led to delays in deployment of the DelTrac integration infrastructure such that, at the time of this report, this infrastructure had not yet been deployed. Thus, the evaluation focuses less on how DelDOT used XML for ITS integration and more on how DelDOT planned to use XML and how those plans evolved.

In the end, this evaluation focused on two different levels with regards to ITS activities at DelDOT, with markedly different results for each. At one level, DelTrac has resulted in considerable programmatic success and has created a great deal of integration and cooperation between organizations at DelDOT. Stakeholders from across DelDOT have been brought together to help identify opportunities to apply ITS to improve DelDOT operations, a number of different ITS projects have been successfully deployed, and the cooperation brought about in deploying ITS has carried over into other areas.

On the other hand, the primary focus of this evaluation was on the Statewide ITMS Integration project. This project was to provide a data repository that could share and archive DelTrac data and a Web server that could provide a consolidated user interface to the various DelTrac applications. This project was also to deploy a new traffic signal control system that would be the first DelTrac subsystem to integrate with the data repository and DelTrac Web server. In these regards, DelTrac was not as successful – as of December 2003, neither the traffic signal control system nor the DelTrac data repository and Web interface infrastructure were operational. DelDOT was testing the traffic signal control system and was expecting delivery of the other two components after this testing was complete.

Thus, this evaluation noted both the successes of the DelTrac program and the difficulties encountered in deploying technology to integrate the different DelTrac ITS projects into an integrated transportation management system. This draft report documents the results of this evaluation.

1.2. An Overview of Delaware and the Delaware Transportation System

Delaware is a small state, consisting of three counties covering less than 2,000 square miles and with a population of nearly 800,000 people. Despite its small size, Delaware exhibited considerable geographic diversity, with much of the State having rural characteristics and most of the population living in urban areas. Delaware also exhibits considerable diversity in its extensive and multi-modal transportation network, which includes highways, arterials, bus, rail, airports, seaports, and pedestrian and bicycle facilities.

At the time of the evaluation, the Delaware transportation system was also experiencing many of the problems that are being faced by other transportation systems across the country. Transportation demand in Delaware was increasing:

- The population increased by 17 percent from 1990 to 2000 (a rate of 37 percent per twenty years).
- The number of vehicle miles traveled on Delaware roads increased by 93 percent from 1978 to 1999 (a rate of 87 percent per twenty years).
- The number of motor vehicle registrations increased by 22 percent from 1985 to 1995 (a rate of 44 percent per twenty years).
- The number of vehicle per household increased from 1.79 to 2.24 since 1970.

Commercial transportation was showing similar increases in Delaware, with the number of licensed commercial drivers increasing by 12 percent from 1996 to 2000 (a rate of 79 percent per twenty years).

While transportation demand was increasing rapidly, the supply of transportation facilities was increasing much more slowly: the number of centerline miles increased by only 7 percent from 1980 to 1994 (a rate of 10 percent per 20 years). While part of this increased demand might be met by Delaware's transit system – transit ridership increased by 25 percent between 1994 and 1997 – transit was meeting only a small fraction of the total transportation demand and much of the public transit system remained underutilized.

Delaware had noted that increased congestion would inevitably result from their transportation demand increasing faster than the available supply – unless steps were taken to better utilize the transportation infrastructure that already existed. This situation closely paralleled the situation in other parts of the country. Thus, the complexities and problems exhibited by the extensive, multi-modal transportation systems in other states were also present in Delaware, and the lessons learned in implementing ITS technologies to better utilize the Delaware transportation system promised to have wide applicable in other parts of the country.

1.3. An Overview of DelDOT

Although the Delaware transportation system as a whole mirrored that in many other parts of the country, a fundamental difference existed between transportation management in Delaware and in many other states – in Delaware, DelDOT managed most transportation facilities in the State. The facilities managed by DelDOT include:

- About 4,000 miles of public roads, including interstate highways, residential streets, and dirt roads that account for 88 percent of the total lane miles in the State
- About 1,300 bridges, including historic bridges, draw bridges, and modern interstate bridges and overpasses that account for 93 percent of the bridges in the State
- A comprehensive transit system – operated by the Delaware Transit Corporation (DTC) – which operates local bus, express bus, inter-county bus, paratransit, subsidized taxi, and passenger rail services and provides more than 50 park-and-ride locations
- Air transportation facilities – operated by the Delaware River and Bay Authority (DRBA) – including the New Castle Airport, the Delaware Airpark, and others
- Ferry facilities – also operated by DRBA – including the Cape May-Lewes Ferry system, and the Three Forts Ferry Crossing

Since the management of Delaware's transportation facilities is more consolidated than in many other states, fewer institutional challenges were expected towards developing an integrated transportation management system.

1.4. An Overview of DelTrac

Within DelDOT, the term "DelTrac" officially referred to the entire ITS program for the State of Delaware. However, this term was often used to refer specifically to the data repository and the Web-based application that provided access to the ITS data that was shared between different ITS subsystems. There was a good reason for this mixed usage – programmatically, DelTrac was all about integration.

On the organizational level, this meant integrating across organizations so that each organization within DelDOT was better aware of the activities in other organizations and the benefits that might occur from closer cooperation. For example, the traffic engineering organization learned that fixed route bus drivers, who navigated many important roads as frequently as once every 4 or 5 minutes, could provide important first-hand information of incidents that occur. The transit organization began to use real-time traffic information from the Transportation Management Center (TMC) to aid them in more quickly rerouting vehicles to avoid congestion. When the DelDOT traffic management organizations discovered the large number of people that transit was moving to and from the Dover International Speedway during events and recognized the resulting reductions in congestion, they worked with transit on ways to help facilitate speedway transit operations. One result was the construction of a bus-only lane to directly serve the Dover International Speedway. This bus-only lane proved an effective means to move a large number of people to and from the events within a short period of time, and significantly reduced congestion in the area during race events.

On a technical level, DelTrac integration meant that systems were designed with their potential interactions with other DelTrac systems in mind. For example, the possibility of providing traffic flow information to other DelTrac subsystems was considered when designing the Traffic Signal Control System. Similarly, the wireless communication system was designed to simultaneously support the data and voice needs of transit vehicles, maintenance vehicles, remote devices for which landline communication was not feasible, and other DelDOT communication needs.

DelDOT also recognized that a key technical element needed to establish integration was a central infrastructure to facilitate interactions between different ITS applications. The central infrastructure being developed for DelTrac includes a central repository for DelTrac data, a central messaging service for managing communication between DelTrac subsystems, and a common Web-based application for accessing the shared data. These elements, depicted in Figure 1–1, help simplify interactions between the subsystems and agencies that rely on transportation data.

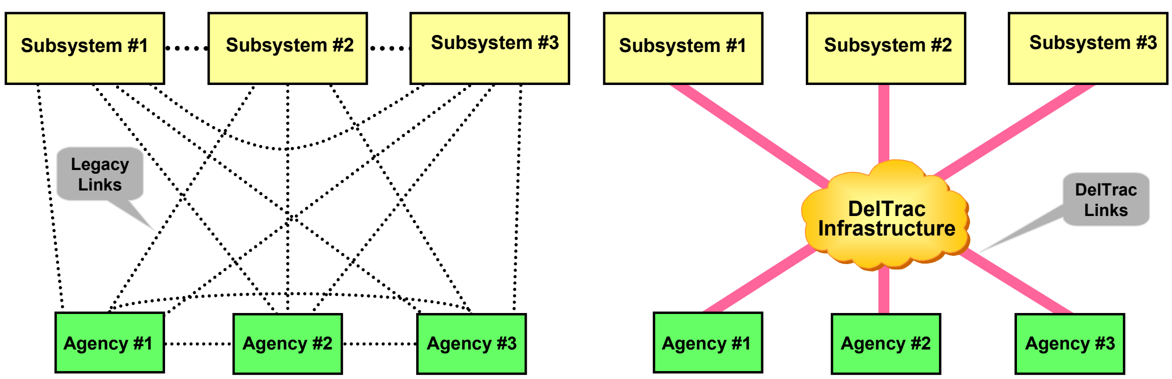


Figure 1–1. The DelTrac Infrastructure

As with organizational interactions, facilitating technical integration can yield new benefits. For example, DelDOT planned for traffic flow information collected by the Traffic Signal Control subsystem to be available to supplement other sources of real-time traffic information. Traffic information gathered to help TMC operators respond to traffic events was to be available to the traveler information systems. The Traffic Signal Control subsystem, designed to facilitate adjustments to signal timings based on current and projected traffic conditions, might be used to help deploy a Transit Priority Treatment subsystem. One goal of the DelTrac Program was to leverage such "induced" benefits in its technical integration effort.

1.5. An Overview of This Evaluation

This evaluation focused on the five key objectives listed in Section 1.1 and the application of these objectives to DelTrac. However, as described in Section 1.4, the term "DelTrac" can mean different things in different circumstances. It was recognized that one of the challenges in conducting this evaluation (and in reading this report) was to understand the appropriate part of the DelDOT ITS program to which each objective applied. Because the genesis of this evaluation was to establish an understanding of how XML was used to facilitate data sharing within DelTrac, the focus of much of the evaluation was on the DelTrac Data Repository, the part of DelTrac that provided that service. In addition to the Data Repository, the evaluation also focused on two other DelTrac subsystems:

- The Traffic Signal Control subsystem, which was to be the first DelTrac subsystem providing data to the Data Repository,

- The DelTrac Web Server, which was to be the first DelTrac subsystem using data from the repository.

The areas of focus for each of the five objectives is summarized in the following list:

- *Identify the key technical and institutional steps required to implement and integrate the system*. For the technical steps, the focus was on the DelTrac Data Repository and, because it was to be the first subsystem to integrate with this repository, the Traffic Signal Control subsystem. For institutional steps, the focus was on the DelTrac program as a whole, which required an understanding of the interactions among all the agencies responsible for DelTrac.
- *Document the use of existing technologies to build a seamless transportation management system*. The focus was on the repository and the Traffic Signal Control subsystem and best practices associated with technology planning and implementation.
- *Describe the use of XML to manage and exchange data*. The focus was on the data repository, the DelTrac Web server, and the Traffic Signal Control subsystem.
- *Identify the steps taken to merge freeway, arterial, emergency, and transit management systems together*. The focus was on the DelTrac program as a whole. With the exception of the Traffic Signal Control System, little technical integration had occurred between the freeway, arterial, emergency, and transit management systems at the time of the evaluation. Organizational and planning steps had been taken to prepare for enhanced integration in the future.
- *Evaluate the integration of legacy systems into a new system*. At the time of the evaluation, there was little integration of legacy systems in the DelTrac system. Most systems were not significantly integrated with other DelTrac Systems. The legacy systems that were integrated were first upgraded to be compatible with the DelTrac Architecture. Therefore, the evaluation will focus on how the design of the DelTrac Data Repository can support the integration of legacy systems rather than on how legacy systems have been integrated.

1.6. An Overview of This Evaluation Report

This report covers a broad mix of material ranging from very technical (how XML was used to exchange information in DelTrac) to non-technical (how institutional issues were addressed in DelTrac) and from very specific (a focus on the DelTrac Traffic Signal Control system) to very general (a review of DelDOT's entire ITS program). The authors recognize that different readers of this report will have different levels of interest in the technical and non-technical and the specific and general sections of this report and have sectioned the report accordingly, as described below:

- Section 1.0 of this report (this section) gives a high-level overview of DelTrac and this evaluation, and is the starting point for this document.

- Section 2.0 gives a more detailed description of DelDOT and the DelTrac program, which encompasses all ITS projects at DelDOT. This section is intended for those readers interested in understanding how DelDOT was managing their ITS program. This section also lays the groundwork for understanding some of the broad integration and organizational issues at DelDOT.

- Section 3.0 summarizes the DelTrac deployment experience, listing some of the key events that occurred during the deployment and lessons learned from those events.
- Section 4.0 describes the key steps required to implement DelTrac, beginning with the steps used to establish DelDOT's ITS program as a whole, and then focusing on the steps specific to the DelTrac application that uses XML to exchange data.
- Section 5.0 describes how DelDOT leveraged existing technologies in their approach to DelTrac.
- Section 6.0 is more technical and describes the details of how XML was used in DelTrac to manage and exchange data. However, detailed technical information has been placed in Appendix A.
- Section 7.0 describes the merging of freeway, arterial, emergency, and transit management systems together at DelDOT.
- Section 8.0 discusses the approach used within DelTrac to address the integration of legacy systems.
- Section 9.0 summarizes the results of this evaluation, including listing the lessons learned noted throughout the report.

This report includes an appendix that provides technical details regarding the DelTrac architecture and how XML was used in DelTrac that may not be of interest to all readers.

The report also uses a technique for documenting the lessons learned that is meant to improve readability of this report. Lessons learned during the evaluation will be called out in the narrative of the report. However, some of the lessons learned require long, tangential discussions to appropriately describe them, and these discussions would tend to break the narrative of the report. Therefore, the authors have moved the detailed description of each lesson learned into section 9.0, leaving only a reference to that description in the narrative. A secondary benefit of this approach is that the descriptions in section 9.0 serve as a stand-alone description of each lesson learned that can easily be extracted and passed on to others.

2.0. DelTrac

2.1. The History of DelTrac

Before DelTrac, the deployment of ITS in Delaware and the types of integration that are part of DelTrac were limited. While there were good working relationships between organizations within DelDOT, the day-to-day interactions between these organizations were typically weak, with each organization within DelDOT operating more-or-less autonomously. Before 1997, there was no integrated communication infrastructure for DelDOT, and the infrastructure that did exist consisted primarily of leased connections between facilities and copper-wire and modem connections to some field devices. The transit organization had an existing wireless system for voice communication. A statewide TMC was in a temporary location in Wrangle Hill. The traffic signal control system that operated from this TMC had limited traffic monitoring capability and was not used for real-time control. There were no other significant control systems in place. Video traffic monitoring was performed with two or three cameras that used dial-up communication. There was little access to other real-time traffic information, and there was no system in place to distribute real-time traffic information.

This situation began to change in December 1997 when DelTrac (then called the Delaware Integrated Transportation Management System or ITMS) was introduced with the publication of the *Delaware Integrated Transportation Management Strategic Plan*. This document defined the technical vision for DelTrac. This document also suggested several technologies for DelDOT to consider when implementing DelTrac. Further, the document pointed out the need for organizational development to support integrated decision-making within DelDOT and to perform outreach to help ensure continued support from local and regional partners, the public, public officials, and other stakeholders. These three themes – integration technology, integrated organization, and outreach – were to become the pillars of DelTrac development.

According to the Strategic Plan, the DelTrac Program is intended to provide the infrastructure that enables all transportation modes to function together to effectively move people and goods. The heart of the planned infrastructure was a set of integrated ITS elements to provide for statewide transportation system management, control, monitoring, and information. The goals and visions for DelTrac included four strategies to guide implementation of the system as follows:

- Create the necessary infrastructure to support transportation management
- Disseminate real-time, accurate information and allow customers to make informed decisions regarding travel route, travel time and mode choice
- Develop partnerships to support transportation management
- Develop internal capacity to support transportation management

In accordance with the above strategies, the following four goal areas were identified for the DelTrac program:

- Improve the performance and safety of transportation system
- Reduce traffic congestion and delay
- Increase the operational efficiency and capacity of the transportation system
- Reducing operating costs by improving the efficiency of planning, operations, and maintenance

DelTrac implementation began in 1998. The program used ITS technologies to integrate systems for all modes of transportation throughout the State and, more importantly, it brought about an organizational integration. In this organizational integration, DOT-wide needs were considered in selecting, designing, and implementing all ITS projects. DelTrac not only impacted technical implementations across the State and across all modes of transportation, but also organizational interactions across the department.

In 1998, Mr. Gene Donaldson was hired as the DelDOT ITS Administrator to help manage the DelTrac program described in the strategic plan. The initial steps in the ITS Program addressed the organizational development within DelDOT. The DelTrac program was tied to the change in emphasis in State DOTs from building roads to maintaining roads and operating and managing transportation facilities. There was some organizational restructuring within DelDOT to better support both this change in emphasis and the DelTrac Program. DelDOT also established a cross-cutting team approach to implementing DelTrac. Members from across the department were involved in ITS decision-making, and an emphasis was placed on how ITS technology could be used to better support the people in these organizations. The DelTrac infrastructure was also incorporated as an important element in the long-range plan for DelDOT. All of these steps helped establish the organizational infrastructure for continued support for DelTrac within the department.

DelDOT also developed formalized institutional arrangements among the ITS program participants to foster the partnerships necessary to support the multi-organization system integration activities. These arrangements took the form of a matrix management approach to DelTrac organization, as depicted in Table 1. This table lists the primary business functions involved in the DelTrac ITS development and the roles of the various DelDOT organizations in supporting those business functions.

Table 1. DelTrac Program Management Matrix

ITMS Functions and Participants	Department of Transportation Participants										CONTRACTED		
Functions	ITS Administrator	Administration	External Affairs	Planning	FM&B	Project Management Team	Preconstruction	Legal Affairs	DTC	Highway Operations	OIT	Consultants	Contractors	OIS
1. Planning	*	*	*	*	*	*	*	*	*	*	*	*		*
2. Design	*	*				*	*	*	*	*		*		*
3. Construction	*					*			*	*	*	*	*	*
4. Implementation	*								*	*	*	*	*	*
5. Training	*	*							*	*	*	*	*	*
6. Operations			*						*	*	*	*		*
7. Maintenance									*	*	*	*		*
8. Evaluation	*			*					*	*	*	*		*
9. Finance	*				*				*	*	*	*		*

Source: State of ITMS 2000 (DelDOT)

The following list summarizes the roles of these organizations within the DelTrac program.

- The ITS Administrator coordinated DelTrac programs across divisions and was the long-term planner for DelTrac.
- The Division of Administration promoted DelTrac awareness within the department and provided DelTrac training. This division was also responsible for contract administration.
- The Division of External Affairs promoted DelTrac awareness to the public and interfaced with the media.
- The Division of Planning incorporated DelTrac into the planning process and evaluated the effectiveness of DelTrac deployments.

- Financial Management and Budget managed the annual budget and coordinated with the Division of Administration for non-traditional procurements.
- The Division of Preconstruction incorporated DelTrac elements into construction projects.
- The Project Management Team incorporated DelTrac elements into projects and coordinated DelTrac construction with other projects.
- The Office of Legal Affairs addressed legal issues related to DelTrac (e.g., resource sharing, privacy issues, enforcement, liability).
- DTC was involved in many phases of ITS transit applications, including design, construction, implementation, training, operations, and maintenance.
- The Division of Highway Operations was involved in many phases of ITS applications for highway operations, including design, construction, implementation, training, operations, and maintenance.
- The Office of Information Technology was involved in many phases of the deployment, operation, and maintenance of ITS technologies, including design, construction, implementation, training, operations, and maintenance.

By 2004, an additional reorganization (see Figure 2–1) continued the trend of consolidating business operations at DelDOT that are sometimes managed independently in other departments.

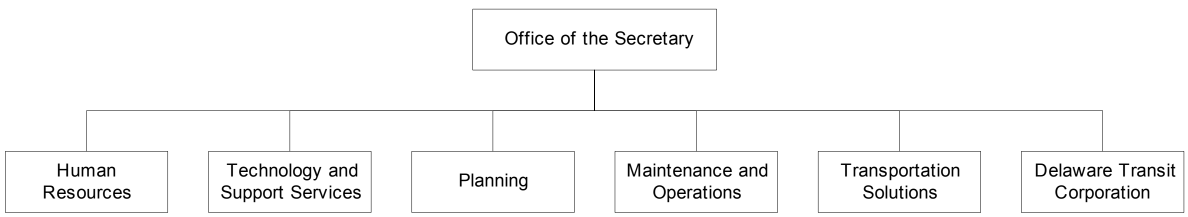


Figure 2–1. DelDOT Organization Chart (January 2004)

For example, Maintenance and Operations has the combined responsibilty for roads, bridges, and toll facilities within the State of Delaware.

In addition to the internal partnership building, the deployment of DelTrac required strong interactions between both public sector and private sector organizations. To this end, outreach activities were initiated to educate those outside of DelDOT about the DelTrac program and the advantages it offered them. Those included in these outreach were legislators, representatives of the Delaware Council on Transportation, both Delaware MPOs, and the Federal Highway Administration (FHWA). Local community leaders were also included in the planning activities, as was the traveling public. In crafting the DelTrac implementation plans, care was taken to maintain and build upon the positive impact of early outreach activities by:

- Continuing to involve public stakeholders.
- Organizing the implementation to achieve "wins" early in the program and periodically thereafter.
- Emphasizing public distribution of transportation data.

On the technical side, progress began with the identification, prioritization, and scheduling of the projects that would result in the DelTrac implementation. Three types of projects were identified as key to a successful implementation:

- Core integration infrastructure projects, because integration of transportation systems requires a common infrastructure for sharing data.

- Traffic management projects, because improvements to traffic management were deemed the most likely to have a dramatic effect on Delaware transportation. Also, the data generated to manage traffic was critical to many other planned systems.
- Data dissemination projects, because making data available to the public could both decrease congestion (as the public used this information to adapt its driving behavior) and maintain public support for the program.

Some of the early milestones of the DelTrac program included:

- The development in 1998 of a communications network to support statewide exchange of transportation data and continued expansion since that time. This established the communications infrastructure needed for DelTrac.[a]
- The publication of the technical architectural framework in August 1999 and regular publication of additional core integration infrastructure development documents after that time. This established the framework for the DelTrac integration infrastructure.
- The purchase of the AM 1380 primary radio license in 1999. This was a key step towards an effective traveler information system.
- The completion in 2000 of upgrades to all traffic signal controllers for compatibility with the communication and integration infrastructure. These upgrades were needed to support the planned Traffic Signal Control System, which was a key component of DelTrac.
- The approval in November 2000 of the design for the new TMC. The new TMC would provide space to co-locate many users of real-time DelTrac data, further enhancing the effects of the technical integration.

[a] Although the communications infrastructure was established in 1998, the fiber expansion did fail to meet some of its expansion milestones.

2.1.1. The Geographic Scope

The geographic scope of DelTrac, as laid out in the strategic plan, was selected based on the consideration of six factors:

1. Congestion.
2. Traffic volumes.
3. Presence of transit routes.
4. Extent of good movement activity.
5. Seasonal and recreational travel demands.
6. Facilities used as an alternate or bypass routes.

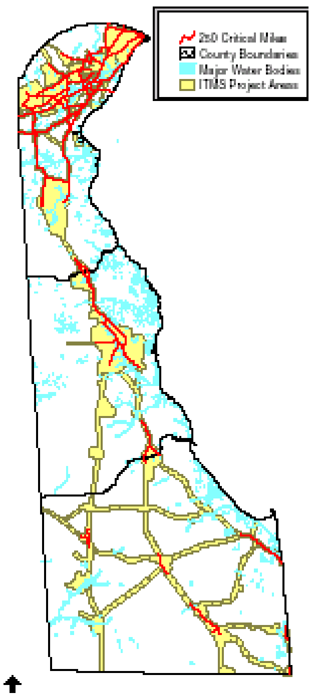


Figure 2–2. The Geographic Scope of DelTrac

An evaluation of the 3,868 centerline miles of State roads and 1,065 centerline miles of suburban development streets for which DelDOT was responsible led to the selection of 675 miles of road identified as Transportation Management Investment Areas (TMIA). DelDOT determined that transportation capital investments in these areas were most likely to give the greatest returns. Further consideration of the resources available to DelDOT and the desire to complete the initial DelTrac development within a 6-year capital program led to further restriction to 250 miles of roads. These roads, dubbed the Critical 250 Mile Network and depicted in Figure 2–2, would be the focus of DelTrac investments.

2.1.2. The Institutional Scope

As described previously, DelTrac was not managed as an ITS organization within DelDOT, but as a cross-cutting team with representatives from all organizations within DelDOT and important stakeholders outside of DelDOT. A matrix management approach was used to draw the appropriate staff (internal and external to DelDOT) to form subcommittees that supported DelTrac's business functions. These subcommittees helped manage the implementation of the subsystem(s) needed for the respective business functions. This matrix-driven group of subcommittees was headed by the DelTrac Administrative Committee, which set the overall direction for development, implementation, coordination, and operations of DelTrac. The ITS Administrator chaired this committee and headed the ITS Administration. The ITS Administration included the only DelDOT staff assigned full-time to DelTrac development. This organizational structure is depicted in Figure 2–3.

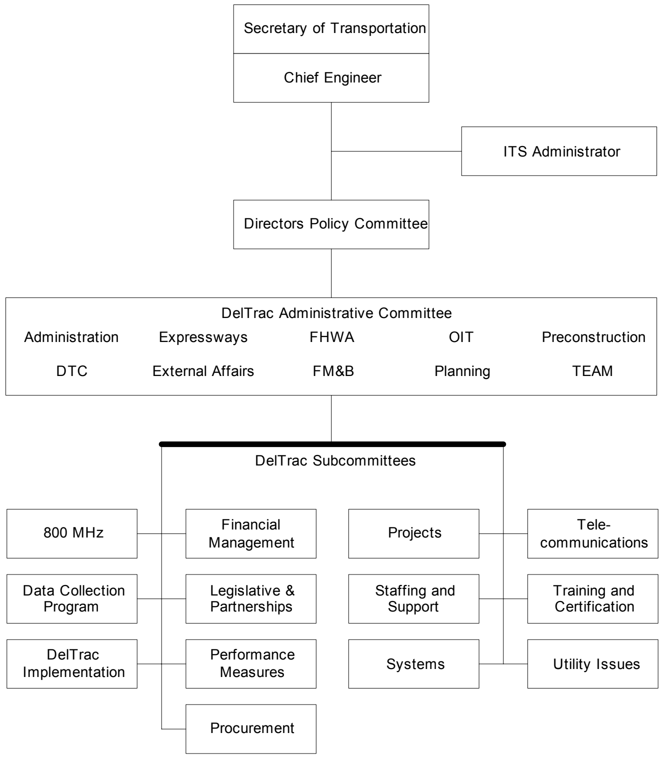


Figure 2–3. The DelTrac Organizational Structure (as of July 2001)

This organizational structure reinforced the importance that was being placed on achieving broad, strong support for DelTrac within DelDOT and on ensuring that DelTrac technologies were integrated into division business practices. First, DelTrac was a key program at DelDOT and received strong support from the top of DelDOT management. The Secretary of Transportation and the Directors' Policy Committee were both involved in the DelTrac program, and Division Managers from across DelDOT served on the DelTrac Administrative Committee. Thus, top management from DelDOT and each division within DelDOT were active participants and supporters of DelTrac. Second, DelTrac implementation was managed through subcommittees that were comprised of representatives from the divisions that were most strongly impacted by each DelTrac subsystem implementation. The following list describes the primary responsibilities of the committees shown in the organizational structure.

ITS Administration. ITS Administration coordinated the DelTrac program across divisions and external agencies, provided insight into the use and benefits of emerging DelTrac technologies, and represented DelTrac to external groups and the media.

Directors' Policy Committee. The Director's Policy Committee served as the DelTrac executive committee, addressing DelTrac policy and legislative issues and making key business decisions.

DelTrac Administrative Committee. This committee, led by the ITS Administrator and comprised of the Division Managers from across DelDOT, helped ensure that DelTrac was integrated into the mainstream of operations in each DelDOT division and monitored development, implementation, coordination, and operations of DelTrac.

DelTrac Subcommittees. The DelTrac subcommittees focused on the details of development, implementation, and operations of specific DelTrac subsystems. The members of each subcommittee represented the DelDOT divisions that were most strongly impacted by each subsystem and included one representative from the DelTrac Administrative Committee. For example, the 821-MHz subcommittee was comprised of representatives from the following DelDOT divisions: Delaware Transit Corporation (DTC); Expressways; External Affairs; Highway Operations; Preconstruction; Planning; and the Transportation Management Center. Because the subcommittees focused on the implementation of specific DelTrac subsystems, new sub-committees were created, as necessary, and each sub-committee existed for only as long as necessary to monitor the implementation of its associated subsystem.

2.1.3. The Technical Scope

The technical scope of DelTrac included the application of any ITS technology within the department. At the time of the evaluation, this scope included thirty-two subsystems classified into six subsystem categories. (This list of subsystems might grow as new ITS technologies are considered for DelTrac.) Figure 2–4 depicts the components of the DelTrac system, and descriptions of the individual components follow.

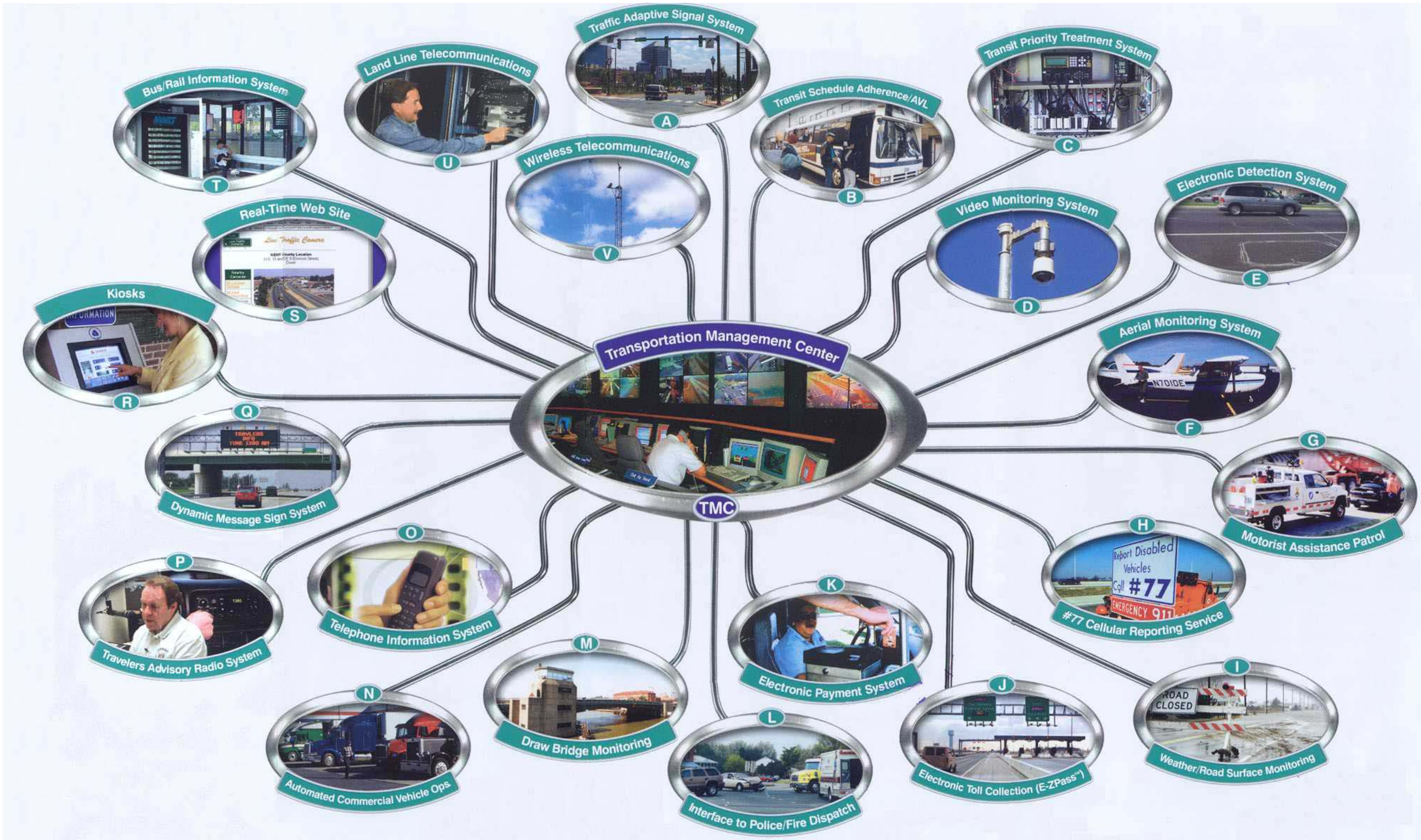


Figure 2–4. The DelTrac System[a]

[a] This diagram is a copy of diagram produced by DelDOT for a pamphlet describing the DelTrac system.

Communications

The communications infrastructure was one of the key infrastructure elements of DelTrac – subsystems cannot be integrated until they can communicate with each other. The communications infrastructure consists of the following two complementary subsystems.

Landline Telecommunications. Landline telecommunications consist of an existing copper network that was being supplanted by an expanding fiber network. Where applicable, the DelDOT network is supplemented with Public Switched Telephone Network (PSTN) and other leased network access and with short-range radio communications.

Wireless Communications. In some remote locations and for some equipment (e.g., mobile equipment), direct connection to the copper or fiber network is not feasible. For these devices, DelDOT established a statewide 821 MHz wireless network.

DelTrac Infrastructure

The DelTrac infrastructure was to consist of the central servers, databases, and software necessary to support data sharing among DelTrac subsystems. When designing a DelTrac subsystem, DelDOT considered the value of sharing the data and functions managed by that subsystem. DelDOT also considered the need to integrate with the DelTrac infrastructure when developing a new subsystem. The DelTrac infrastructure, in turn, was designed to provide an open, Web-enabled, role-based client access to its various data and functions. For example, the DelTrac infrastructure was designed to provide XML-based methods for viewing and modifying traffic signal control settings and the traffic signal control system was designed to support these XML-based methods. (As already noted, deployment of these designs was delayed.)

Transportation Management Center

The TMC is a critical component of DelTrac, which houses the central system hardware, application software, telecommunications, and personnel for operating and maintaining the DelTrac system. The TMC is both an important consumer of ITS data – serving as the central facility for integrated operations, management, and control of the transportation system – and an important re-broadcaster of this information – sharing traveler information through traveler advisory radio (TAR), dynamic message signs (DMS), the Internet, kiosks, telephone information systems, and interfaces with commercial broadcasters (e.g., broadcast and cable television, radio). The evolution of the TMC was as follows.

Wrangle Hill TMC. The statewide TMC originally operated from a temporary location in Wrangle Hill, Delaware. This TMC included the capability to manage and coordinate the traffic signal system, monitor and control traffic surveillance cameras, update DMS, view traffic detector data, broadcast TAR messages, and support incident management. Status: replaced.

Interim TMC. In December 2000, the statewide TMC relocated to the Delaware Emergency Management Agency (DEMA) facility. The interim facility maintained the capabilities of the Wrangle Hill TMC plus the operation of the #77 system, control and management of transit schedule adherence system components, and enhanced coordination with public safety agencies. Status: replaced.

New TMC. Construction of the new TMC, which was attached to the existing DEMA facility, was begun in July of 2001. The new TMC inherited and supplemented the functionality of the interim TMC, and integrated emergency support systems. Status: operational.

Transportation Management and Incident Response Vehicle (TMIRV). The TMIRV is a specialty command post vehicle that was intended to function as an alternate TMC to support on-site engineering analysis, incident management, and special event management. Status: not a current priority.

Monitoring Systems

The monitoring systems provided critical data on the current performance of the transportation system to help facilitate the operation of the control systems for managing transportation and the information systems for broadcasting this information to the public. As of December 2003, these systems included:

Video Monitoring System. This system provided real-time video of the transportation network, which was available at the TMC and other DelDOT facilities and to the public through the Internet, information kiosks, and feeds to cable and broadcast television. Status: operational.

Electronic Detection System. This system consisted of a number of technologies (e.g., loop detectors, radar detectors, E-ZPass transponders) used to monitor traffic parameters such as volumes, speeds, queue lengths, and travel times. This information was available through the core infrastructure to support other DelTrac subsystems and was broadcast from the TMC to the public. Status: partially operational.

Parking Management System. This system was to provide real-time monitoring of parking capacities and occupancies and guides motorists to locations where available spaces existed. Plans were to accomplish this using technology and cooperative efforts with municipal and private parking entities. Status: on hold.

Aerial Monitoring System. The aerial monitoring program provided real-time monitoring and management of transportation systems using trained observers in aircraft. The aircraft was equipped with 821 MHz radio to provide direct contact to the TMC and other agencies. Status: operational.

Motorist Assistance Patrol. DelDOT employees patrolled the highways during rush-hour and in construction related congestion areas in specially equipped and marked vehicles to offer motorist assistance, incident management assistance, and communicate traffic and roadway problems and observations to the TMC. Status: operational.

#77 Cellular Reporting Service. The #77 system allowed any motorist with a cell phone to report traffic problems, disabled vehicles, and incidents toll free to the TMC. Status: operational.

Weather/Flood/Road Surface Monitoring. The weather/flood/road surface monitoring system was a planned combination of weather sensors that were to be embedded in the pavement and located on a tower or pole set back from the pavement. Plans were for these sensors to provide comprehensive real-time data about weather conditions on the roadway surface and the surrounding atmosphere. Status: in planning and engineering.

Electronic Toll Collection. Electronic toll collection (ETC) was the system that automatically collected tolls through the reading of electronic tags installed on customers' vehicles. The tags stored the customers' account information, which enabled the electronic deduction of tolls from prepaid toll accounts. Status: operational.

Electronic Payment System. This technology was being implemented for the automated collection of transit fares, parking fees, and highway tolls. The available technologies – including magnetic stripe, bar-code, debit card, charge card, smartcard, and other hybrid variations – were being considered to replace of the more traditional cash transactions. Status: on hold.

Electronic Red Light Enforcement. This system was to automatically detect and record traffic signal red light violations. The planned system had cameras capturing digital images of a violating vehicle, including the vehicle's position within the intersection and its license plate information, from which motor vehicle records would be retrieved and used to identify the owner of the vehicle for citation. Status: operational.

Interface to Police/Fire Computer Aided Dispatch (CAD). DelTrac was interfaced to the Police/Fire Computer Aided Dispatch (CAD) systems. The system automated the exchange of data between DelTrac and CAD. Status: operational.

Draw Bridge Monitoring. Plans for the Draw Bridge Monitoring system call for alerts to TMC Operators when draw bridges throughout the state are opened or closed. Status: on hold.

Control Systems

The planned control systems would allow system operators to manage operations in the transportation system in response to information received from the monitoring system.

Traffic Adaptive Signal System. This system provided real-time control and monitoring of the statewide traffic signal network. The traffic adaptive signal system was to allow automated real-time adjustments to signal timings and operations based on current and projected traffic conditions. Status: partially operational.

Transit Schedule Adherence/AVL System. Through real-time monitoring of fleet location and operational status, this system provided real-time management of the fixed-route and paratransit systems. This capability allowed DelDOT to manage the transit fleet to ensure schedule adherence, provided real-time schedule information through multiple DelTrac traveler information systems – including bus stop displays – and facilitated the planned future implementation of a transit traffic signal priority treatment system. Status: partially operational.

Transit Priority Treatment System. Plans for this system would result in automatic adjustments to signal timings in real-time to either extend the green phase to allow a transit vehicle to clear an intersection or provide a "transit-only" phase to allow a transit vehicle to get in front of a queue of vehicles. Status: on hold.

Variable Speed Limit Sign System. This system was to provide the capability to automatically adjust speed limits based on observed traffic conditions. Status: testing.

Electronic Lane Use Sign System. This system was intended to provide the capability to automatically change electronic signs to display lane use assignments, provide warnings, and automate alternate routing based on observed traffic conditions or time of day. Status: planning.

Gate Control/Monitoring System. This system was to provide remote control and monitoring of emergency access gates. Status: operational.

Incident/Event Management System. This system provided real-time guidance to TMC operators and field personnel during incidents and events and provides a tracking mechanism for documentation purposes. Status: planning.

Information Systems

DelTrac collected real-time and accurate traffic information to help operators manage the transportation system. It also leveraged this information by making the information available to the public through dynamic message signs (DMS), Web-based kiosks, travelers advisory radio (TAR) system, commercial radio, automated telephone based information system, broadcast and cable television, and a variety of wireless-based information devices. These systems included:

Automated Commercial Vehicle Operations. Plans for Automated Commercial Vehicle Operations (CVO) called for implementation of information technology designed to assist trucks and buses in moving people and goods safely through the State. Status: planning.

Automated Telephone Information System. This system was expected to allow travelers to dial into a central telephone system for updated information about travel conditions statewide. Information would include roadway conditions and incidents, transit schedules, and other pertinent travel information (e.g., weather conditions). Status: planning.

Travelers Advisory Radio System. The Travelers Advisory Radio (TAR) system provided AM radio broadcasts updating travelers on roadway and transit conditions. At the time of the evaluation, DelDOT broadcasted from AM 1380 near Wilmington and simultaneously from low wattage transmitters near the resorts area. Status: operational.

Dynamic Message Sign System. This system provided travelers with real-time information about roadway conditions, event information, incidents, and transit status and availability. Status: operational.

Kiosks. A kiosk was an information tool used to disseminate traveler information to the public for use in planning prior to and during their trips. Status: operational.

Real-Time Web-site. The Website provided for customer input and provide real-time traveler information to include transportation system conditions, incidents, congestion, construction, travel time, transit schedules, weather and event information. Streaming video from the video monitoring system was also provided. Status: operational.

Bus/Rail Stop/Station Information System. This system, which was being tested during the evaluation, provided travelers and transit users with real-time information regarding the arrival, departure, and schedule adherence performance of buses and trains at bus stops and train stations. Status: testing.

Transportation Channel on Cable TV. DelTrac plans included an interface to cable television systems in Delaware. Transportation system status related graphics, audio, and video would be provided from the TMC. Status: planning.

Interface to Broadcast Radio and Television. Broadcast radio and television stations were planned to provide access to real time information from the TMC. This would include transportation system status video, and audio and graphics. Status: on hold.

2.2. DelTrac Development Timeline

Because of the breadth and complexity of the DelTrac program, this document will not provide a detailed schedule of all DelTrac activities. Instead, Table 2 summarizes the status of each of the key ITS activities in the DelTrac program, and Figure 2–5 is a timeline that summarizes this status information. More details about these activities are provided in the paragraphs that follow that figure.

Table 2. Current Status of Deltrac Subsystems (As of January 2004)

ID in Figure 2–4	DelTrac Subsystem	Current Status	Planned Completion Date	Completion Date	# of Units Planned	# of Units Deployed to Date	Remarks
TMC	Transportation Management Center	Functional	2002	2003	1	1	
A	Traffic Adaptive Signal System (Phase I)	Partially operational	2001		1000	400	
B	Transit Schedule Adherence/AVL	Partially operational	5/2001	2/2004			
C	Transit Priority Treatment	On hold					Future
D	Video Monitoring System	Operational	2002		100-150	80+	Function enhancement, improve communication network
E	Electronic Detection System	Partially operational, Testing RTMS	2002				Continue process, more detection in planning and engineering phase
F	Aerial Monitoring System	Operational	2003				Issues related to 9/11 events
G	Motorist Assistance Patrol	Operational			3	2	Plan to add a new one for beach or statewide patrol
H	#77 Cellular Reporting Service	Operational					Police and transportation operator work together at TMC
I	Weather/Flood/Road Surface Monitoring	Planning and engineering	2001	2/2004	20		Contract opening
J	Electronic Toll Collection	Operational					Integrated with E-ZPASS
K	Electronic Payment System	On hold	2003				May not be suitable for DelDOT
L	Interface to Police/Fire Dispatch	Operational	2002	2003			Enhancements in progress
M	Draw Bridge Monitoring	On hold					May start planning phase, focus on critical bridges
N	Automated Commercial Vehicle Operations	Planning					Review CVISN
O	Telephone Information System (Phase I)	Operational	2002	2004			Plan to cover whole state (transit and Highway system)
P	Travelers Advisory Radio System	Operational					Expand to cover whole state, 24 hour service, provide redundancy
Q	Dynamic Message Sign System	Operational		2003	20	5	Control software developed to manage DMS and fixed signs, portable signs controlled at TMC

ID in Figure 2–4	DelTrac Subsystem	Current Status	Planned Completion Date	Completion Date	# of Units Planned	# of Units Deployed to Date	Remarks
R	Kiosks	Operational		2002		6	Update the software and communication network
S	Real-Time Web-site	Operational		2003			Enhancement in progress
T	Bus/Rail Information System	Operational	2002	2003		25	Display static information
U	Land Line Telecommunications	Continuing build out			250 Miles	100+ Miles	Option as the backbone of communication system
V	Wireless telecommunication	Continuing build out					Optional as the backbone of communication system
N/A	Variable Speed Limit Sign System	Testing	2003	3/2004	110	23 (80)	Software testing completed
N/A	Electronic Lane Use Sign System	Planning	2003				
N/A	Gate Control/Monitoring System	Operational					Integration with DelTrac and enhancements in progress
N/A	Incident and Event Management System	Planning	3/2004				As priority task, finalize contract, implemented interface with State police system
N/A	Transportation Channel on Cable TV	Planning					
N/A	Interface to broadcast Radio & TV	On hold					Future consideration
N/A	Transportation Management and Incident Response Vehicle	Planning					
N/A	Parking Management System	On hold					Consideration of application
N/A	Electronic Red-Light Enforcement	Operational				3	

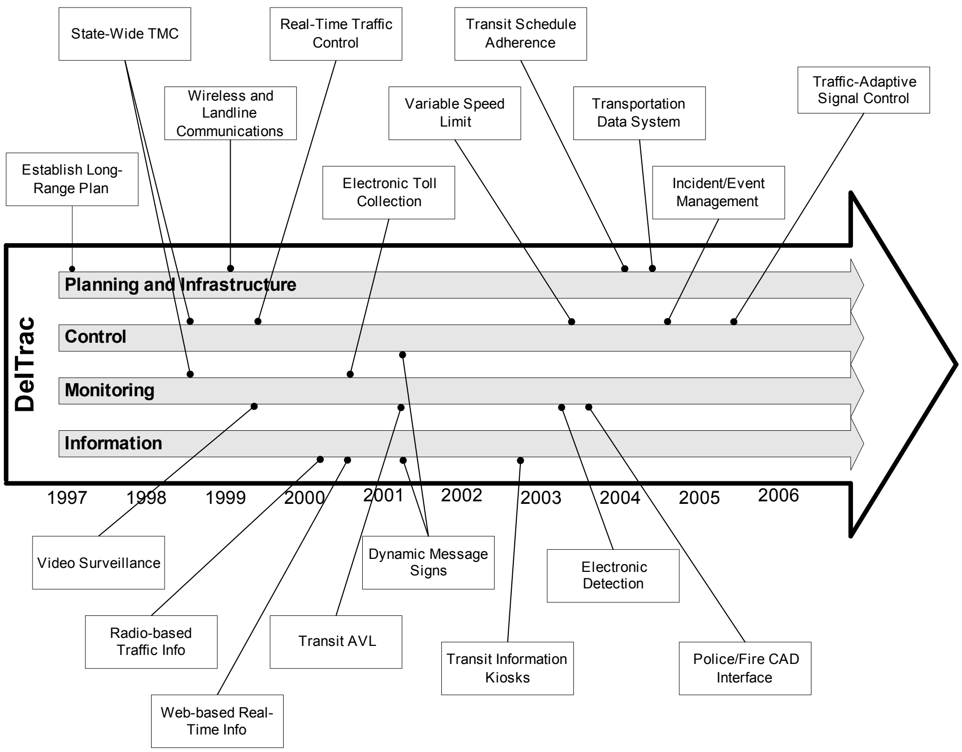


Figure 2–5. The DelTrac Schedule

Control Systems: DelDOT recognized that traffic control strategies are critical to DelDOT. Efficient traffic control system can reduce traffic congestion, reduce or spread out demand, enhance traveler safety, etc. DelDOT identified 250 critical miles of roadway along which DelDOT will upgrade the signals and provide real-time information about traffic and transit delays, roadway conditions and accidents. Initial plans were to include nearly 1,000 traffic signals in the program by the end of 2004, but these plans have been delayed. Another key component of the DelTrac is a Transportation Management Center (TMC). Linked to the new statewide emergency management center, it will provide for the centralized control, monitoring, and information for transit and roadway operations. It is among the first in the nation to be an intermodal transportation management center.

- **Transportation Management Center (TMC)** – The TMC supports a 24-hour operation and coordinates DelDOT's response to incidents and events that impact the transportation system. TMC operations are temporarily located in the State's Emergency Operations Center. A new wing of the State Emergency Operations Center was built and houses TMC operations and DelDOT's Traffic Section. Occupancy of the new TMC was scheduled for December 2002 but it was delayed until March 2003. Among the tools used to manage Delaware's roads from the TMC are aerial surveillance, electronic message boards, and traffic signal control. At the TMC, operators can view more than 70 statewide traffic cameras with video available on DelDOT's Web-site at www.deldot.net. DelDOT hopes to have twice that number of cameras controlled from the new building within 5 years.

- **Traffic Adaptive Signal System** – DelDOT is in the process of upgrading legacy traffic signal control systems so that they can be managed using a single integrated computerized system, Actra. Approximately 400 of the 1,000 traffic signal locations in the state have been upgraded, but deployment delays have limited the use of Actra. A custom Web interface to Actra is being developed that relies on XML and Java. This interface will allow DelTrac to integrate new systems with legacy systems.

Currently, the work on the central control system is behind schedule. The Actra system from Eagle Traffic Control Systems (ETCS) is a third-generation ATMS based on the proven algorithms of ETCS, thus displaying all the strengths of a time-tested system. The central software works in conjunction with intelligent local controllers, either directly or through masters, to coordinate signal operation. The system supports NTCIP and ECOM protocols and works with NEMA and Model 2070 controllers. Actra is designed to be multi-jurisdictional and to integrate the SCAT adaptive control systems as well as third-party traffic control systems or devices, such as CCTV and others. Actra systems are presently being deployed in three major areas in Delaware.

- **Transit Schedule Adherence/AVL** – Trapeze software for transit and paratransit has been implemented. The operational data acquired by the transit information system has resulted in changes to the transit schedules and routes to enhance operational performance.
- **Incident and Event Management System** – This system provides guidance to TMC operators during incidents and accidents; logs incidents; displays incidents on the DelTrac GIS system; and consolidates record management activities. This system will integrate and exchange information with the Police/Fire computer-aided dispatch system, the #77 Cellular Reporting System, and will accept direct operator input.

Information Systems: The DelTrac Information Exchange System provides a multi-platform base to capture information from the control and monitoring systems and to disseminate information, in multiple formats, to a variety of devices such as the DelTrac Web Site, DMSs, kiosks and PDAs. A GIS System, installed in the TMC, provides a system level data and a map update program that enable TMC operators to update GIS database and mapping information for control and monitoring displays at the TMC.

- **Automated Commercial Vehicle Operations** – The CVO implementation is on hold. DelDOT is participating in the I-95 Corridor Coalition Commercial Vehicle Information Systems and Networks (CVISN) program.
- **Telephone Information System** – The plan is to tie the telephone number to DelDOT's traveler radio station WTMC. DelDOT is also working with the I-95 Corridor Coalition on a 511-system.
- **Travelers Advisory Radio System** – DelDOT operates a primary licensed transmitter at 1380 AM WTMC, which broadcasts travel information on a 24-hour basis. WTMC currently covers half the state. There is a plan to provide statewide radio coverage (FCC license application is in progress). WTMC can also be heard on www.deltrac.com. DelDOT's goal is to be able to record and broadcast travel information within 5 minutes of an incident occurrence.
- **Dynamic Message Sign System** – Presently there are five fixed DMS operated from the TMC. As part of the variable speed limit sign (VSL) project, an additional 15 to 20 fixed DMS will be installed statewide. Portable DMS are being equipped to have wireless communications so that the signs can be updated from the TMC. DelDOT is also implementing approximately 110 VSL signs along the interstates and expressways, with 23 VSL signs currently deployed and undergoing testing.
- **Kiosks** – Six Web-based kiosks were installed during Fall 2002 and are now operational. The kiosks provide travel information for both auto and transit (bus/rail) usage. One of the major technical issues is how to put the kiosks on the high-speed network. The software implemented at the kiosks is based on the functionality and features of the DelTrac Web site.

- **Real-Time Website** – The Website includes real-time travel advisories and traffic camera images. As of early 2003, information about DelTrac has been available on the Web.
- **Bus/Rail Information System** – This information is tied to the Trapeze software. DelDOT has implemented signs at 25 bus stops to display static information. DelDOT is working on incorporating the AVL data into the real-time bus/rail information. The transit schedule information component has been tested but not deployed.
- **XML** – DART is working towards using TCIP-OB (on-board) in XML form for reporting real-time bus location information. It will also demonstrate a trip-based travel information system (for kiosk applications) that integrates driving and bus instructions, using parts of TCIP-PI and SCH (passenger information, schedules) reporting

Communications Systems: A variety of communication systems including statewide fiber optic system, radio, cellular phone, e-mail, and Web-based communications are deployed by DelDOT. DelDOT is also investigating the application of broadband wireless technology as an interim communication capability until the entire fiber infrastructure is completed. The new statewide communications network is able to enhance the DelDOT's communication capability along the Critical 250-Mile Networks.

- **Land Line Telecommunications** – DelDOT has implemented 100+ miles of a 250-mile fiber optic telecommunications system. Efforts to build out the fiber network continue. However, the build out is slower than anticipated because the scope of the fiber network within the statewide network has not been completely defined and costs have been higher than expected.
- **Wireless Telecommunications –** Construction for the statewide wireless telecommunications system to support field devices and mobile data terminals has begun. The AVL system uses 821 MHz for voice communications and 450 MHz for data. For statewide communications, the 450 MHz and 220 MHz bands are used. DelDOT has been implementing a new wireless telecommunication system, and will also be testing new microwave detection systems designed to acquire volume, speed, and occupancy information. DelDOT is building a 250-to-300- mile statewide fiber optic system, made easier because the department controls 90 percent of the roads in the state. Over 100 miles of fiber have already been installed.

Monitoring Systems: DelTrac's monitoring systems provides real-time traffic information to help transportation managers making informed transportation management decisions and developing effective transportation control plans. Nearly all of the transportation management action items developed depend on collecting, processing, and managing information on the transportation network.

- **Video Monitoring System –** The system is fully operational with more than 80 cameras, all of which are integrated into the TMC. DelDOT will continue adding more cameras as part of the planned system build out. (Before DelTrac, DelDOT had installed two or three cameras with dial-up communication links.) The current communications network supports the CCTV system includes leased line, fiber-optic, and wireless links. The video of most cameras is accessible to the public on the Internet (one of the most popular Web sites on the State's portal). The State is building a Web interface to enable traffic managers to control and adjust the camera settings using a Web browser. This approach reduces the response time when camera breakdowns occur.
- **Electronic Detection System** – To support the adaptive traffic signal control systems to be installed statewide, various types of detectors have been installed to provide real-time data. Because of the delay in the build out of the traffic signal system, the deployment of electronic detection was also delayed. Some Remote Traffic Microwave Sensor (RTMS) detection systems have been added and are being tested as part of the VSL project.

- **Aerial Monitoring System** – DelDOT has contracted the Delaware Wing of the Civil Air Patrol to provide aerial traffic monitoring flights. Aerial monitoring system operations are on hold because of various issues, including the lack of personnel, training, re-organization, finance, and flight restrictions imposed after the September 11, 2001 events. Once these issues are resolved, the aerial monitoring system will be put in operation again.
- **Motorist Assistance Patrol** – Two patrol vehicles are currently in operation. The TMC staff operates these vehicles. Plans for adding a third vehicle exist.
- **#77 Cellular Reporting Service** – #77 is operational with all calls going to the TMC. There are some issues with calls coming from surrounding states.
- **Weather/Flood/Road Surface Monitoring** – The installation of DelTrac's weather, flood, and road surface monitoring system has been delayed. A request for proposal for this work will be issued soon. The project will be designed to provide interfaces with other agencies but focus on DelDOT's needs. DelDOT is working with other state agencies and the University of Delaware to design and implement the Delaware Environmental Observation System (DEOS).
- **Electronic Toll Collection** – The E-ZPass program has been completed and is fully operational for all toll plazas of the Delaware Turnpike. DelDOT is in the design process to add E-Zpass to highway-speed lanes at the other major toll plazas.
- **Electronic Payment System** – DelDOT had considered implementing an electronic payment system. Plans for this system are now on hold.
- **Interface to Police/Fire Dispatch** – An interface to the State Police CAD was operational. This system filtered the data being entered into the Police CAD and sent the relevant traffic incident data to DelTrac. There was also a plan to automate the accident data entry at the police mobile data terminal (MDT) for two DSP barracks. However, funding for this project is not currently available. The long-term vision is for DelTrac to have an interface with all local police agencies.

3.0. The DelTrac Deployment Experience

3.1. Overview

The DelTrac deployment experience included both successes and unmet challenges. Programmatically, the DelTrac approach to managing ITS has been successful at creating a great deal of organizational integration and cooperation at DelDOT. Stakeholders from across DelDOT have been brought together to help identify opportunities to apply ITS to improve DelDOT operations, and this cooperation with regards to ITS has carried over into other areas. Numerous examples of this increased cooperation are noted throughout this evaluation report, including:

- DTC's purchase of a radio system that was compatible with other organizations within DelDOT.
- Location of the DelDOT TMC at a DEMA facility.
- Sharing data between the DelDOT TMC and the police/fire CAD system.

In these ways, DelTrac has helped bring about considerable organizational integration at DelDOT.

On the other hand, the primary focus of this evaluation was on a particular project that was to deploy technology to provide several key elements needed to support technical integration of the various DelTrac subsystems. In particular, this deployment was to provide a data repository that could share and archive DelTrac data and a Web server that could provide a consolidated user interface to the various DelTrac applications. In addition, a new traffic signal control system was being deployed that was to be the test application for the data repository and Web server infrastructure. In these regards, DelTrac was not as successful. While DelDOT had received several versions of the traffic signal control software and the DelTrac data repository and Web interface infrastructure, none of these systems were operational as of January 2004. (The originally planned completion date was May 2001).

In January 2004, DelDOT received for testing an updated version of the traffic signal control system software. Depending on the results of those tests, DelDOT may begin using that software, in which case the vendor intended to deliver the DelActra Web interface software for the traffic signal control system and the data repository. The remainder of this section describes DelTrac's experience in attempting to deploy the DelTrac infrastructure with the traffic signal control system.

3.2. The Origins of the Project

The origin of the DelTrac program was the *Delaware Integrated Transportation Management Strategic Plan*, published in December 1997. This document identified the use of ITS to help create an integrated transportation management system as one of the key strategies for DelDOT's future and began the process of integrating ITS into DelDOT's operations. However, it did not refer explicitly to the DelTrac infrastructure components that are the main subject of this evaluation.

The concept that led to the technical vision for the DelTrac data repository and Web server infrastructure began to take shape in 1998. In a 1998 interview[a], the ITS Administrator expressed many opinions that mirrored the views of the 1997 strategic plan and reinforced the need to integrate transportation management systems:

- "To implement technology you have to make it part of a program. … by selling 'management of a transportation system' you end up having to use ITS technologies."

[a] *Selling ITS by Stressing the End Game*, Newsletter of the ITS Cooperative Deployment Network, October, 1998.

- "ITS causes you to think differently, to do procedures differently and to set policies differently."
- "You have to create an organization to spearhead that change."
- "The highway component is very important but, of course, it's just a part of the overall system. You have to manage it as a system, not as individual components vying for their own little piece of the pie."
- "We will implement major components of the Integrated Transportation Management System (ITMS) in … three priority areas, which include the northern part of the state, the central part of the state, and our resort areas."

By 1999, DelDOT was working with a contractor on the conceptual design for the Integrated Transportation Management System, which was later renamed DelTrac.

3.3. The Conceptual Design of the System

In 1999, DelDOT began working with a contractor on the conceptual design for the DelTrac infrastructure. This work resulted in the completion of two design documents: the *Conceptual Design Specification* (Version 1.0 published in October 1999) and the *Functional Requirements and Architectural Framework* (Version 1.4 published in October 1999).

The *Conceptual Design Specification* established the conceptual configuration for the DelTrac infrastructure, identifying the following key elements of that infrastructure:

- The identification of DelTrac subsystems that should be integrated.
- The support for multiple methods for accessing each DelTrac subsystem, including thick and fit client workstations[b] that interact directly with the subsystem interfaces and Web clients that access DelTrac functionality through the Web.
- The use of a Web server that would provide access to each DelTrac subsystem.
- The use of a central database for sharing and archiving data between the integrated subsystems.
- The use of interface components to connect the various DelTrac subsystems to each other – a Database Interface to interact with the central database and an Application Web Interface to support a Web-based interface for each application.

The *Functional Requirements and Architectural Framework* extended the conceptual design in three ways: it identified the need for a GIS to provide a map interface to DelTrac data, it listed very high level requirements for the DelTrac infrastructure and DelTrac applications, and briefly described the role of each subsystem in the overall DelTrac architecture. For example, the description for Web Traveler Information was:

> *The public shall be able to request VMS information on specific routes from the ITMS Web Server. This shall be done in concert with other ITMS subsystems providing route recommendations to users, detour information, construction locations, slow-downs, and other related information.*

In retrospect, it is perhaps at this stage that the first signs of the difficulties that would be encountered first appeared. This document included the following six sections: Architectural Framework, General ITMS

[b] Thick, thin, and fit client refer to three different for managing processing in a client-server or n-tier environment. The client refers to the computer that provides a user interface and the adjective refers to the amount of processing that is done on the client computer rather than the server computer. For a thick client, all processing is done on the client. For a thin client, all processing is done on the server (e.g., as in a Web browser). For a fit client, processing is allocated between the client and the server according to which computer best "fits" the processing requirements.

Requirements, ITMS Control Subsystem Requirements, ITMS Information Subsystem Requirements, ITMS Monitoring Subsystem Requirements, and Communications. Missing from this list is a section that might have been titled The ITMS Infrastructure, which would have recognized that the design of the DelTrac integration infrastructure was of equal importance as the design of the individual subsystems. Thus, while this document described an architectural framework for DelTrac, it did not identify the refinement of this framework as a separate DelTrac development activity. In the end, this framework was implemented as part of deploying the DelTrac traffic signal control system, which resulted in strong dependencies between these two systems.

3.4. The Design Process

The project to deploy the DelTrac infrastructure began in earnest with the application in February 2000 to FHWA for Earmark ITS Integration Program funds for the Delaware Statewide ITMS Integration project. This project was to tie traffic signals, video monitoring cameras, and transportation monitoring sites "into the statewide IP-based communications network and connect them to the ITMS central control system and operations software." Although not stated explicitly in the application, the intention was for the contractor for the traffic signal control system to also develop the DelTrac database and Web server infrastructure components, and for these components to use XML as a tool to facilitate communication between DelTrac subsystems.

The importance of XML in DelTrac was clarified by the publication of the *DelTrac Client Applet and Traffic Control System Detail Design* document (Version 1.0 on June 2000). This document described the DelTrac ITMS Client Applet and the Actra Traffic Signal Control System, two of the elements whose deployments were reviewed during this evaluation.

The DelTrac ITMS Client Applet was described as a generic applet that "reads the XML document describing each application and represents it in a browser." The description of this client applet further refined the DelTrac framework to include an XML Repository for sharing and archiving DelTrac data and a message broker for managing communication between DelTrac applications and the XML Repository. It also listed the types of interactions that would occur between DelTrac subsystems and the client applet, including database messages for updating data and alert messages for notifying DelTrac subsystems of activities that occur in another subsystem. (For more information on the design for DelTrac subsystem interactions, see section 1.0 and Appendix A.) This document described the DelTrac Web interface for the Actra Traffic Signal Control System.

In retrospect, this design document continued the trends that would lead to significant deployment difficulties later:

- The document did not include a section on the design of two critical elements of the deployment, the database repository and the messaging service.
- The document showed a strong emphasis on the traffic signal control system, with no discussion of the needs of other DelTrac subsystems that might use the general infrastructure being developed.
- The information in the document was still very general, given its title as a detailed design document.

In the opinion of the evaluation team, some of the most important omissions in this document were evidence of an independent design effort for the DelTrac infrastructure components, the client applet, the data repository, and the messaging service, being deployed. The intent of these components was to provide common infrastructure pieces that would be used by all DelTrac subsystems. So, the design of this system would require a careful analysis of the anticipated needs of each DelTrac subsystem that might later use this common infrastructure. However, this document focused primarily on the needs of the traffic signal control system.

A second important omission was a clear definition of the interfaces between the various DelTrac components. One of the advantages of developing component-based systems is that the interactions between the subsystems occur only through the interfaces. Thus, individual subsystems can evolve without impacting other subsystems so long as they continue to support the same interface. While the detailed design document gave several examples of XML messages, it did not define any of the subsystem interfaces. In fact, it did not indicate that interface specifications for these interfaces would be defined and controlled to prevent changes that might impact integrated DelTrac subsystems.

The design process continued with the development of an *Administrative Tool Detail Design Specification* in September 2000 and an *Application Integration Requirements* in March 2001.Neither of these documents added a significant level of detail to the description of the system or the interfaces between DelTrac subsystems.

3.5. The Deployment Process

Despite the lack of concrete design specifications, development of the DelTrac infrastructure components seemed to be making good progress, leading to the demonstration of a prototype of the system in 2002. This prototype exhibited the use of the DelTrac Client Applet to interface with the Actra traffic signal control system and used the repository to share Actra data. Design specifications for the various interfaces were still not available and the prototype was not a fully functional traffic signal control system.

The first signs of difficulties began to appear in early 2003, when an upgrade to the Actra traffic signal control system was installed to correct some problems with the earlier version of that software. Internal changes to the Actra application resulted in changes to its external interfaces. Because these external interfaces were not under configuration control, complimentary changes were not made to the DelTrac Data Repository and the DelTrac Client Applet.[c] Although the new TSC application functioned better than the previous version, its installation "broke" the interface between the TSC subsystem and the DelTrac infrastructure, so that the DelTrac Client Applet and the Data Repository no longer worked correctly with the TSC subsystem. At the same time, the TSC application had some additional bugs that needed to be worked out, and DelDOT requested that the contractor focus their attention on correcting problems with the TSC application rather than on the DelTrac infrastructure.

At about that time, a series of internal reorganizations at the contractor resulted in further delays and introduced new opportunities for DelDOT to consider.

3.6. The End of the Deployment

When the project began, DelDOT was interested in obtaining a TSC system that would support a Web interface, but the vendors they approached were not interested. Consequentially, developing a custom Web interface to an existing TSC system became part of the DelTrac program. By 2003, vendors (including DelDOT's TSC vendor) were beginning to upgrade their systems to include a Web interface. DelDOT began to consider the advantages of a COTS TSC system with a Web interface over a custom version. At the same time, they reconsidered other elements of the DelTrac infrastructure that might benefit from a redesign using newly available tools, and noted that Web portal technology could be used to integrate DelTrac applications rather than relying on the custom approach that was under development.

[c] One goal of a component-based design should be to develop interfaces that do not reflect the internal functioning of an application, so that changes to the application do not affect the application interfaces. Ideally, the DelTrac subsystem interfaces would have been designed with this goal in mind and these complimentary changes would not have been required. Less ideally, the interfaces would have been under configuration control and a management process would be in place so that changes to the interfaces would have triggered a requirement for complimentary changes to the applications that use the interface.

As of January 2004, DelDOT was testing the updated Actra software. This software did not include Web interface capabilities, but did interface with the DelTrac Data Repository. If this testing goes well, the vendor had proposed to deliver the DelActra Web interface for testing in February 2004.

Even if this schedule holds, the scope of the DelTrac infrastructure that will be deployed is being reconsidered. The original plans called for this infrastructure to serve as a portal to other DelTrac applications. Currently, DelDOT is considering whether to use this infrastructure or to consider other options, such as the purchase of Web portal technology for department-wide use. The original plans also called for the DelTrac infrastructure to support both data sharing and sharing of services and alert notifications between DelTrac applications. The existing plans, as of February 2004, call for sharing DelTrac data and a single user interface for DelTrac applications, but do not call for sharing services and alert notifications.

In fact, while the project to deploy the traffic signal control system and the DelTrac infrastructure experienced delays, DelDOT has had more success with other ITS projects that include integration elements. For example, a very successful interface to share data between the State Police dispatch system and the TMC was deployed that uses a database that is much like the data repository to facilitate data sharing. As previously mentioned, DelDOT is evaluating a Web portal that will provide a common interface to not just DelTrac applications, but to all Web-enabled DelDOT applications. Also, DelDOT has agreed on a department-wide GIS standard and has hired a contractor to integrate DelDOT GIS applications and data. This is a necessary first step to using a shared map-based interface to different DelDOT applications.

Thus, although the first attempt to deploy the infrastructure needed for an integrated transportation management system did not succeed, other DelTrac activities have succeeded that will– with some delay – result in an integrated transportation management system for DelDOT.

4.0. Key Technical and Institutional Steps Required to Implement and Integrate the System

4.1. Overview

ITS provides a new paradigm for improving transportation by using technology to improve the operating efficiency of the existing transportation infrastructure instead of using construction to provide more infrastructure. However, changing the operating paradigm of an organization is always difficult, and is particularly difficult when it comes to ITS. Transportation workers accustomed to deciding where to build new and enlarge existing roads in order to meet demand must think on a much broader scale. Can transit be used to meet some of the expected demand if transit is given travel priority to increase its attractiveness to travelers? Will travelers time shift if they are provided with reliable traveler information? Can enhanced control systems such as VSL and ramp metering spread the demand to help roads operate at peak efficiency during periods of high demand? Considering these new questions is made even more difficult because of the rapidly changing nature of computer technology. Instead of slow, methodical improvements in construction practices that can be projected into the future with some reliability, there are rapid, helter-skelter changes that introduce entirely new sets of capabilities every few years.

> Lesson Learned 1 - Focus on solving transportation problems, not implementing ITS.

All too often, these conflicts between past practices in transportation and new practices demanded by ITS have resulted in divisions between those focused on implementing ITS and those focused on operating the transportation system. DelDOT has sought to avoid this problem by focusing on the one thing that all the groups within DelDOT have in common – the desire to solve transportation problems. This problem-solving focus helps define the institutional and technical steps that are used to apply ITS at DelDOT, as described in the remainder of this section.

4.2. Key Institutional Steps Required to Establish the DelTrac Program

> Lesson Learned 2 - Include ITS in the long-range plans for the department.

The steps to implement the DelTrac program began in 1997 with the publication of the *Delaware Integrated Transportation Management Strategic Plan*. This document began by describing the challenges faced by the Delaware transportation system and identifying the development of an integrated transportation management system (ITMS) as the best approach to meeting those challenges. This was DelDOT's first step in making DelTrac a central part of the long-range plans for the department and demonstrated the commitment of DelDOT management towards achieving this long-term goal. Including ITS in long-range plans with management support was an important step in achieving better buy-in for ITS technologies and applications across the department.

The 1997 strategic plan also served notice to DelDOT that management was expecting a change in the way that DelDOT did business. Instead of each organization within DelDOT operating independently, it was expected that these organizations would work more closely together. Instead of focusing on building new infrastructure, DelDOT would focus on better utilizing the existing infrastructure. Instead of operating in the slowly changing world of construction, DelDOT would begin to operate in the more rapidly changing world of computer technology. DelDOT helped cement this emphasis in re-working how they did business by creating the ITS Administrator position, hiring an Administrator and, at the same time, conducting an internal reorganization.

This reorganization also accomplished two other important objectives. First, it helped overcome some of the barriers to integration by moving people between organizations within DelDOT, spreading knowledge of the capabilities and needs of each organization to others. Second, it helped spread knowledge of ITS throughout DelDOT. At about the same time, the DelTrac Administrative Committee was formed to include representatives from all the major organizations within DelDOT. Taken together, these changes helped create an environment that was ready for change.

One sign of the extent to which ITS was integrated into DelDOT plans was the publication in 2000 of a DelDOT document entitled *Transforming Transportation, The Delaware Story*. This document began with the words, "The Delaware Department of Transportation is transforming the very way it thinks about, plans for and implements transportation services." The document also committed DelDOT to "use technology as a means of enhancing mobility and improving Departmental management."

The most important change instituted by the DelTrac program was the focus on integration. As noted in the 1997 strategic plan, the objective of DelTrac is to create a seamless transportation system that incorporates all modes of transportation. DelDOT laid part of the organizational framework for achieving integration through its internal reorganization. The technical framework for achieving integration was being formed through a wide variety of technical tools focused on integration, such as XML, virtual private networks, messaging systems, and component-based architectures. These technical advances supported the use of Internet protocols to integrate different computer systems.

Taken together, all of these changes created an environment that would support better organizational and systems integration within DelDOT. However, there was still the potential for internal competition between DelDOT organizations – particularly internal competition for funding – to be a roadblock for integration. As each DelDOT organization sought to solve its specific transportation problems, there was the potential that the advantages of integration would be lost as each organization focused on its individual needs. The DelTrac Administrative Committee helped counteract this internal focus by creating a body that took a department-wide view of ITS deployment. This helped ensure that integration issues received appropriate attention in the ITS deployments.

One example of this involves the purchase of a new radio system by Delaware Transit Corporation. Not long after the DelTrac program began, DTC had the need to replace their radio system, and planned on using an analog 450-MHz system. The ITS Administrator encouraged DTC to use instead a digital 821-MHz system that would be compatible with other DelDOT radio systems; however, the cost of the 821-MHz system was considerably more expensive. In the end, additional funds were provided through the DelTrac program to offset some of the additional costs and an 821-MHz system was purchased.

This choice between a cheaper, non-integrated solution and a more expensive, integrated solution is a common theme in technology deployment. While the costs of an integrated solution are immediate and obvious – and born by the deploying organization – the benefits are more distant and nebulous – and spread across the department. From the standpoint of each individual organization, a comparison of costs and benefits points to the non-integrated solution. From the standpoint of the department as a whole, especially when the potential long-term benefits of an integrated transportation system are considered, the integrated system is a better choice. Creating the DelTrac Administrative Committee and channeling ITS funding through the DelTrac program helped to restore a balance between the organizational and departmental needs at DelDOT.

In the example cited above, the decision to pursue an integrated solution paid significant dividends. DelDOT recognized that purchasing the 821-MHz system was more costly for DTC and helped share that cost. As part of the discussions associated with this purchase, DTC also proposed placing a transit console at the TMC. This was to help provide DTC with better and more current traffic information on which to base re-routing decisions. (This proposal was later set aside because union and staffing issues would make it difficult to man the consoled.) Despite this setback, cooperation between DTC and the TMC is still significant. For example, it is not uncommon for DTC and TMC staff to establish a radio talk group when a problem is detected (such as a failure of traffic signals along a bus route). This has lead to enhanced operational efficiency for both DTC and the TMC.

The success of this initial integration effort, and the resulting improvement in communication channels between DTC and other organizations within DelDOT, led to greater cooperation in other projects, not all of which involved ITS. For example, a better understanding of transit needs has resulted in one case of queue-jumping signals being deployed to facilitate transit operations, especially during construction activities. When fibers were pulled along signal corridors to support the traffic signal control system, additional junction boxes were installed near bus shelters to allow both agencies to share this fiber resource.

Perhaps the most striking example of cooperation occurred when a bus-only ramp on DE 1 was constructed to facilitate transit operations during races at Dover International Speedway. Before DelTrac, DTC and other organizations with DelDOT had been cooperating to help manage race day traffic. DTC staff noted that DelTrac helped further increase this level of cooperation, which helped lead to construction of the bus-only ramp. DTC currently uses about 50 buses to move over 10,000 people in less than one hour during Dover International Speedway races.

Lesson Learned 12 - The planned budget should account for uncertainties in the design and in the availability of skilled labor.

Another advantage of this funding mechanism was that it gave the DelTrac management more flexibility to deal with the uncertainties in costs that are associated with ITS projects. Because ITS projects often rely on leading edge technologies, it is very difficult to anticipate all of the costs of deploying, operating, and maintaining ITS technologies. This was the case with deploying DelDOT's fiber network, when changes in electrical codes significantly increased deployment costs for the network.

While, internally, DelDOT focused on creating an organizational structure that would encourage the integration of transportation management systems, they also recognized the importance of reaching out to stakeholders outside of the department. Early in the DelTrac program, DelTrac supporters met with a wide array of outside stakeholders to explain to them the DelTrac program and what it would achieve. These stakeholders included the FHWA, Delaware Senators and Representatives, other State agencies, and local organizations.

An important part of selling ITS, both within DelDOT and to outside stakeholders, was defining a message that could convince people that a change was in order. DelDOT did so by relating ITS integration to the change in emphasis from building roads to better maintaining and operating the existing transportation facilities. FHWA and other transportation leaders were already publicizing this new paradigm in transportation management, and the promise of ITS integration fits in naturally with this paradigm.

In summary, the key institutional steps required to establish the DelTrac program were:

- Develop a long-range plan for DelDOT that included the long-range plan for DelTrac.
- Make changes within DelDOT to prepare DelDOT for the types of integration called for by DelTrac.
- Build support for DelTrac both within and outside of DelDOT.
- Empower the DelTrac leaders with the support of upper management in DelDOT and the financial control they will need to ensure that integration of ITS elements in DelDOT is achieved.

4.3. Key Institutional Steps Required to Deploy and Maintain the DelTrac Program

Lesson Learned 4 - Plan the program to produce enough wins along the way in order to maintain the momentum of support.

Once the steps above were completed to establish the DelTrac program, additional steps were necessary to begin deploying and maintaining the program. Using the strategic plan as a guide, DelDOT began prioritizing and scheduling the deployment of the elements described in that plan. Among the highest priority projects were those that established the basic infrastructure necessary for integration – the communication network and the data sharing architecture. While these projects were necessary to establish integration, they would not produce any highly visible results. DelTrac personnel stated that, in order to maintain support for DelTrac, it was necessary to regularly generate visible results so that the continued progress and benefits of the DelTrac program would be apparent.

Lesson Learned 3 - Try to not do too many things in parallel.

This led to the early deployment of several other DelTrac elements. DelDOT began with the Traffic Signal Control system because, in a state like Delaware where most of the traffic occurs on arterials, the efficient operation of the TSC has a large impact on the transportation system. Motorist Assist Patrols were also begun because of their high profile, and a new TMC was deployed to manage the integrated transportation system. DelDOT began broadcasting traveler information via a traveler advisory radio station (WTMC) and over the Internet because of the importance of traveler information in the DelTrac vision – and its high-profile nature.

Lesson Learned 5 - Be certain to proactively manage personnel issues related to applying ITS technologies.

Although, for the most part, the early DelTrac deployments went well, the rapid expansion of the DelTrac program began to cause some problems. Chief among these problems were staffing difficulties associated with learning how to use and maintain the systems being deployed. In 2000, DelDOT conducted a self-evaluation that reported the following issues:[a]

- Staffing levels that are inadequate to support normal operations, support, and maintenance of DelTrac.
- Staff without the appropriate skills and training to construct, manage, and maintain DelTrac.
- Insufficient standard operating procedures and policies for daily operation of the TMC.

Lesson Learned 11 - The traditional procurement process may not offer the flexibility needed to support ITS procurements.

Some difficulties associated with personnel adapting to the new ITS technology were also apparent on the procurement side of DelDOT. For example, it was noted that the DelDOT procurement process, which was intended to support the design and construction of roads, was not flexible enough to support ITS procurement. Manpower shortages meant that DelDOT fell behind on some construction inspection activities and funds tracking activities. It was simply difficult for DelDOT to retrain existing employees quickly enough in the skills they would need operate and maintain DelTrac.

Despite these difficulties, DelDOT continued to make good progress on the planned deployments and continued to hold onto its support within DelDOT. In part, this was because DelTrac had strong support at the highest levels within the department, which helped smooth over the difficulties that were encountered. By including staff from across the DelDOT in the DelTrac decision-making process, they had also created

[a] See the report entitled State of ITMS – 2000 (2001 Update).

an environment of team cooperation with a shared goal of deploying DelTrac. Both of these strengths were a result of the steps taken to build support for DelTrac while establishing the DelTrac program.

4.4. Key Technical Steps Required to Implement and Integrate the DelTrac Data Repository, Web Server, and Traffic Signal Control Subsystem

Two of the key elements of the DelTrac vision were to (1) enable integration of the various ITS subsystems and (2) leverage this integration by designing DelTrac subsystems so that they could be operated from a common transportation workstation. The key technical steps required to achieve this vision are listed below:

- Develop a communications network that provides data transfer connectivity between the various subsystems to be integrated. Systems cannot be integrated until they can communicate, so this step is often the first in any integration project. For DelTrac, this involved extending their communications network so that more field devices could become part of the DelTrac system.
- Design a system for passing messages between subsystems. There are many different methods (see section 6.5) for passing messages between subsystems with advantages and disadvantages to each. The DelTrac system was designed to use a central database to store shared data and a central message broker to pass messages between subsystems. The use of a central database can help provide scalability by handling data requests without bogging down the individual subsystems. The use of a central message broker can help decouple systems by eliminating the need for a subsystem to locate a different subsystem with which it might interact.
- Design protocols and interfaces that use this network to share data between the integrated subsystems. One of the goals of a component-based system architecture is to develop a system that is not only integrated, but one that is integrated through stable interfaces that are not likely to change as the underlying systems evolve. To achieve this goal requires careful design of the interfaces between the system components. As described in section 5.2, difficulties with the DelTrac deployment arose because of limitations in their interface design.
- Upgrade existing systems to be compatible with the new integration infrastructure. This could, as was the case with DelTrac, require both hardware and software upgrades to these systems. For DelTrac, traffic signal controller hardware was upgraded to be compatible with the Actra software and the Actra software was upgraded to be compatible with the DelTrac integration infrastructure.

5.0. Use of Existing Technologies to Build a Seamless Transportation Management System

5.1. Overview

One of the decisions that must be made with any technology deployment is whether or not to use existing technology, customize existing technology, or develop new technology to provide some of the technical services required for the deployment. This decision is particularly difficult – and important – for ITS deployments since one of the key objectives of all ITS deployments is sharing transportation data; often, existing technology was not designed to meet that objective. When faced with this decision, DelDOT typically took the approach of working with the vendors to customize the existing technology to provide the right interoperability to integrate with the DelTrac system as a whole. The purpose of this section is to summarize the DelTrac approach to deciding when and how to use existing technologies, and to present the results of a detailed review of how that approach was applied to deploying the traffic signal control system.

5.2. Using Existing Technologies in the Traffic Signal Control Subsystem, the DelTrac Data Repository, and the DelTrac Web Server

DelDOT's plans called for the TSC, Data Repository, and Web Server subsystems to be designed and deployed as part of a single development effort by the contractor providing the TSC subsystem. Figure 5–1 depicts the role existing technologies played in these subsystems.

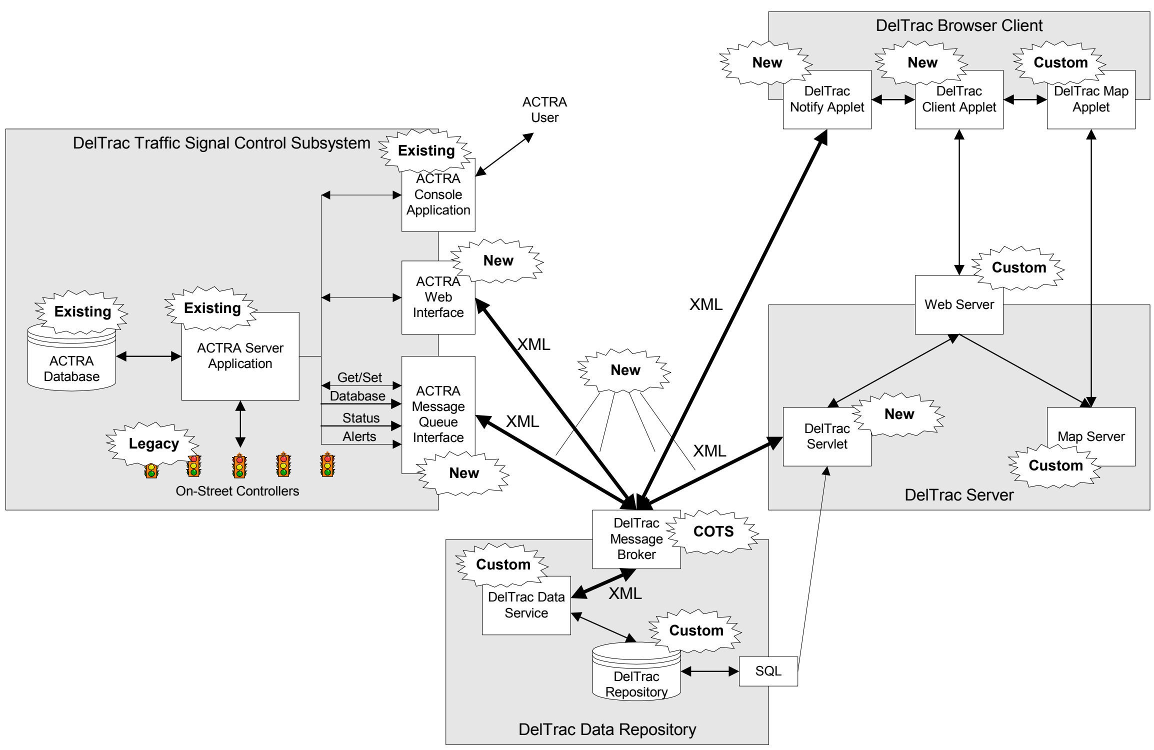


Figure 5–1. Existing Technologies in TSC Subsystem

The DelTrac TSC (left side of this diagram) is Actra, an off-the-shelf TSC application. However, as part of the purchase agreement for the system, the vendor was required to develop interface software to integrate the Actra application with the Data Repository (for sharing data), the Message Broker (for sharing services), and the Web Server (for providing a browser-based interface to Actra). This process of interfacing the Actra application with the DelTrac integration infrastructure was made much easier because Actra already included an Application Programming Interface (API) that exposed Actra functionality. Therefore, few modifications to the actual Actra application were required in order to interface with DelTrac. Instead, the vendor focused on developing interface routines to translate between the existing Actra API and the DelTrac interfaces.

Some of the other examples of existing technology used in these systems are as follows:

- The DelTrac Message Broker is a COTS Java application that provides XML-based messaging services between Java applications.

- The Data Repository is an Oracle database, which includes a built-in capability to generate and process XML documents.

- The Map Server is a COTS application for serving maps over the Internet. Customizing this server amounts to providing the required map data to the server and defining the maps that should be displayed.

- The Map Applet is a Java Applet that is provided by the Map Server vendor and was customized for DelTrac.

- The Web Server is a COTS Web server, but key functionality of this server is provided by the custom DelTrac Servlet.

DelDOT made maximum use of existing technologies, when possible. For example, most of the new development is associated with the interfaces between subsystems, and this development is unavoidable. Even here, DelDOT minimized the amount of new development required by choosing a TSC application with an existing API.

Despite the attempt to use existing technologies whenever possible, DelDOT did encounter significant difficulties with this deployment. First, the Actra package selected by DelDOT was a new release of that TSC application that was still evolving. This led to two problems with the DelTrac deployment. The first problem was simply that the first releases of Actra provided to DelDOT did not function as expected – for example, the Actra functionality that was to periodically poll the traffic signal controllers to determine their current status and state would stop working, requiring DelDOT to reboot the system.

Lesson Learned 9 - The design of the message-based interface between subsystems is one of the most important steps in integrating ITS subsystems.

The second problem was subtler and was related to the integration that is key to creating a seamless transportation management system. During DelTrac development, little design effort went into developing the interface between the various DelTrac components. In the case of Actra and the Data Repository, this resulted in an interface that closely mirrored the underlying data structures used in the Actra software. So, any change to the Actra data structures would likely require a corresponding change to the Actra interface to the Data Repository, which would then require similar changes to the Data Repository itself. These changes, in turn, would likely require changes to any other DelTrac systems that interacted with Actra through the Data Repository. In this way, changes to Actra had the potential to percolate through and "break" components throughout the entire DelTrac system.

This is exactly what happened between two releases of the Actra DelTrac software – changes made to the Actra software required corresponding changes to other DelTrac components, which were not made.

When the new version of Actra was installed, the other DelTrac components quit working correctly. The solution to this problem is to design interfaces that are independent of the underlying component implementations.

Lesson Learned 7 - Carefully manage the risks of using cutting edge applications.

The other place that new development was required was with the DelTrac Browser Client Applets, the DelTrac Servlet, and the Actra Web Interface. In the case of the DelTrac Client Applets and the DelTrac Servlet, new development was required because the DelTrac browser-based user interface was new. The applets and servlet developed for the browser interface were designed for reuse as other subsystems are integrated with DelTrac. Taken together, along with the DelTrac Web Server, these elements comprised a system that was to integrate loosely coupled applications into a single user interface in order to create a common transportation workstation. While the DelTrac developers were creating a system to perform this sort of user interface integration, commercial developers were developing Web Portals to provide similar services. Although DelDOT did make progress in developing its own DelTrac-specific Web Portal technology, at the time of this report they were evaluating a commercial Web Portal product that would be used to create a common interface to all Web-enable DelDOT applications.

6.0. Use of XML to Manage and Exchange Data

6.1. Overview

XML is a method for formatting structured data so that it can be easily transmitted between different computer systems and the messages can be enhanced in the future without disrupting systems that are dependent on the previous message format. Because of these characteristics, DelDOT planned to make the use of XML a critical element of the DelDOT central transportation management system, the core component responsible for sharing data across DelTrac components. This section describes how DelDOT planned to use XML in DelTrac (identifying lessons learned during that usage) and how that planned usage evolved during the DelTrac deployment. Other topics, such as how DelDOT maintained compatibility with ITS standards, ensured security, and leveraged existing tools in applying XML, are also considered.

6.2. What is XML?

XML, or Extensible Markup Language, is a method for storing structured data. Structured data is stored in an XML document, which contains both the data structure for the data and the data itself. An XML document stores the data structure in terms of tags that denote the meaning of the data content associated with that tag. It stores the data in terms of either tag attributes or content. For example, an XML document for a book might look something like the following:

```
<Book>
   <Title>A Book About XML</Title>
   <TableOfContents>
      <Line Section="1.0" Page="1">Section 1.0 Title</Line>
      <Line Section="1.1" Page="2">Section 1.1 Title</Line>
      <Line Section="2.0" Page="3">Section 2.0 Title</Line>
   </TableOfContents>
   <Section Title="Section 1.0 Title">
      </Paragraph>Paragraph Text</Paragraph>
   </Section>
</Book>
```

In this example, the items such as "`<Book>`" and "`<Title>`" are known as tags and describe the content (e.g., the tag "`<Book>`" indicates that the data contained between that start tag and the "`</Book>`" end tag that follows describes a book). The items such as "`Page=`" contained within a tag are attributes that define data that is associated with a tag. Items such as "`<Title>A Book About XML</Title>`" contained within another tag (in this case the "`<Book>`" tag) are child tags that contain structured information associated with a tag. Finally, the text contained between a start and an end tag is the content of that tag. The text "`Section 1.0 Title`" is the content of the first "`<Line>`" tag.

As this example demonstrates, the original purpose of XML was to store documents in a way that separated the content and format of the document. In an XML document, tags are used to define the structure of a document and attributes and content are used to fill in that structure. Formatting can be applied later by specifying a style sheet that identifies the proper presentation format for different types of structures within the document. (This differs from HTML, in which the set of tags are predefined and specify the presentation format for the content.)

After its initial development, it was quickly realized that this approach could also be applied to more traditional computer data. This is demonstrated in the following example of an XML document that describes part of the menu structure for the DelTrac Web application.

```
<DelTracMenu>
   <Tab Title=Subsystems>
      <Folder Title="Traffic Control System" ID="1A32FB29"
         <function Title="System Graphics" id="A124BCFF"></function>
         <function Title="Intersections" id="A126BA23"></function>
      </Folder>
      <Folder Title="Live Traffic Video" ID="1A32FB30"
      </Folder>
   </Tab>
</DelTracMenu>
```

In this case, the data stored in the XML document does not represent a document at all – it represents data that is used to manage the DelTrac Web application.

Although, at its core, XML is a method for storing structured data, it also includes several other, related features. One can define a document type or an XML schema that defines the type of information that contained in an XML document. By checking a document against a document type, one can verify that the document does contain data that is correctly structured. For example, the document type for `DelTracMenu` might require that it include at least one "`<Tab>`" tag defining the tabs that should be displayed on the DelTrac menu. XML also supports some automated processing of XML documents through the use of Extensible Style Sheets, which define transformations that should be applied to an XML document. Because of its popularity, the list of tools and extensions to XML is growing.

But, for the purpose of using XML to manage and exchange data, the important thing to note is that XML allows one to store structured data that can then be transmitted between different DelTrac subsystems. The following paragraphs describe some of the considerations for using XML in this way.

- **An XML document is human readable.** Because XML is presented as text and every piece of data in an XML document has an associated tag describing what that data represents, an XML document can be easily interpreted. This has several advantages when building an XML-based system. For example, testing a data transfer does not require special software to test the transferred data – a human can examine the data by hand. Similarly, generating test XML documents for a system does not require special software – the documents can be generated by any text editor. Of course, it also means that any intercepted message can be easily deciphered, which increases security concerns for XML-based data transmissions.[a]

- **An XML document is very compatible with the Internet architecture.** Because an XML document is text (like an HTML document), transmission of the document is permitted across most firewalls and other network security systems that can prevent some types of data transmissions.

- **An XML document is verbose.** Because every piece of data within an XML document has an associated tag, an XML document for storing a given set of data will typically be larger than if the same data were stored using some other method. In data intensive, bandwidth-restricted applications, another storage and transmission method might be preferred.

- **Elements can be added to an XML document without preventing existing software from using the document for data transmission.** In most ad hoc methods for storing data, each data element occupies a fixed position in the data. For example, a date written as "7/61" is interpreted correctly because the sequence always presents the numbers in the same order – first month, then year. Suppose it is necessary to track the day, so dates are now written as "7/28/61". Then,

[a] Security standards for XML documents were developed. Of course, applying XML security to a document means that the document is no longer human readable until after it is unencrypted.

systems that were designed to expect "mm/yy" dates will be unable to process the new "mm/dd/yy" dates. XML avoids this problem by tagging each data element (e.g., <Date Month=7 Year=61>). If new data must be added to the structure (e.g., <Date Month=7 Day=28 Year=61>), then old applications can still function correctly simply by ignoring the new data elements.

6.3. How XML Was To Be Used in DelTrac

In the original concept for DelTrac (see Figure 6–1), XML was to be used almost ubiquitously. [b] All interactions between DelTrac subsystems were transmitted as XML messages, data in the Data Repository was to be stored as XML document files, and meta-data used to define the Web DelTrac interface was also in the form of XML documents. Figure 6–1 depicts the portion of the initial design for the DelTrac architecture that centers on the Traffic Signal Control subsystem and marks those messages that were to be transmitted using XML.

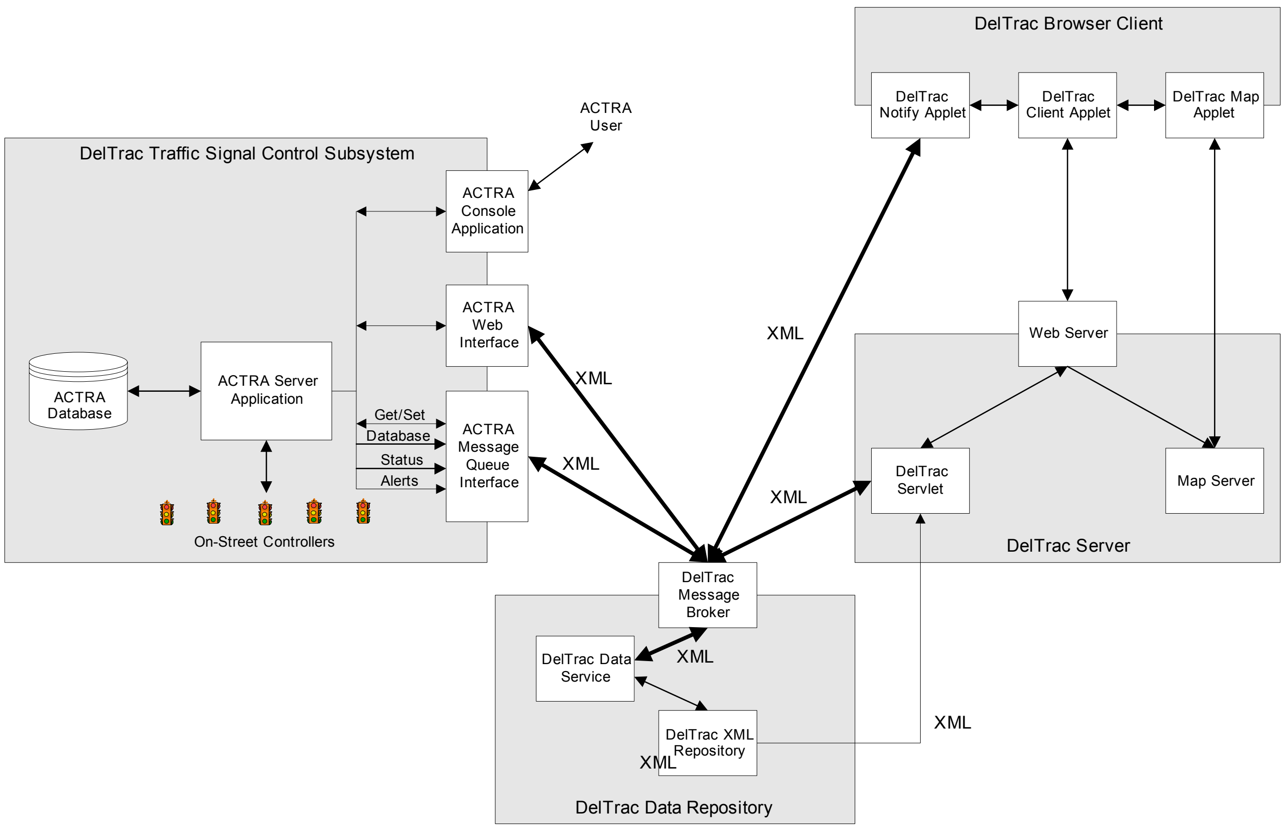


Figure 6–1. The Initial Concept for the Use of XML in DelTrac

The following list describes the key elements in this figure and their use of XML.

- The DelTrac Message Broker was intended to be a commercial off-the-shelf (COTS) software application that routes messages between applications. It would have been responsible for features

[b] Note that the DelTrac design discussed in this section was never fully implemented. Deployment difficulties caused some initial delays, which were exacerbated by institutional changes within the contractor organization developing the DelTrac infrastructure. By the time these issues were being resolved, advances in the available commercial technology made many of the custom DelTrac applications unnecessary and further development was delayed further while DelDOT considered whether to rethink the architecture to take advantage of the newer technologies. For a more complete description of the DelTrac deployment history, see section 3.0.

such as ensuring that each message reached its intended destination, that messages were delivered in the order they were received, and that messages could be broadcast to a list of applications that have registered to receive specific types of messages. The messages to be processed by this message broker were in the form of XML documents.

- The Actra Message Queue Interface was intended to convert information to and from XML for the Actra Server Application. For example, if a user of the DelTrac Browser Client made a change to a timing parameter for a traffic signal controller, the requested change would be transmitted through the Web Server to the DelTrac Servlet, converted to XML and passed through the DelTrac Message Broker to the Actra Message Queue Interface. The Actra Message Queue Interface would convert the XML request into COM method calls that instructed the Actra Server Application to perform the requested change.

- The DelTrac Data Service was intended to provide a similar service for the DelTrac Repository as the Actra Message Queue Interface did for the Actra Server Application – it would convert between XML requests and native requests (e.g., SQL) to the DelTrac Repository.

- The DelTrac Servlet was intended to route requests for services from the DelTrac Browser Client to the Web Interface for the correct DelTrac Application. For example, if a DelTrac Browser Client user clicked on a menu item, the DelTrac Servlet would recognize the menu item that was clicked and send a message to the DelTrac Application (via the DelTrac Message Broker) to process the users request.

- The DelTrac Notify Applet was intended to register with the DelTrac Message Broker to receive notification messages. For example, if a user was viewing the settings for a specific traffic signal controller, the DelTrac Browser Client might register to receive notification if another user changed the settings for that controller. If the Browser Client received a change notification, it could initiate a request to the DelTrac Server to update the data being displayed.

- The Data Repository was intended to store shared DelTrac data as XML documents. Whenever a DelTrac application changed shared data in the application database, it would also update the Data Repository to ensure that the data in the Data Repository and the application remained synchronized.

- The DelTrac Servlet was to rely on meta-data about the DelTrac applications to integrate the applications into a single Web interface. This meta-data would be in the form of XML documents that defined, for example, the menu structure that should be displayed and the action that should be taken when the menu item is selected. (See section 6.2 for a simplified example of such an XML document.)

In summary, the initial DelTrac conceptual design called for XML to be used both to store data and to transmit messages between DelTrac applications. In particular, the following four types of messages were defined in the DelTrac design documents.

- Get XML Messages. A Get XML Message requested that data be extracted from the DelTrac Data Repository, packaged as an XML document, and transmitted to the component requesting the data.

- Set XML Message. A Set XML Message requested that data in the DelTrac Data Repository be changed to the values in the Set XML message.

- App Server XML Message. An App Server XML Message requested that the Web Interface for a DelTrac Application process the XML message in order to provide the requested service.

- Alert XML Message. Alert messages were used to notify the DelTrac Browser Client or other DelTrac Applications of changes that occur in a DelTrac Application. For example, if one DelTrac user modified traffic control point data that is being reviewed by other DelTrac users, a Status Alert XML Message would be generated by the Actra Server and broadcast via the DelTrac Message Broker to all other DelTrac users that were reviewing that data.

Taken together, these four types of messages could support a broad range of integration between DelTrac applications. DelTrac applications could exchange data using Set XML Messages to update the Data Repository and Get XML Messages to retrieve data from the Data Repository. DelTrac applications could use App Server XML Messages to request services from another DelTrac application (e.g., the DelTrac Client Applet requests that Actra update signal timing settings for a signal controller). DelTrac applications can also respond to events that occur in other DelTrac applications through Alert XML Messages. (For more information on using messages to support application integration, see Appendix A.)

The DelTrac design documents also provided information on the look and feel of the DelTrac Client Applet, as specified by XML meta-data. The DelTrac Client Applet browser-based interface was to consist of two panels, a navigation panel on the left and a data panel on the right (see Figure 6–2). The navigation panel would allow the user to browse through an organized collection of objects from each of the DelTrac subsystems so that an object of interest could be selected, in which case data about that object would be displayed in the data panel.

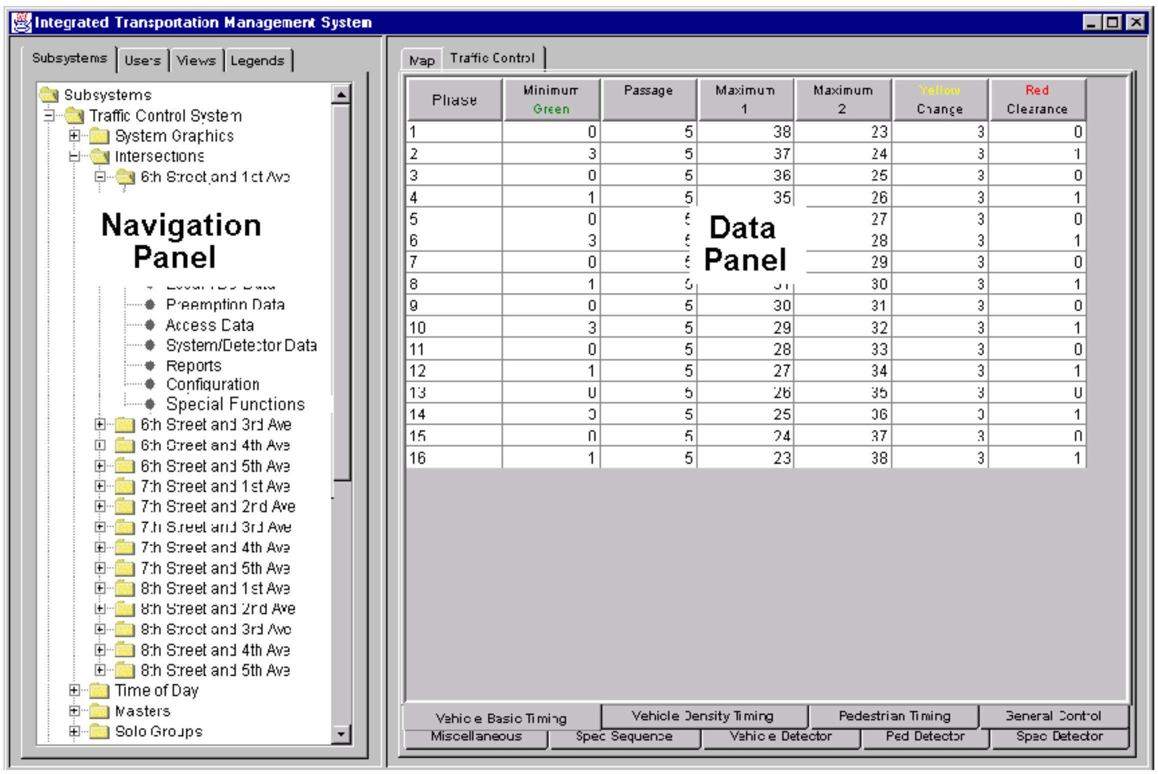


Figure 6–2. The DelTrac Browser-based Interface

In the example above, the user selected the Traffic Control System, a DelTrac subsystem, and then chose to view the phase data at the 6th Street and 1st Avenue intersection. The data panel then displayed the phase data for the traffic controller at that intersection. XML was used to specify the items that would appear as part of the menu in the Navigation Panel and the action that should be taken when a menu item was selected.

This conceptual design for the use of XML in DelTrac began to evolve even before the first design documents were completed. The first such change was the replacement of the file-based Data Repository with a relational database that was capable of generating and responding to data in the form of XML documents. Late in 2001, the first commercial relational database products with strong XML support were released. This allowed DelDOT to change the design for the Data Repository from an XML-document based design to one based on a COTS relational database. In this way, the Data Repository would combine the advantages of using XML interact with DelTrac applications with the increased speed, security, robustness, and accessibility of a relational database.

Lesson Learned 8 - XML is not the best approach for all messages.

A second change in the use of XML in DelTrac was prompted by the election to replace the XML-based Data Repository with a relational database. Using a XML file-based Data Repository required that DelTrac applications communicate with the Data Repository through the DelTrac Data Service, which would translate Get and Set XML Messages in order to update the XML files in the repository. With a database as the repository, applications could use direct database connections to update the Data Repository. In fact, custom DelTrac applications could be designed to use the Data Repository to store application data, eliminating the need for additional steps (e.g., Set XML Messages) to keep the application database and the Data Repository synchronized. Although the Traffic Signal Control subsystem was still designed to use XML (via Get and Set XML messages) to communicate changes in traffic signal control data to the Data Repository, DelDOT suggested that future subsystems would probably access the Data Repository database directly.

A third change in the use of XML in DelTrac was being considered at the time this report was being written in December 2003. One of the objectives of the DelTrac concept was to create a Web server infrastructure that would provide an interface to all DelTrac applications. The result would be a common transportation workstation that would be available to any computer that could access the DelTrac Web Server. The initial version of DelTrac achieved this objective by developing a Web Server application that used meta-data about the DelTrac applications to integrate the applications into a single Web interface. This meta-data was in the form of XML documents that defined, for example, the menu structure that should be displayed and the action that should be taken when the menu item is selected. (See section 6.2 for a simplified example of such an XML document.)

Lesson Learned 7 - Carefully manage the risks of using cutting edge applications.

Because of the deployment difficulties documented in section 3.0, the end of 2003 was reached without a working version of the DelTrac infrastructure in place. By this time, Web Portal technology had matured into commercial products that could provide services similar to those envisioned for the DelTrac Web Server – the ability to consolidate multiple Web-enabled applications into a user-customizable interface. As of February 2004, DelDOT was considering the use of a commercial Web portal, in which case the DelActra Web interface would be just one of the DelDOT applications available through the DelDOT Web portal.

Although the final design for the DelTrac infrastructure was not complete at the time of this report, Figure 6–3 depicts an architecture that is consistent with the discussions between the evaluators and the DelTrac designers. Notice that, in this design, the role of XML is no longer as strong and self-evident as in the initial design depicted in Figure 6–1.

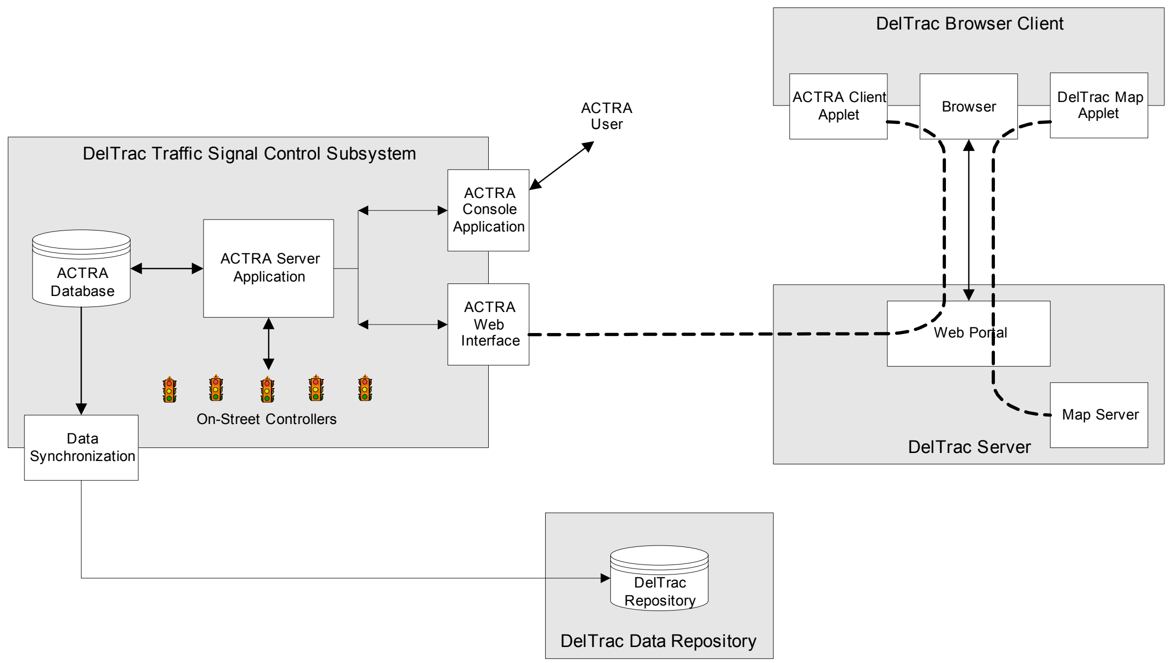


Figure 6–3. A Possible Final Concept for the Use of XML in DelTrac

To a large extent, this difference is because elements of the design that once required DelDOT to develop custom code are now subsumed by COTS applications. To a lesser extent, this is because the overall capabilities of the proposed system have been reduced. The Data Repository is one example where the XML capabilities are now embedded in a commercial application. In this case, DelTrac applications would have the capability of using XML to interact with the Data Repository, but could also use traditional database connections. Similarly, the DelTrac Servlet and its use of XML to store meta-data for integrating DelTrac applications has been replaced by a Web Portal, which connects the Browser with the various DelTrac applications that are part of the DelTrac Client Browser interface. Note that the interactions between the various client-side applications (e.g., the Actra Client Applet) and the associated application server could – and likely will – occur through exchange of XML data. However, this is no longer a requirement of the DelTrac design. Also, the access to data from the Data Repository (not shown in the figure) could occur either through traditional SQL statements or through the XML capabilities of the underlying database.

One area where the overall capabilities of the proposed system have been reduced is in relation to direct interactions between DelTrac applications. In the original design, one DelTrac application could request services from a different DelTrac application through App Server XML Messages and could respond to events that occurred at another application through Alert XML Messages. At the time of this report in February 2004, DelDOT does not have an immediate need for these types of interactions between DelTrac applications, so the DelTrac design limits the integration to sharing data between applications. DelDOT may revisit this issue in the future when the need for more sophisticated DelTrac application interactions is more immediate.

6.4. Example XML Messages

As described in the previous section, a working version of DelTrac that relied on XML messages was not completed during the period this evaluation was active. Indeed, the DelTrac concept began migrating away from an architecture that relied on an extensive set of XML messages. Furthermore, the lead contractor did not document the interfaces between the DelTrac components, which would have defined the XML messages that were to be used. (See section 5.2 for information about the consequences of not developing interface documentation.) Consequentially, it is not possible to present examples of XML messages from the DelTrac system. Instead, the remainder of this section will describe different types of sample messages that were documented in the DelTrac design documents.

The first example demonstrates an XML document that represents part of the DelTrac menu structure. In this example, each Subsystem is a top-level menu item in the DelTrac menu. The ID attribute for the subsystem uniquely identifies each subsystem.

```
<Subsystems Title="Subsystems">
   <Subsystem Title="Traffic Control System" ID="1A32FB29"></Subsystem>
   <Subsystem Title="Customer Event Tracking" ID="FF7690BA"></Subsystem>
   <Subsystem Title="Financial Systems" ID="2BA1543D"></Subsystem>
</Subsystems>
```

The unique Subsystem ID relates each Subsystem to additional XML documents that define the structure of each Subsystem. For example,

```
<Subsystem ID="1A32FB29">
   <Function Title="System Graphics" ID="98765432"></Function>
   <Function Title="Intersections" ID="87654321"></Function>
   <Function Title="Users" ID="21324354"></Function>
</Subsystem>
```

Another example is of a vendor configuration XML document, which lists a number of parameters used to control access to a specific DelTrac application.

```
<?xml version="1.0">
<!-- ActraXMLConfig.xml  Config File example Vendor Config XML file -->
<Config>
   <RunFreq>60</RunFreq>
   <OutputPathName>http:\\ITMS-web-01\xml\eagle\actra\data\</OutputPathName>
   <StatFreq>10</StatFreq>
   <StatPortNum>5000</StatPortNumber>
   <StatOutputPath>http:\\ITMS-web-01\xml\eagle\actra\status\
      </StatOutputPath>
   <LogOutputPath>http:\\ITMS-web-01\xml\eagle\actra\log\</LogOutputPath>
   <MonitorOutputPath>http:\\ITMS-web-01\xml\eagle\actra\monitor\
      </MonitorOutputPath>
   <ErrorOutputPath>http:\\ITMS-web-01\xml\eagle\error\</ErrorOutputPath>
   <InputPathName>http:\\ITMS-web-01\xml\eagle\actra\input\</InputPathName>
   <ControlSettings>disable</ControlSettings>
</Config>
```

Notice that most of these configuration parameters merely refer to the location where other types of XML documents can be retrieved from a DelTrac application. For example, the <StatOutputPath> tag content specifies where the DelTrac Server would locate Status XML messages. These status messages, which were to be used to notify other DelTrac subsystems of events that occur within the Actra subsystem, correspond to the Alert XML messages described previously.

There were no other examples of XML in the design documents provided to the evaluators. Perhaps the most important thing to note about these examples is not the specifics of the examples, but the small number of XML messages specified in the design documents and the lack of detail in those that were specified. The original design for DelTrac called for using XML to define the interfaces between DelTrac subsystems. In a component-based system, the definition of these interfaces is even more important then the definition of the user interfaces – whereas human users can normally adapt to minor modifications in an interface, a computer-to-computer interface is not likely to work correctly unless the interface is followed exactly. Because of this, XML interface messages should be documented with the same care that software interfaces between components are typically documented – each interface is completely documented and placed under configuration management so that the impacts of changes to the interface can be identified before any changes are allowed.

6.5. Alternatives to Using XML

Because XML is just one of many existing methods for storing structured data, there are numerous alternatives that could be used instead of XML. Before deciding to use XML for a particular use, these other alternatives, including some of which are described in the following list, should be considered:

- Ad hoc methods have long been used to support data exchanges, with each system that "owns" data prescribing the protocol that must be used to access that data. While ad hoc methods are typically easy to set up for the system that "owns" the data, they require that every user of that data to develop custom methods for interpreting the ad hoc data structures.
- Abstract Syntax Notation One (ASN.1) is an international standard for specifying data used in communication protocols. For example, ASN.1 was used to define the message sets in some ITS standards. It provides a very robust way of defining the structure of a message, similar to how an XML document type definition defines the structure of an XML document. Once a message structure is defined, one can apply any of several encoding rules, including rules for encoding data as an XML document, in order to store data. In general, ASN.1 is becoming less popular for specifying message content.
- Open Database Connectivity (ODBC) is an Application Programming Interface (API) that allows an application to interact with a database in a standard way. ODBC is the standard approach on Microsoft® platforms. In general, ODBC will be more efficient and flexible than XML when accessing data directly from a database in a client-server environment. It is less appropriate for a browser-based client or when accessing data from a source other than a database.
- Remote Procedure Calls (RPC) is a method for accessing methods in one application from another application. For example, a client application could directly access an Actra Server method to update a traffic signal control setting by issuing an RPC call from the client computer to the Actra Server. Common approaches to RPC are DCOM and CORBA, with SOAP often used if the remote calls must pass across the Internet. (Interestingly, SOAP uses XML to store the procedure call information.) RPC is appropriate for application-to-application interactions, especially when object-oriented techniques are used to develop the applications.
- Enterprise Java Beans (EJB) is an approach that, among other things, simplifies the application of Remote Procedure Calls for Java applications. EJB is appropriate for application-to-application interactions with Java applications.

Lesson Learned 8 - XML is not the best approach for all messages.

There are many other alternatives to XML that might apply to specific operating circumstances. One lesson learned during this evaluation of the DelTrac deployment is that XML is not necessarily the best approach for all XML messages. There are many alternatives to XML, such as those listed above, that should be considered. The decision of which approach to use should be made independently for each interface based on the particular needs of that interface.

6.6. Compatibility with ITS Standards

DelDot identified seventeen ITS standards that were considered during the DelTrac deployment, four of which were already approved before the DelTrac design was begun and thirteen that were under development or being planned. The four approved standards were:

- AASHTO 2001, NTCIP - Class B Profile (approved 3-1-1998).
- AASHTO 1202, NTCIP - Object Definitions for Actuated Traffic Signal Controller Units (approved 4-1-1997).
- AASHTO 1203, NTCIP - Object Definitions for Dynamic Message Signs (approved 10-1-1997).
- AASHTO 1204, NTCIP - Object Definitions for Environmental Sensor Stations (approved 10-1-1998).

DelDOT adhered to ITS standards by selecting NTCIP-compliant traffic signal controllers. In general, there were no approved ITS standards that covered messaging between the subsystems that were developed as part of this DelTrac deployment. Consequentially, these messages were not developed to comply with any specific ITS standards.

6.7. XML and Data Security

When the project to develop a DelTrac version of Actra began, security of XML messages was a concern. At that time, no security standards existing for safeguarding XML messages and secure methods for connecting to a network over the Internet were still being developed. Also, the proposed approach of using XML files to store data in the Data Repository did not provide the data security features that are common when using a database to store data.

For example, most relational database engines require a user to log in before accessing data in the database, and the privileges of each user to access and modify data are restricted. The database will also include numerous other features meant to safeguard data, such as data locks to prevent data inconsistencies when different users from simultaneously modify the same data and transaction processing to prevent data inconsistencies when only a few of a series of related data changes can be applied. These data security features were not available with the original concept for a file-based Data Repository. The design change from a file-based Data Repository to a database gave DelDOT the tools to better secure the data in the Data Repository.

Another potential security threat relates to the XML messages themselves. XML messages are, by definition, plain text messages that are easily interpreted and easily produced. This makes it easier for a malevolent user with access to the communications network to submit false messages, which would be unacceptable for safety-sensitive application like a traffic signal control system. DelDOT intended to help ensure security of this system by limiting its use to those physically connected to the DelTrac network. Of course, this also limited the advantages of developing a Web-based common transportation workstation.

Since the DelTrac Actra project began, technology has made these concerns less relevant. First, virtual private networks allow secure access to intranets through firewalls, enabling DelDOT to deploy DelTrac on an intranet that is protected from outside users by the standard assortment of network security tools. Valid users who are not physically connected to the network can use off-the-shelf virtual private network tools to access the network. If additional security is desired (e.g., to help prevent users with access to the DelTrac network from sending inappropriate XML messages), new XML encryption and security standards are now available that provide message authentication and security.

6.8. Application of XML-Based Tools

DelDOT's current design for DelTrac takes advantage of two existing XML-based tools. First, the message broker, which is responsible for managing communications between all DelTrac subsystems, uses XML to format the messages that are communicated between these subsystems. Second, the Data Repository is a relational database that provides support for storing and retrieving XML data. The use of both of these tools provided significant functionality to the DelTrac project through off-the-shelf products. In general, since the initial design concepts for DelTrac were developed, these designs have been migrating from the development of custom tools that use XML directly to providing needed DelTrac functionality through the use of off-the-shelf tools.

7.0. Steps Taken to Merge Freeway, Arterial, Emergency, and Transit Management Systems Together

7.1. Overview

One of the key elements of the DelTrac program was the integration of freeway, arterial, emergency, and transit management operations that are often managed by separate entities within a State and/or separate organization within the State DOT.[a] This separation of responsibility results in numerous difficulties and can make implementation of an integrated system difficult. Some of these difficulties include the following:

- The development of an integrated system requires compatible long-term plans among all of the stakeholders, which often requires an unprecedented level of cooperation among them.
- The components of an integrated system are designed to provide services to multiple organizations, making cost allocation difficult. The cost of deploying and maintaining an integrated system can be greater than the costs for a stand-alone system and it may not be clear whether this additional cost should be borne by the primary "owner" of the system or shared among the stakeholders. Also, some components are common to all stakeholders and do not have a clear owner, thus presenting another cost allocation complexity.
- The existing or planned technologies at different organizations might be incompatible, and organizations may have to compromise some of their plans in order to achieve better integration.

The purpose of this section is to describe the specific steps taken to merge freeway, arterial, emergency, and transit management systems together in the DelTrac program.

7.2. The Delaware Freeway, Arterial, Emergency, and Transit Management Systems

Because of the limited amount of freeway miles in Delaware, less separation between freeway and arterial systems in Delaware was observed than exists in many other states. The Division of Highway Operations managed both roadway systems, though construction and maintenance activities for expressways and for each of the three districts in the state were managed separately. Freeway and arterial operations were not separate at DelDOT.

Transit was managed by a division of DelDOT, the Delaware Transit Corporation (DTC). Despite being part of DelDOT, prior to DelTrac there was not a history of strong interaction between DTC and other DelDOT divisions. After DelTrac began, the level of interaction between DTC and the rest of DelDOT increased significantly.

A long history of good working relations between emergency management and DelDOT was reported, and the DelTrac program took steps to further that level of interaction. For example, in December 2000, the statewide TMC relocated to the Delaware Emergency Management Agency (DEMA) facility. This and other steps greatly facilitated the level of DelDOT and emergency management interaction.

More recently, DelDOT reorganized in a manner that directly merged freeway and arterial management, (see Section 2.1). In this new organization chart, Maintenance and Operations has the combined responsibility for inspecting, maintaining, managing, and operating Delaware roads, bridges, and toll facilities. Transportation Solutions has the responsibility for project development and construction.

[a] In Delaware, management of most transportation assets – including freeway, arterial, and transit – is performed by DelDOT. DEMA has responsibility for emergency management operations in Delaware.

Within this organizational structure, the traditional segregation of freeway, arterial, and toll construction, operations, and maintenance have been completely removed.

7.3. Merging the Transit Management System

When the DelTrac program began, DTC was an operating division of DelDOT that managed Delaware transit services, including fixed route bus, paratransit, and commuter rail, as well as other transit-related services like park and ride facilities and a ridesharing program. Despite being an operating division within DelDOT, there was little interaction and coordination between transit and other DelDOT operations. In fact, DTC had little interest in implementing ITS technologies such as AVL for its transit operations and was not actively participating in the DelTrac program.

DTC's involvement with DelTrac began with an effort to upgrade or replace their radio system, which was not Y2K compliant. DTC was planning to modify their existing 450-MHz radio system. During this planning phase, they were encouraged by the Delaware Secretary to work with the ITS Administrator to select a radio system that would be compatible with other DelDOT plans. DelDOT was considering a 821-MHz radio system for DelDOT operations. DTC was at first resistant to this approach because the costs were significantly higher – about $4,000 for a digital, 821-MHz radio versus about $1,000 for an analog, 450-MHz radio. After careful consideration involving compromises from both sides (e.g., use of DelTrac funds to offset some of the additional cost, addition of a transit console at the DelDOT TMC), DTC elected to use the 821-MHz system.

The choice of the 821-MHz radio system and the increased integration this brings with DelDOT traffic operations led directly to benefits that were recognized by both parties. For example, the new radio system allowed DTC to create share talk groups at the TMC when a traffic problem (e.g., failure of traffic signals along a bus route) was detected. This has helped DTC respond more quickly and effectively to traffic problems that could disrupt their transit services. This success, in turn, helped lead to higher levels of coordination that resulted in other improvements, such as those listed below:

- During some construction activities that had the potential to delay DTC fixed route buses, queue-jumping signals was used on one occasion to reduce the additional delay experienced by DTC buses and help them maintain their schedules. Prior to the DelTrac program, the impact of construction activities on transit operations was not typically considered.

- When communications were being deployed for DelTrac signal operations improvements, the fact that DTC was planning for kiosks and other bus information systems at bus shelters was considered. Additional junction boxes were installed near bus shelters to support future bus shelter enhancement plans.[b] Prior to the DelTrac program, the potential synergies between the traffic signal communications project and future transit projects were not likely to be considered.

In addition to these successes, which hinged mostly on organizational integration, DelTrac also succeeded in integrating transit plans for ITS into the DelTrac program. For example, DelTrac literature (see Figure 2–4 on page 15) listed twenty-two DelTrac technologies that are planned, along with the TMC that was central to the application of these technologies. Of these, five were directly related to transit operations:

- Transit Schedule Adherence/AVL System.
- Transit Priority Treatment System.
- Kiosks.
- Real-time Website.
- Bus/Rail Stop Information System.

[b] These kiosks have not yet been deployed.

This fact indicated the high degree to which transit ITS plans had been successfully integrated into DelDOT ITS plans. The anecdote listed previously, in which plans for pulling fiber to support traffic signal operations were modified to provide better support for future transit ITS, provided further evidence of the degree of integration that was achieved.

When DTC personnel were asked to note some of the key items that led to these successes, they noted the following.

- **Education.** When DTC first began cooperating more closely with other DelDOT operations, the different agencies had little understanding of each other's missions or operations. The process of working together on some projects (e.g., selecting a radio system, Dover International Speedway race transportation) led to a greater understanding of each other's organizations, which led to even better future coordination. One important part of this education is an understanding of how each organization can benefit from others. For example, DTC educated traffic operations personnel on the benefits of using bus drivers for traffic monitoring.

- **Shared technology and infrastructure.** Incompatible technologies can create barriers that limit coordination. Using shared technologies, like the 821-MHz radio system, helps eliminate these barriers and creates opportunities to enhance operations that are difficult to identify while those barriers are in place. An important type of shared technology is the basic infrastructure needed to support coordination, such as shared radio communications and shared network access.

- **Skilled personnel.** ITS presents both technical and cultural challenges to an organization – technical because of the technology involved and cultural because the benefits of ITS are only achieved if they result in operational changes within the organization. It is important that an organization have the right personnel available to manage these challenges.

- **Minimize funding competition.** One of the difficulties often encountered in coordinating activities between different organizations is related to funding the activities – each organization tries to protect its funds from being used to help other organizations. One result of this approach is a lack of emphasis on integration and coordination in ITS projects. At DelDOT, all ITS funds are allocated through the DelTrac program (see Figure 7–1). This helps DelTrac management to ensure that all DelTrac projects consider the integrated needs of all the DelDOT organizations that have a stake in that project.

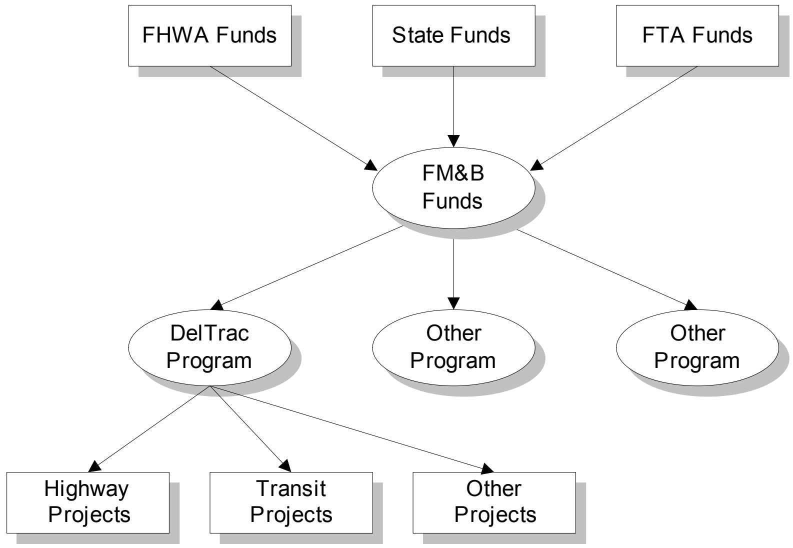


Figure 7–1. The DelDOT Funds Allocaton Process

- **Establish processes to facilitate coordination.** Almost every ITS project has the potential to benefit multiple stakeholders. For example, DTC identified that event management activities at the TMC could help DTC re-route bus traffic when an event occurs and that an advanced traffic signal control system could be used for transit signal pre-emption. An ITS program should have processes in place to help ensure that these opportunities for cross-organizational benefits are identified. One important process at DelDOT was the DelTrac Administrative Committee, which gave each organization in DelDOT a fair voice in resolving institutional issues.

7.4. Merging the Emergency Management System

As with other facets of DelTrac integration, merging of Delaware emergency management operations has occurred through a combination of institutional and technical activities. On the technical side, there are three DelTrac ITS projects that are directly related to emergency management:

- Motorist assistance patrols to provide faster DelDOT response to incidents that occur.
- #77 cellular reporting service to help motorists reports incidents that they observe.
- Interface to police and fire dispatch to speed notification at the TMC of incidents that occur and to help coordinate DelDOT and police/fire incident response.

Lesson Learned 10 - A flexible strategy is necessary to manage potential schedule delays.

In fact, one of the success stories of DelTrac to date is the police and fire dispatch interface with the TMC. While the DelTrac traffic signal control project, which was the focus of this evaluation, experienced deployment difficulties that delayed the deployment of the DelTrac Data Repository and other key elements of the DelTrac infrastructure, the police and fire dispatch interface was completed and was operating on a database that DelDOT intended to scale up into the DelTrac Data Repository.

In addition to these three projects, DelDOT noted that each DelTrac traffic surveillance project (i.e., the video monitoring system, the electronic detection system, the aerial monitoring system) had the potential to help detect incidents more quickly and monitor incident response activities. Also, it was noted that each DelTrac traveler information system (i.e., the telephone information system, the travelers advisory radio system, the dynamic message sign system, and the real-time Website) had the potential to reduce the impacts of incidents that did occur. The DelTrac approach to managing ITS activities by involving all stakeholders – including emergency management stakeholders – in ITS deployments helped ensure that emergency management needs were considered in the design of each ITS project.

The involvement of emergency management stakeholders in the design of DelTrac ITS activities is also the key institutional step that helped merge the Delaware emergency management system into DelTrac. One result of the institutional involvement of the three key stakeholders in Delaware emergency response – the Delaware Emergency Management Agency, the Delaware State Police, and DelDOT – was the choice of location for the new DelDOT TMC. This TMC was located at a DEMA facility, which will help DEMA benefit from the TMC technologies when an emergency occurs.

8.0. Integration of Legacy Systems Into a New System

8.1. Overview

For DelTrac, few of the systems that will eventually be integrated into DelTrac were pre-existing, so the problem of legacy systems was slight. The primary legacy system was the Traffic Signal Control subsystem, and this system was upgraded in order to become part of the DelTrac integrated transportation management system. (See section 6.0 for more information on how DelTrac integrated subsystems into an integrated transportation management system.)

Despite the fact that DelTrac, as of the time of this evaluation, did not require integration of any legacy systems, the DelTrac system was designed to accommodate legacy systems. In fact, DelDOT reported that the design for the DelTrac Data Repository was very similar to another data integration system at DelDOT known as the Enterprise Data Exchange Engine (EDEE). Like the DelTrac Data Repository, EDEE provides a framework for sharing data, with DelTrac focusing on DelDOT ITS data and EDEE focusing on data that is essential to DelDOT as a whole. DelDOT does have experience integrating legacy systems with EDEE.

8.2. Migrating Away From Legacy Systems

Legacy systems are difficult to replace for a number of reasons. The most prevalent of these are listed below:

- Legacy system data may be difficult to access. Legacy systems often use custom or proprietary data storage techniques. Accessing this data may not be possible (e.g., for a proprietary system where the vendor will not provide documentation and tools for accessing the data) or require developing custom tools (e.g., for data stored using a specialized file structure). If some cases, data can be accessed using "screen scraper" technology that extracts the necessary data from reports that are usually sent to the screen or a file. If one cannot obtain access to the legacy data, little can be done to migrate away from that system and a simple replacement may be required.

- Legacy system functionality may be difficult to access. Legacy systems typically use older software architectures that do not expose an API that provides other software access to the functionality of the legacy system. Providing access to legacy system functionality (e.g., to produce a Web interface to the legacy system) will be difficult if an API is not available. In some cases, legacy system functionality can be accessed by developing custom tools that simulate the appropriate user interaction with the legacy system. In other cases, it may be easier to simply emulate that functionality by developing new software that makes the appropriate changes to the legacy data – assuming one has read-write access to that data. As a general rule, the primary reasons for accessing or emulating legacy system functionality is to ease the migration away from the system or to provide an improved user interface for a legacy system that is too difficult to replace.

- Legacy system activities may be difficult to monitor. Legacy systems typically use older software architectures that do not broadcast events when critical activities occur (e.g., traffic signal timings are updated). If the legacy system uses a modern relational database, critical events can sometimes be generated by database triggers that "fire" when database changes occur. Because users and other systems are already functioning without responding to events within the legacy system, it is seldom required to expose legacy events.

- Legacy systems are often mission-critical systems that are used by a large number of other users and other systems. Replacing a mission-critical system requires that the replacement system be completely reliable, a requirement that is difficult to achieve without "live" testing of the new system. If a large number of users and other systems rely on the legacy system, then replacing that system also requires upgrading each of these other systems and retraining each of these users. Because the simultaneous replacement of a legacy system, upgrade of each system that depends on it, and retraining of each user is typically not possible, replacement of a legacy system usually consists of a slow migration away from the system.

Taken together, these difficulties are often enough to prevent the replacement of the legacy system.

8.3. Legacy Systems at DelDOT

At the time of this evaluation, there were no legacy systems integrated into DelTrac. DelDOT did identify several legacy systems that might require integration in the future, including the traffic detection element of the Traffic Signal Control subsystem; the AVL and CAD systems used to manage the transit fleets; the ATIS procedures; and the DelDOT asset management systems as legacy systems. The following paragraphs summarize information about these legacy systems and how they might be integrated with DelTrac.

Electronic Detection (from Traffic Signal Control subsystem). A large number of electronic detectors were associated with the traffic signal controllers in the DelTrac TSC subsystem. DelDOT had planned to extract this data so that the detector data could be used to supplement other traffic detectors. However, the detectors were tied directly to the traffic signal controllers in the field, and these controllers did not include the capability to export that data. DelDOT began working with the vendor to gain access to that data. At the time of this evaluation that effort was placed on hold while other difficulties with the TSC subsystem were resolved.

Lesson Learned 6 - Avoid proprietary data and closed, proprietary systems.

AVL. DTC completed the AVL deployment in May 2001, and planned to make vehicle location available from transit kiosks and the DTC and DelTrac Web sites. However, this information was contained within a proprietary systems purchased to support transit operations.

Transit Priority. DelDOT planned to implement a transit priority treatment system in the future, but no work had been done on the system at this time.

8.4. The DelTrac Approach to Integrating Legacy Systems

The DelTrac focus on integration lent itself naturally to helping with legacy systems because, as described above, one of the biggest limitations with legacy systems is the inability to integrate them with other systems. By focusing on integration, DelDOT managed to address issues of legacy systems naturally, as demonstrated in the following two examples:

- Focusing on integration helps improve upgrades to a legacy system. An example of this at DelDOT was the choice of an 821-MHz radio system for DTC when an upgrade to the DTC radio system was required (see section 4.2). DTC's initial plans were to upgrade their existing radio system. This would have resulted in a radio system that was not compatible with the radio system planned for other DelDOT organization. DTC acknowledged several benefits were received from selecting a compatible radio system.

- Focusing on integration can help prevent legacy problems in the future. In order to reduce the likelihood that new systems might become difficult-to-integrate legacy systems in the future, DelDOT considered the future uses of each DelTrac subsystem during its design. For example, even though there was no immediate use for shared traffic signal control information, the design for the new TSC subsystem required that data from this subsystem be available through the DelTrac Data Repository. This emphasis on the future integration needs was common at DelDOT.

Although there were no examples of legacy systems integrated with the DelTrac infrastructure during the course of the evaluation, DelDOT personnel were well aware of the potential for the DelTrac infrastructure to facilitate the migration away from a legacy system. For a legacy system, integration with the DelTrac Data Repository could serve as a first step in migrating away from the legacy system. Once a legacy system is integrated with the Data Repository, the other systems and users that rely on it can be upgraded to use data from the Data Repository, instead. Removing the dependencies of other systems on the legacy system would make it much easier to replace.

8.5. Legacy Systems in the Traffic Signal Control Subsystem

As depicted in Figure 8–1, the only true legacy elements in the Traffic Signal Control subsystem of DelTrac were the on-street controllers – all of the other elements of the system were introduced with the DelTrac deployment.

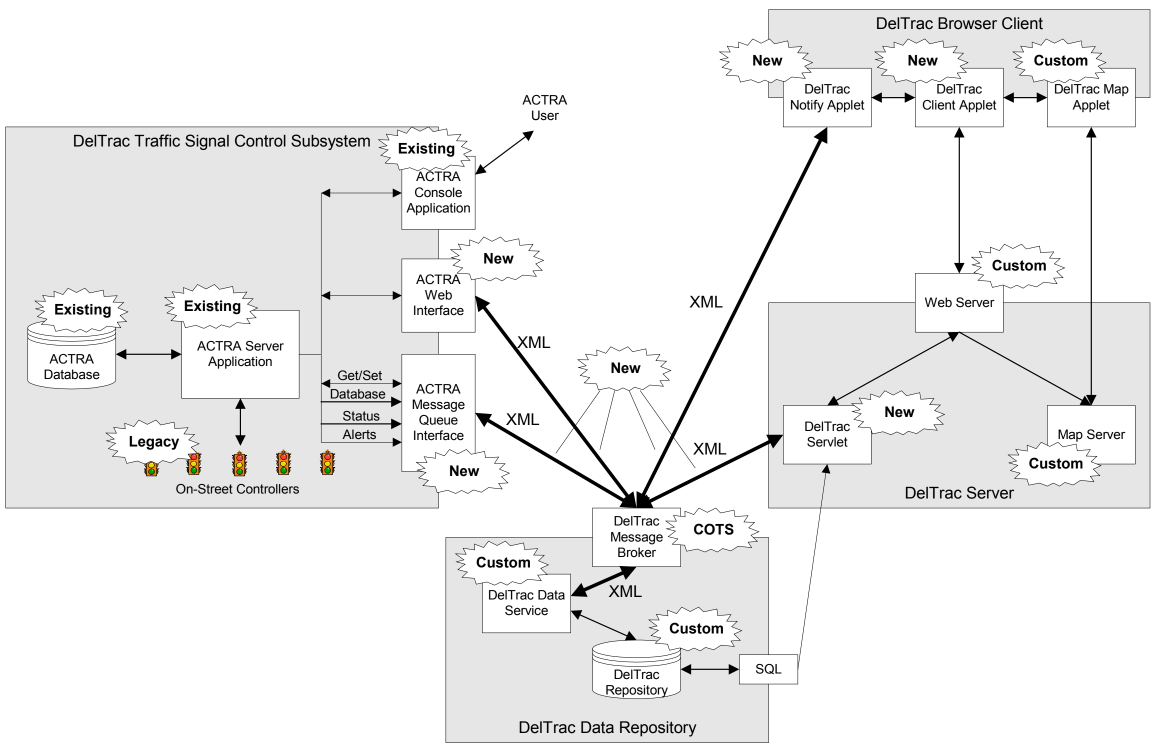


Figure 8–1. Legacy Systems in the Traffic Signal Control Subsystem

Even in the case of these controllers, hardware upgrades were applied to make them compatible with the Actra signal control system that was being purchased. In fact, this was common theme to the DelTrac projects – these projects involved new development rather than integration of legacy systems.

9.0. Summary

9.1. Summary of the Evaluation

The primary objectives of the DelTrac project reviewed during this evaluation were to:

- Develop an application infrastructure for integrating DelTrac subsystems so that each subsystem would be able to use the data and services of other DelTrac subsystems.
- Develop a Web server infrastructure that would consolidate DelTrac subsystems into a single Browser-based application, resulting in a common transportation workstation.

These objectives were to be met in conjunction with deploying a new traffic signal control system for DelDOT, and the TSC system would be the first DelTrac subsystem to interface with the DelTrac application and Web server infrastructure.

Although this specific project did not result in a successful and timely deployment of the DelTrac infrastructure, the deployment was, in a way, a remarkable demonstration of the strength of the concepts underlying these objectives. On its surface, it appeared that the plans for the DelTrac deployment changed dramatically during the evaluation period. An XML database was replaced by a relational database that includes an XML interface. A custom Web Server driven by XML documents may be replaced by a commercial Web Portal. Alert and service requests were dropped from the DelTrac design. Nonetheless, the primary objectives of DelTrac and the basic approach for achieving it (i.e., by establishing an application integration infrastructure and a Web server infrastructure) has remained the same.

What has changed is the technology DelDOT intends to use to achieve these objectives. When the DelTrac deployment began, DelDOT recognized the promise of XML as a basic tool to facilitate communication between DelDOT subsystems. However, few commercial products were available that used this new tool to provide the types of functionality that DelDOT needed for DelTrac. DelDOT and their lead contractor took on the difficult task of developing that general-purpose functionality from scratch. Meanwhile, in the commercial world, commercial products were being developed to provide the general-purpose functionality. By the time the DelTrac contractor was beginning to overcome the difficulties faced during the deployment, COTS packages were available that provided much of the general-purpose functionality that DelDOT was seeking.

This project also demonstrated some of the strengths of the DelDOT approach to managing their ITS program. From the beginning, the ITS leaders at DelDOT worked to involve stakeholders from throughout DelDOT in the ITS process. The emphasis was not on pushing ITS deployment, but on encouraging DOT employees to help identify how ITS could help solve transportation problems in Delaware. Efforts were also made to secure the support for DelTrac from key DelDOT management and important stakeholders outside of DelDOT.

The evaluators believe that the difficulties with the project to deploy the DelTrac infrastructure had the potential to cause additional problems for the DelTrac program, as a whole. This project was expected to be the first to demonstrate the power of integration, and the purpose of DelTrac was to create an integrated transportation management system. One might question whether integration across DelDOT was feasible given that integration of a single subsystem was so difficult. However, those with whom the evaluators spoke remained optimistic about ITS at DelDot, recognizing the shortcomings of this deployment, identifying how to avoid those shortcomings in the future, and continuing to plan for future DelTrac deployments.

For example, while the DelTrac traffic signal control integration project was failing to develop a DelTrac infrastructure and integrate into it, a project to integrate the police/fire CAD systems with TMC operations succeeded. Despite the lack of success in providing a portal to all DelTrac applications, DelDOT is evaluating Web portal technology that will provide a common interface not just to DelTrac applications, but to all DelDOT, Web-enabled applications. Despite the difficulties in deploying a common transportation workstation for DelTrac, DelDOT managers maintained their belief in the value of a common application interface and will likely apply this concept to DelDOT applications department wide.

Another important sign for the future of DelTrac is the increasing levels of cooperation and integration among transportation-related organizations in Delaware, brought about in part by the DelTrac program. Traffic operations, the Delaware Transit Corporation, the Delaware Emergency Management Association, and the Delaware State Police all make use of the new TMC. A new bus-only lane facilitates transit during Dover International Speedway events, helping to relieve congestion. Transit drivers help traffic operations by reporting problems they observe on their routes, and data from the TMC helps transit more quickly respond to traffic events that might disrupt their schedules.

Perhaps the final word on this evaluation should be simply that the organizational strengths underlying ITS deployment at DelDOT were more than enough to overcome the technical challenges and difficulties they faced in the DelTrac traffic signal control project.

9.2. Summary of Lessons Learned

Table 3 summarizes the lessons learned noted during this evaluation, with more detailed descriptions of these lessons learned provided in the text that follows this table.

Table 3. A Summary of Lessons Learned

Lesson Learned	Page	Planning	Design / Engineering	Deployment	Operation / Maintenance
Focus on solving transportation problems, not implementing ITS.	60	✓	✓		
Include ITS in the long-range plans for the department.	61	✓			
Try to not do too many things in parallel.	62		✓	✓	
Plan the program to produce enough wins along the way in order to maintain the momentum of support.	62		✓		
Be certain to proactively manage personnel issues related to applying ITS technologies.	62	✓		✓	✓
Avoid proprietary data and closed, proprietary systems.	63		✓	✓	
Carefully manage the risks of using cutting edge applications.	64		✓	✓	
XML is not the best approach for all messages.	65			✓	✓
The design of the message-based interface between subsystems is one of the most important steps in integrating ITS subsystems.	66		✓	✓	✓

Lesson Learned	Page	Planning	Design / Engineering	Deployment	Operation / Maintenance
A flexible strategy is necessary to manage potential schedule delays.	68	✓	✓		
The traditional procurement process may not offer the flexibility needed to support ITS procurements.	69	✓	✓		
The planned budget should account for uncertainties in the design and in the availability of skilled labor.	69		✓	✓	

Lesson Learned 1 - Focus on solving transportation problems, not implementing ITS.

DelTrac is not so much an approach to implementing ITS, as it is an integrated approach to managing a transportation system that makes use of ITS technology to meet transportation system objectives. The goal, first and foremost, is to figure out how to better manage the transportation system. This viewpoint brings with it a couple of advantages.

First, it focuses immediately on how to address the problems of the transportation system, not on the "gee-whiz" qualities of ITS. For example, a fundamental problem facing many transportation planners today is how to get more capacity out of the existing roads – the traditional solution of building your way out of capacity limits just no longer applies. In many cases, the solution to this problem involves advanced technology. Traveler information helps optimize traveler distribution on the roadway. Ramp meters help prevent over-crowded highways that can result in reduced capacity. Adaptive traffic signal controllers can adjust signal timings to improve traffic flow. So, ITS is introduced not as a technology looking for an application, but as a solution to real problems that already exist. This focus on solving transportation problems will help win support within the transportation organization and with the public, elected officials, and other important stakeholders whose support is necessary for any successful transportation program.

Second, it helps ensure that you deploy just the technology you need just when you need it. The transportation needs differ from place to place and department to department in the United States, and technology that makes sense for one department may not make sense for another. For example, much of the traffic in Delaware is carried on signalized highways, and controlling the signal timing is a key factor in maintaining capacity on those highways. Thus, a long-term objective for DelTrac is establishing an adaptive signal control system, and many of the initial DelTrac ITS deployments were steps towards meeting that objective. In other areas of the country, the capacity of limited access highways is the bottleneck in the transportation system, and an adaptive signal control system would have a much lower priority.

At DelDOT, ITS was not implemented via a special team that was responsible for deploying ITS. Instead, ITS advocates were distributed across DelDOT so that they could educate others in how ITS could improve projects that were being planned. In this way, project managers became willing and active participants in ITS deployments they helped design instead of reluctant partners in ITS deployments that were thrust upon them. This resulted in broader application of ITS in those projects where it could result in the most benefits.

To be sure, there was a need for a second track of ITS deployment activities that was not based on existing projects. In some cases, achieving the most out of ITS requires re-organizing the way you do business and, in particular, better integrating activities between offices within the department. Department organizational structures that made sense when data was scarce, data sharing difficult, and data processing limited, may not be best for a highly integrated, data-rich environment. Also, the integration necessary to achieve these benefits probably requires shared technology infrastructure that will not develop by considering individual projects. At DelDOT, a DelTrac Administrative Committee, which was comprised of leaders from across DelDOT organizations and led by the ITS Administrator, provided the top-down, department-wide view of ITS at DelDOT that helped address these big-picture issues.

Lesson Learned 2 - Include ITS in the long-range plans for the department.

This is almost a corollary to the previous item; if the focus of ITS is on solving transportation problems, then ITS should be subject to the same planning process as other approaches to solving transportation problems. This has the obvious advantage for the department of exposing ITS projects to the same competition for funding as traditional projects, so the department can be more certain that ITS projects are being implemented because they are cost-effective solutions to transportation problems. However, there are also a number of significant advantages for ITS:

- Including ITS in the long-range plans for the department helps ensure more stable, predictable funding for ITS projects, which can allow for better planning for ITS projects. This can allow ITS managers to deploy ITS in a more logical and consistent manner.
- Integrating ITS as part of the department's long-range approach to transportation requires upper management to buy-in to the promise of ITS – and requires ITS managers to sell the ITS approach. Winning buy-in as part of the department's long-range plans is often easier in the long run than winning on-going battles for approval for each project.
- The combination of management support indicated by inclusion in the long-range plan, better justification for ITS in terms of expected transportation benefits, and better integration with other transportation projects can also result in better buy-in for ITS across the department.
- A long-range plan for ITS can result in more cost-effective deployment choices. For example, in Delaware the long-range plans for ITS called for connecting many miles of road to a common telecommunication backbone. Then, actual installation of segments of this backbone was tied, whenever possible, to existing building or maintenance projects, resulting in much more cost-effective fiber installation. As another example, a primary radio license became available in 2000, well before the ITS infrastructure was in place to provide real-time traffic information to use this station for travelers advisory radio. However, because the long-range plans at DelDOT called for radio broadcast of traveler information, DelDOT was ready to take advantage of the opportunity that did arise.
- A long-range plan for ITS can result in better deployment decisions. For example, if long-range plan calls for signal priority for transit vehicles, then a traffic signal control system can be selected that has the capability to support this feature.

One example of how ITS was integrated in DelDOT's long range plans is the direct reference to the DelTrac program in the 2002 Statewide Long-Range Transportation Plan. This plan notes that, "we will improve the management of Delaware's transportation system through the application of Intelligent Transportation System (ITS) technologies." This level of commitment to ITS was observed not just in the planning documents, but also in the personnel with whom the evaluators spoke.

Lesson Learned 3 - Try to not do too many things in parallel.

Each ITS application brings with it project risks associated with deploying new technology in the department and training staff to use the new technology. Such risks are multiplied because of the integrated nature of ITS deployments – if two interacting applications are being developed simultaneously, then changes in either system will affect the development of the other, multiplying the risks of both projects. Also, placing department staff in an environment of constantly changing technology can make it difficult for them to learn and use that technology.

At DelDOT, some symptoms of too rapid an ITS implementation schedule were noted. The *State of ITMS* report pointed out that DelTrac construction activities were unable to keep up with the levels of available funding. The need for DelDOT staff to learn new systems and support new deployments while still operating and maintaining the transportation system led to inadequate staffing levels. In many cases, time for important activities for efficiently using the new systems, such as training and developing operating procedures, was not available. In-house construction inspection services could not satisfy the need for construction inspection activities. These staffing limitations also led to greater use of consultants, which increased DelTrac costs.

Lesson Learned 4 - Plan the program to produce enough wins along the way in order to maintain the momentum of support.

Remember that ITS technologies are invisible, and this invisibility can be a major impediment to maintaining long-term support. If visible outcomes of the ITS deployments are not produced – and publicized – regularly, stakeholders may develop the impression that these deployments are not generating results. Projects that do not generate results will not survive. One way to help ensure that an ITS program produces outcomes is to tie each project to existing transportation problems, then to measure the changes in that problem as the ITS deployments proceed. If ITS is expected to decrease congestion, then measures of congestion and congestion relief (e.g., the proportion of drivers that adjust their travel time to avoid heavy congestion) should be performed.

Also, be careful to look out for other benefits derived from the increased cooperation generated through efforts create an integrated transportation system. For example, a much closer working relationship between transit and traffic management was created because of work on DelTrac. In several instances, this closer cooperation resulted in better consideration of the impact of construction on transit operations and implementation of mitigation measures (e.g., signal priority) during construction. In another instance, construction of a bus-only lane was included in a project to help relieve congestion around the Dover International Speedway.

Lesson Learned 5 - Be certain to proactively manage personnel issues related to applying ITS technologies.

Full utilization of ITS will require that department personnel integrate ITS into how they do business, which will require that these personnel become accustomed to the new technology. And, installing, operating, and maintaining the ITS infrastructure, with its communications optic networks and variety of application servers, will require people with different skill sets than traditional transportation workers. At DelDOT, keeping existing personnel ahead of the ITS learning curve and hiring new workers to provide the necessary technical support for the ITS infrastructure was a challenge.

Early in the DelTrac program, DelDOT noted limitations with both the number and skill sets of available staff. This situation was worsened as DelTrac projects were completed because each project introduced additional technology that required new operation and maintenance activities. Oftentimes, these projects included technology with which the existing DelDOT staff was not familiar. In response to these staffing limitations, DelDOT was forced to introduce new training programs, which further restricted the amount of time available from existing staff. DelDOT also used consultants more often, which increased program costs.

A related difficulty was the lack of sufficient standard operating procedures and policies for operating the TMC. The lack of available, trained staff made development of operating procedures difficult, and the lack of operating procedures made it difficult to train staff in the correct response procedures. The requirement to train existing staff in how to use new systems, to obtain new staff to help maintain them, and to develop operation procedures for how to use them should be part of the planning process for deploying ITS projects. All of these problems were noted by DelDOT in 2000 as part of a draft report on the state of the DelTrac deployment – seven of sixteen issues noted in that report had to do with staffing problems.

One of the challenges in addressing this difficulty is to convince upper management that the right people are needed to do the job and that the right training is necessary to help existing staff grow into the "right people." If ITS is going to change the way the department does business, than the department personnel must be trained in this new way of doing business. Thus, an active ITS training program is needed to help department personnel make the transition to the use of ITS. Try to make technical training and hiring of new technical personnel an integral part of long-range ITS plans; otherwise, personnel issues might prevent ITS projects from achieving their expected goals, which might have negative consequences for the entire ITS program.

Lesson Learned 6 - Avoid proprietary data and closed, proprietary systems.

The focus of the DelTrac program was on integrating ITS components, which is difficult to do with proprietary data and closed, proprietary systems. For example, DelDOT had planned on using data from traffic signal control loop detectors to augment their electronic detection capabilities. However, this data, which was managed by the proprietary signal control systems, proved difficult to obtain, and these plans were set aside.

In fact, the focus of the DelTrac project reviewed in this evaluation was the creation of the infrastructure needed to support open, integrated systems instead of closed, proprietary ones. The goal was to create a database for shared DelTrac data and to require that all future DelTrac applications integrate with this shared database. This would have the effect of opening up a close system.

For example, Actra is designed to use a proprietary database for storing traffic signal control data. The DelDOT version of Actra, DelActra, includes additional functionality to integrate the Actra database with the DelTrac Data Repository. The Data Repository maintains a mirror image of Actra data that should be shared with other DelTrac applications. When Actra changes traffic signal control values in the Actra database, it also transmits a request to make the same changes to the Data Repository so that the two databases remain synchronized. In this way, DelTrac provides an open, non-proprietary copy of Actra's closed, proprietary data.

The same approach was planned for other DelTrac applications that relied on a proprietary database. DelDOT suggested they might streamline this approach for applications developed specifically for DelTrac by using the Data Repository as the application database. This would eliminate the need to implement methods to maintain mirror image copies of application data.[a] In this way, the Data Repository would provide open access to all shared DelTrac data.

[a] The Evaluation Team noted that doing so might eliminate one of the benefits of maintaining a separate enterprise database for sharing data – decoupling components. If the enterprise database is used to store application data, then any change to the application that modifies the database structure will affect all other applications that use that data. It might be preferable to design the enterprise database separate from the application database so that it is less likely to change. In other words, one might

It is also worth noting that the process of coordinating data in Actra and the Data Repository was facilitated by the fact that Actra already included an application programming interface (API) that exposed most Actra data and services. This allowed Actra developers to write wrapper routines that used this API to provide the functionality needed to synchronize the Actra and Data Repository data. Thus, even though Actra relied on a proprietary database, the Actra system itself was open (via the API), which helped create an open version of that proprietary data.

Lesson Learned 7 - Carefully manage the risks of using cutting edge applications.

To their credit, the DelTrac designers foresaw the tremendous potential for XML and the Web to facilitate messaging between system components in order to develop a seamless transportation management system. However, XML was still just beginning to be used and the tools for using it were limited. This required that the DelTrac projects develop several core tools that provided basic functionality to help leverage power of XML and the Web. In this sense, DelDOT was developing cutting edge XML applications.

In many cases, the DelTrac development simply could not keep up with commercial developers who were also developing tools to leverage XML and the Web. By the time DelDOT had developed some of these core tools, commercial applications that provided similar – or even better – capabilities had become available. Once they were available, the use of the commercially available applications had many advantages over the DelTrac-specific applications, including reduced development and upgrade costs and a more standardized application infrastructure. In these cases, DelDOT might have been better off to have delayed development of some portions of DelTrac to wait for the commercial applications. (Of course, when DelTrac development began, it was very difficult to foresee whether and when these commercial applications would become available, so risks of waiting also existed.)

For example, the original DelTrac design called for the use of a XML file-based Data Repository. While still in the design phase, commercial database vendors began to announce the availability of database products that included an XML-based interface to the data. This allowed DelDOT to change from the file-based Data Repository to one based on a relational database engine. This change brought to the Data Repository the advantages of increased data security, robustness, and accessibility built into commercial database products.

A similar example occurred with the design of the DelTrac Web Server, which was intended to provide the infrastructure needed to combine different DelTrac applications into a common transportation workstation. Developing the DelTrac Web Server required definition of metadata standards that provided the Web Server software with the information it needed to provide a single Web-based user interface to multiple applications. In the commercial world, the potential of this approach was realized in the form of Web Portal software, which provided standardized ways to loosely integrate different applications in a Web-based interface. At the time of this report, DelDOT was evaluating a commercial Web portal product for use in place of the custom DelTrac Web Server technology.

Because there are increased risks in deploying untested, cutting edge technologies, the risks associated with their use should be closely managed. For example, one could survey the industry before beginning the deployment to determine if emerging COTS products could be used instead of developing new applications. One should also keep abreast of emerging technologies and be prepared to adopt these new technologies if they will improve the deployment. Finally, one might use a different approach for managing a deployment that includes untested technology by (a) ensuring that the schedule includes sufficient time to overcome the challenges that come with applying new technologies and (b) requiring

tune the application database for speed and tune the enterprise database so that the database structure is less likely to change over time.

more frequent intermediate deliverables so that the department can better assess the progress being made. For example, a spiral development model might allow closer monitoring of the deployment progress while also giving the department more time to familiarize itself with the capabilities of the new technologies.

Lesson Learned 8 - XML is not the best approach for all messages.

In the initial design specifications for the DelTrac Traffic Signal Control subsystem, XML was to be used for all communications between subsystems and shared data from a subsystem was to be stored as an XML document. As work progressed, this vision was changed to rely less and less on XML.

The first step in that direction was the choice to use an Oracle database to store the shared data rather than a file service based system storing XML documents as files. Until recently, system designers had to choose between the advantages of document-based storage for XML documents and database storage of XML data. Some of the advantages of document-based storage are:

- Data in an XML document can be located regardless of the actual structure of the data. Thus, as an application evolves and data is moved within a document, an application that uses XML-based searches can locate the item despite its location. In a database, the specific structures of the tables used to store data must be known in order to retrieve data.
- XML documents are easily viewed by common applications, including browsers, word processors, and other common desktop applications. Data stored in a relational database requires a database application to access the data.
- XML documents are easily transferable between systems – just copy the document. Databases store information internally in a proprietary manner and special techniques must be used to transmit data between different databases.

On the other hand, the same advantages of database storage over file storage for non-XML data apply equally well to XML documents:

- Databases provide indexing and search procedures that are many times faster than the brute-force searches natural to file-based data.
- Databases provide security measures to protect data from unauthorized access and update and transaction processing to protect data from unintended loss.
- Databases support data relationships and other data validation techniques to ensure that changes to the data do not introduce inconsistencies in the data.
- Databases provide for higher performance and better scalability.

Recently, major relational database vendors have offered powerful new capabilities for managing XML data within a relational database. With this advance, DelDOT chose to replace the planned file-based XML repository with an Oracle database that provided XML services.

After making this change to the design plans, a second opportunity for improvement was noted. The DelTrac Traffic Signal Control subsystem, which was originally designed with a file-based repository in mind, used Set XML messages to update data in the shared repository. However, application-to-database messages such as this are easier to develop and maintain and more efficient if they are handled by one of the traditional tools for such exchanges, such as ODBC. In fact, ODBC was designed expressly for application-to-database exchanges, is robust and efficient, and is well-understood by most developers. Although DelDOT did not retrofit the Traffic Signal Control subsystem for ODBC access to the Data

Repository, DelDOT plans to use direct database access when future subsystems are integrated with the Data Repository.

It is also worth noting that XML is just one small part of the solution for establishing interoperability among ITS subsystems. XML is sometimes oversold as a key to integration, and it is important to keep in mind the integration steps do and do not benefit from the use of XML. The following paragraphs list some of the most important steps in integrating two different subsystems and the role played by XML in each step.

Identifying Message Delivery Methods. There are a number of different ways of communicating between subsystems. Subsystems residing on the same computer might simply call processes within the other application, a feature that is built into most software development languages. RPC (e.g., DCOM, CORBA) offers the same type of capability for subsystems residing on different computers. Files can be transferred via direct network connections, ftp, email, or any number of other techniques. For DelTrac, DelDOT chose to use the Sonic MQ Broker, which serves as a sort of mailman for delivering messages between systems. Identifying the message delivery method that will be is an important part of the system architecture. Although XML plays no role in helping identify the best method to use, some methods are compatible with the use of XML for transmitting messages and others are not.

Identifying Messages. The first step in any integration is to identify the messages that must be transmitted between different subsystems. For the Traffic Signal Control subsystem, several types of messages were used. Get and Set XML messages were used to retrieve and to modify traffic signal control data. Database, Status, and Alert messages were used to notify other applications of changes occurring within the Traffic Signal Control subsystem (e.g., database values changed, unusual events occurred). Identifying the messages that must be supported by a subsystem is an important part of the high-level design of the system. XML plays no role in this step.

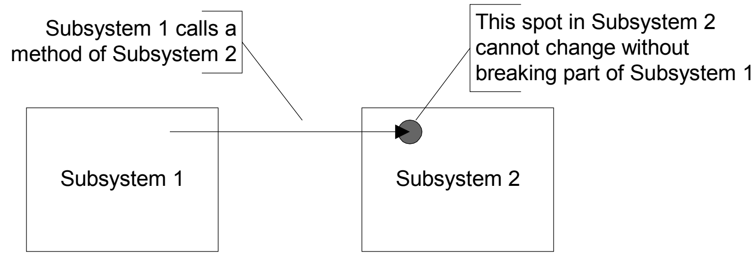
Identifying Message Content. Once the need for a message has been identified (e.g., a message to update control parameters for a single signal controller), the actual content of the message must be determined. For example, a message to update signal control parameters might include the ID of the signal controller of interest, the time period during which the change applies, and the new parameter values to apply. In some cases, the message content could be complicated – some parameters might be optional, might allow multiple values, or might have complex relationships with other parameters. Identifying the message content is an important part of the detailed design of the system. XML plays no role identifying the message content. However, XML does play a role in specifying the content standards for the messages in terms of either document type definitions or XML schemas.

Developing a Message-based Interface. Once the messages, message content, and delivery methods are known, the software that actually receives, processes, and generates XML messages must be developed. While the use of XML does not help develop the software, the ease of generating and reviewing XML documents can help with testing and debugging the system. Also, the wealth of tools available for creating and processing XML documents can simplify the development process.

XML does not eliminate any of the hard work associated with figuring out how two different subsystems should interact. Once the design process is complete, XML does format the messages in a way that can be easily processed by a number of different computers.

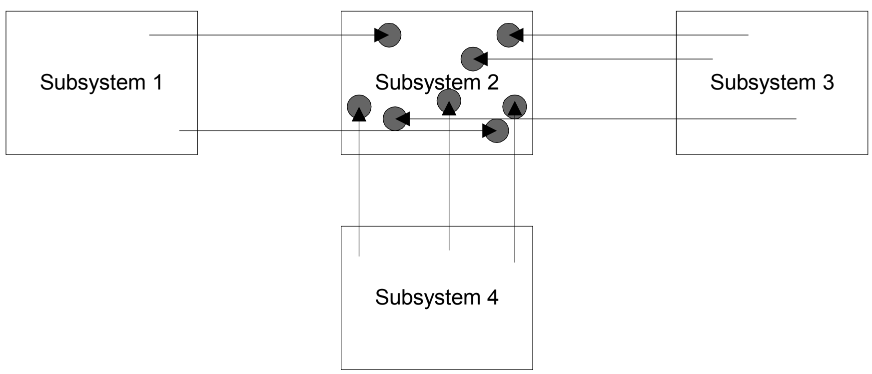
Lesson Learned 9 - The design of the message-based interface between subsystems is one of the most important steps in integrating ITS subsystems.

One of the most difficult challenges in implementing integrated subsystems is managing the dependencies between the subsystems. The fundamental problem is that, each time a subsystem calls a method of another subsystem, it places a constraint that limits how the second subsystem can be modified in the future – if the method called from the external subsystem is changed, it will break the external subsystem (see the figure below).



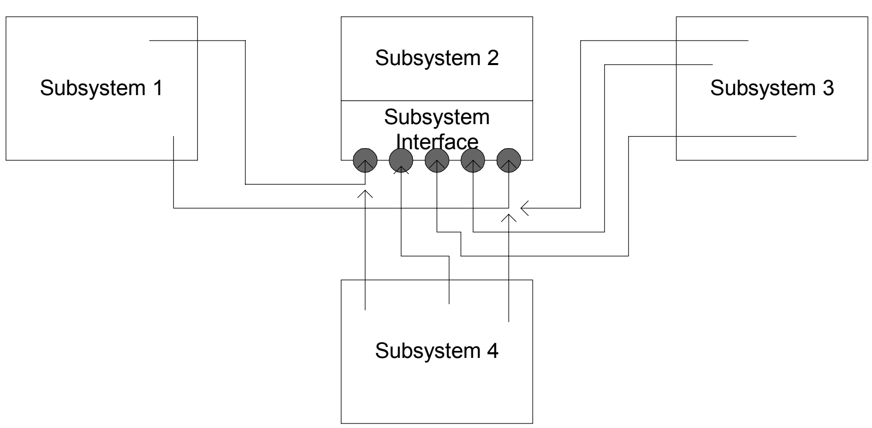
While creating a single tie between two subsystems does not seem to introduce a significant difficulty, the difficulties arise because:

- The ties between subsystems are often poorly documented or documented in only one of the two subsystems. Thus, developers modifying Subsystem 2 are often unaware of the constraints until modifications to the subsystem are deployed and Subsystem 1 fails to work correctly.
- A large number of constraints in a subsystem can make it very difficult to modify the subsystem without breaking something. And, if the constraints are not well documented, one might unintentionally break a mission critical subsystem.



It is this combination of problems that has made many legacy systems virtually irreplaceable and extremely difficult to upgrade.

Using well-defined interfaces between subsystems eliminates these problems by requiring that all subsystems that need to get services from another subsystem use only services that are exposed in the subsystem interface, as depicted in the figure below.



Thus, all of the dependencies between subsystems are concentrated in the subsystem interfaces and a subsystem can be upgraded without concern for the impact on other subsystems, so long as the interface is preserved. Of course, this means that the design of this interface is exceedingly important because the interface needs to remain constant while other parts of the subsystem change. If the interface is to remain constant, then it needs to consider several factors that may not be considered in the design of the subsystem itself, such as the needs of other subsystems or the changes to the subsystem that may occur in the future.

DelDOT encountered these types of difficulties while developing the Traffic Signal Control subsystem. With the DelTrac Traffic Signal Control subsystem, the only subsystem interactions were between the Actra TSC subsystem, the DelTrac Data Repository, and the DelTrac Web Server. After release of a working version of each of these subsystems, modifications to the Actra subsystem were made. When the upgraded Actra subsystem was deployed, the DelTrac Data Repository no longer functioned correctly because some modifications to the Actra database fields were incompatible with the DelTrac Data Repository database. The developers had modified the interface between Actra and the DelTrac Data Repository by changing the fields that were passed between the two systems.

On a more fundamental level, the evaluation team felt that the wrong type of interface was planned for the DelTrac Traffic Signal Control subsystem. The planned interface would have provided other DelTrac applications with the ability to request changes to the traffic signal control parameters. In order for a DelTrac application to make intelligent requests, it must include a significant amount of "knowledge" about traffic signal control and the current state of the traffic signal control system. For example, an incident management application might detect an incident and request changes to signal timings in order to facilitate vehicles taking alternate routes to bypass the incident location. Determining the appropriate signal timing changes is probably outside the scope of an incident management application. A better interface for the traffic signal control system for the purpose of interacting with other DelTrac applications might include the following types of service requests instead of requests to alter specific signal timing parameters:

- Allow more flow along a specified arterial.
- Expect decreased flow through a specified location.
- Provide a green signal to a vehicle that is expected to arrive at a specified intersection within a specified window of arrival times.

Note that an interface based on these types of service requests limits the need for an understanding of traffic signal control parameters to the traffic signal control subsystem. All other subsystems would make requests of the traffic signal control subsystem based on the desired traffic outcome, and would leave the decision as to how to best modify signal control parameters to achieve that outcome to the traffic signal control subsystem.

Lesson Learned 10 - A flexible strategy is necessary to manage potential schedule delays.

The deployments of some DelTrac subsystems have experienced schedule delays caused by a variety of factors. On the technological side, DelTrac includes various sophisticated subsystems (e.g., Traffic Adaptive Signal System) that bring numerous technological challenges, as well as delays, especially systems that require software development. On the institutional side, the ability to deploy integrated ITS on time depends on the successful coordination among the numerous agencies involved in the project. Although DelDOT organizational structure is much simpler that that of many DOT's, successful coordination takes time and can cause delay in project implementation and system deployment.

Some level of deployment delay on large and complex ITS deployments may be inevitable, but some methods used by DelDOT have minimized the delays:

- Get something out, deliver a tangible product, even a prototype, and refine it later rather than to wait for the perfect application.

- Provide strong oversight of software development, strong oversight of software development leads to better interaction and eliminates problems. Greater interaction with the developers or vendors leads to faster and less expensive development.

Lesson Learned 11 - The traditional procurement process may not offer the flexibility needed to support ITS procurements.

At DelDOT, there was a lack of understanding within the process of the unique needs of ITS procurements. FHWA has also noted that procurement can be "a hindrance to ITS deployment." Construction projects for roads and bridges typically involve using well-known techniques to build easily defined products. ITS projects involved much higher levels of uncertainty in terms of the technologies being used and the final results that are desired. Consequentially, additional flexibility is required to support the unique procurement needs of ITS.

For example, a software development project often requires a much higher degree of coordination during the project than for a road construction project. Oftentimes, it is difficult to define the exact requirements for a software development project at its inception. Without exact requirements, it is difficult to estimate costs. Even if exact requirements are know ahead of time, software development typically involves the application of leading edge technologies, which is inherently more risky than traditional road construction projects.

To offset these risks and uncertainties, different procurement practices are sometimes required for ITS projects. In general, these practices must be more flexible and will require that a DOT be a much more active partner in an ITS project than they might be in another type of project. For example, an ITS procurement might include a requirements generation phase, after which cost estimates are revised and the DOT would make a decision on whether to proceed given the revised cost estimates. Also, it is common for users of a new software system to propose new requirements as they become more familiar with the capabilities of the system – users often find it difficult to anticipate how they might use a system until they get hands-on experience with it. The procurement process for software systems should include methods for changing the requirements during the deployment and for revising the costs and schedules to account for those changes.

Lesson Learned 12 - The planned budget should account for uncertainties in the design and in the availability of skilled labor.

In Delaware, a combination of local experience and existing economic conditions led to higher material and labor costs that expected. For example, a shortage of DelDOT staff with the appropriate technical skills meant that many of the implementation and support duties that were to be performed by DelDOT staff were actually performed by contractors. The original DelTrac budget expected in-house personnel to support most new signal system work and to setup and install controllers and cabinets. Inadequate staffing levels did not allow this, which increased deployment costs.

Other unanticipated changes also introduced higher costs. For example, the original schedule and budget for fiber deployment called for installment on existing poles owned by utilities. However, revised National Electric Safety Code (NESC) rules and the lack of clear attachment agreements with the utilities increased the costs of this approach. This led to increased installation of underground conduit and duct systems for the fiber network.

Similarly, operating and maintenance costs have been a major challenge in ensuring the continued success of the DelTrac deployments. Operating and maintenance costs almost universally higher than initially expected, in part because the high-tech and often first-generation nature of many ITS technologies means that there is little experience on which to base operating and maintenance cost estimates.

At DelDOT, several cost containment methods have been used:

- Lower costs through integration. The deployment of DelTrac revealed that ITS integration not only produced great benefits, but also reduced costs.
- Keep systems open and make use of standards. Closed proprietary systems may be a good investment in the short run, but in the long run, such systems can lead to greater costs. This is especially true with greater ITS integration, since proprietary systems may not allow integration.
- Develop an implementation plan. At DelDOT, a DelTrac implementation plan was developed that mapped out the level of effort required to complete the DelTrac build out. This implementation plan considered both development, operations, and maintenance activities and identified the level of effort required in terms of minimum full time equivalents, costs, time, and materials.

9.3. Evaluating the Evaluation

The last part of this report will review the extent to which this evaluation met the five objectives laid out in the evaluation statement of work. In general, the extent to which these objectives were met was limited by two factors. First, the project being evaluated was only the first step in DelDOT's plans for integrating ITS applications in Delaware. This DelDOT project included (a) development of infrastructure components for sharing data and creating a common user interface for DelTrac applications and (b) deploying a traffic signal control system that integrated with this infrastructure. It did not include integration of other DelTrac applications with the infrastructure and, therefore, did not demonstrate integrate between ITS applications. It was, however, a necessary and immediate precursor to such integration.

The second limitation was that the project met with significant deployment delays, so that the deployment of the traffic signal control system, data sharing infrastructure, and common user interface infrastructure was not completed at the time this evaluation report was written. Thus, this evaluation reports on the deployment plans and the capabilities of incomplete versions of the planned components. It does not report on the final deployment of the DelActra traffic signal control system.

On the other hand, the evaluation does provide a good example of the difficulties of developing custom applications using relatively new technology, such as XML. The experience of DelDOT with using XML also provides a good backdrop for describing what XML can and cannot do in helping to integrate systems. Moreover, because DelDOT's plans are to integrate many of their ITS applications, this evaluation took advantage of the interviews and other meetings with DelDOT staff to discuss not just the traffic signal control project, but also DelDOT's other ITS activities. Thus, while the evaluation does not describe the final deployment of the DelActra traffic signal control system that was the focus of the evaluation, it does provide information on a broader range of DelDOT ITS activities.

The following paragraphs summarize the effects of these factors on the extent to which the evaluation met the five objectives originally stated by FHWA in the statement of work for this evaluation.

Identifying the key technical and institutional steps required to implement and integrate the system. This objective was met to a limited extent for the DelActra project and, to a greater extent, for the

DelTrac program as a whole. Because the plans for DelActra involved no integration, the opportunities to identify integration issues were limited. Because the DelActra project did not complete on schedule, review of the final implementation steps was not possible within the timeframe for this evaluation. The Evaluation Team, with support from DelDOT, did extend the scope of this objective to consider the entire DelTrac program at DelDOT.

Document the use of existing technologies to build a seamless transportation management system. To the extent possible given the plans for DelActra, this objective was met. To a significant extent, many of the technologies used in DelActra were new – the COTS Actra signal control system was a new version that was being developed in the same time frame as DelActra and the data repository and Web server technologies were new, though they relied on existing technologies (e.g., the message broker). Thus, the evaluation documented the use of existing technologies, but this usage was limited.

Describe the use of extensible markup language (XML) to manage and exchange data. The evaluation documented the plans for the use of XML to manage and exchange data in DelActra, and the evolution of those plans as the DelActra project proceeded. This provided some interesting examples that help delineate the capabilities of XML. The evaluation did not report on final XML message sets used by DelDOT because the DelActra project was not completed in time for DelDOT to provide message set schemas to the Evaluation Team.

Identify the steps taken to merge freeway, arterial, emergency, and transit management systems together. In the Evaluation Strategy, it was noted that the DelActra project did not involve a significant merging of freeway, arterial, emergency, and transit management systems. The Evaluation Team did consider programmatic steps to merge freeway, arterial, emergency, and transit management systems together.

Evaluate the integration of legacy systems into a new system. The Evaluation Strategy proposed the use of interviews to (a) identify legacy systems that were integrated into the new system, (b) describe the steps taken by DelDOT to ensure continuity of operations while integrating the legacy system, and (c) identify lessons learned while integrating legacy systems. As it turned out, there was little integration of legacy systems in the DelActra project. Legacy traffic signal controllers were upgraded to be compatible with the new traffic signal control system, and the remainder of the system (e.g., data sharing and Website interface infrastructure) was new. The Evaluation Team did document these facts.

Appendix A. The Planned DelTrac Application Architecture

One of the objectives of the DelTrac program was to design software applications that would work together to provide better functionality than could be provided by stand-alone applications. For example, a transit system application might use real-time traffic information to better estimate arrival times for fixed-route buses and, at the same time, provide bus travel time data to improve the quality of real-time traffic information. In other words, applications that work together could leverage each other's capabilities to provide more functionality at a lower cost. The planned DelTrac application architecture was to provide the technological backbone necessary to support applications working together by providing a Data Repository that would be used to share data between applications and a Message Queue that would be used to support communications between applications.

In addition to this application interoperability backbone, DelDOT identified the Web browser as a key DelTrac application. The goal was to create a DelTrac Web browser-base application that could view and modify most shared data and access much of the functionality that would be available from the various DelTrac applications. So, the DelTrac application architecture included tools to support Browser-based access to DelTrac data with standard techniques for integrating new DelTrac applications with the DelTrac Web Server.

Taken together, Data Repository/Message Queue and DelTrac Web Server were to form the backbone of the DelTrac system, allowing the various DelTrac applications (or subsystems) to operate together and with the Web to fulfill the promise of a seamless transportation management system. This appendix provides an overview of these systems.

It is important to note that the architecture described in this appendix is as developed for the conceptual design for DelTrac and was never fully functional. (The deployment difficulties encountered are described in the body of this report.) However, the conceptual backbone of the planned system – the need to support a central Data Repository to support data sharing, a messaging system to support communications between applications, and a browser-based application to provide a unified interface to all DelTrac applications – remains valid. What changed during the evaluation was the technology that DelDOT planned to use to create this backbone. Because this appendix addresses both the rationale for DelTrac's conceptual design and the design itself, the evaluators felt that the information in this appendix may still be useful for others interested in integrating transportation applications.

A.1 Background

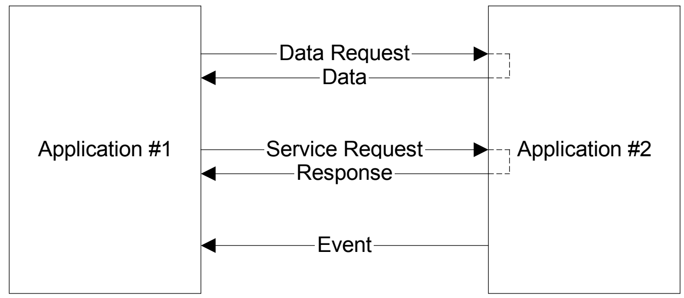
This section introduces some of the key ideas behind application interoperability and Web services.

A.1.1 An Overview of Application Interoperability

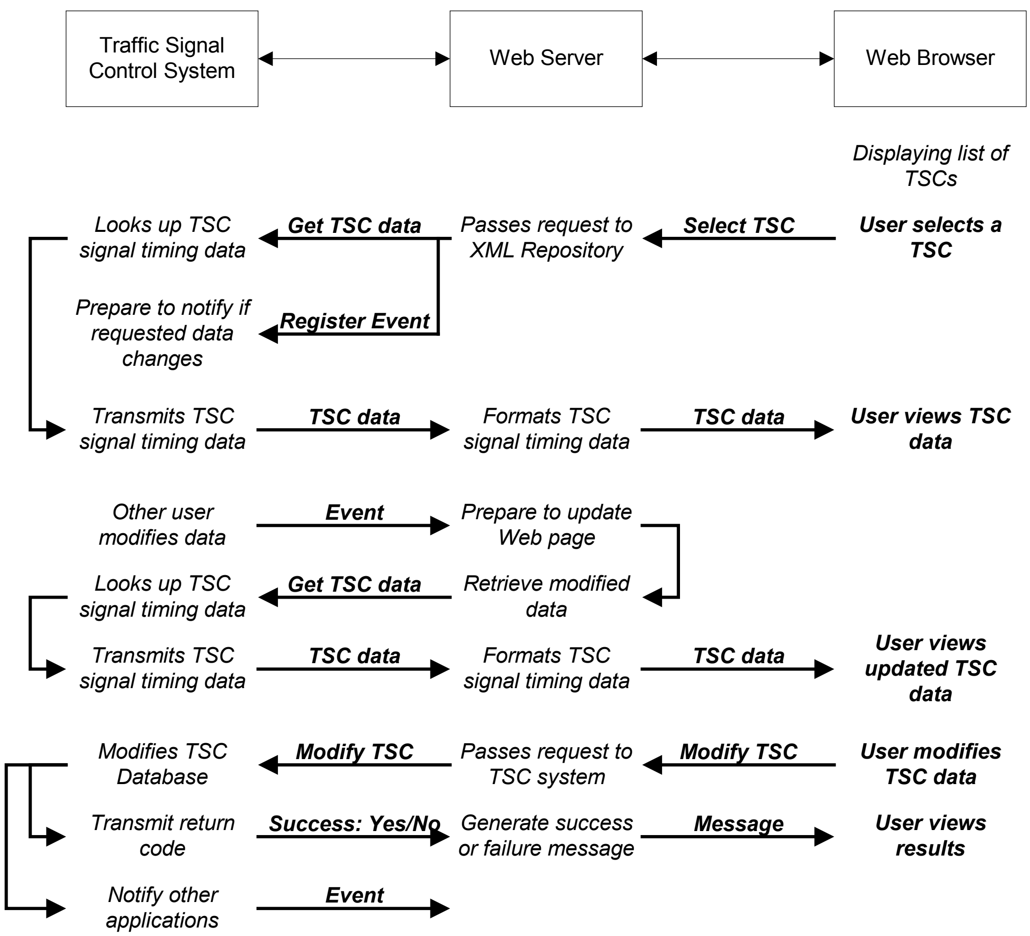
On the logical level, applications must support three types of interactions (see the figure at the right) to support application interoperability.[a] First, applications must be able to share data by requesting and receiving data from other applications. For greater interoperability, an application should also be able to request a service provided by another application and be informed whether the request service was provided. For example, an application might request that another application modify some of the data it

[a] The breakdown into these three types of interactions is somewhat artificial. For example, service requests can be used to support both data requests (by exposing data request services) and events (by exposing methods used to register to receive event notifications). Because these types of interactions are indicative of different degrees of interaction between applications and are often handled using different techniques, considering the three separately is still useful.

had received via a data request, and might wait for a response as to whether the modification was successful. At the highest level of interoperability, an application would be able to monitor activities that occur within another application. For example, an application might request data from another application and might want to be notified if another user changes that data. The figure at the right depicts these three types if interactions.



The process of using data requests, service requests, and events to manage application interactions is exemplified in the following process (see the figure below), which describes a hypothetical interaction between a user modifying traffic signal control data using a Web browser and a traffic signal control system. The example begins with the user viewing a list of available traffic signal controllers and selecting one of the controllers from the list in order to display the timing data for that controller. The Web Server receives this request and generates two requests from the traffic signal control system. First, the Web Server requests a copy of the timing data so that it can be formatted and presented to the Web Browser. Second, the Web Server asks to be notified if another user modifies that data so that the Web page can be updated.



If another user does modify that data, then the Web Server is notified that the data has been changed so that the user's Web page can be updated. (In practice, this would require the use of some client-side code, such as a Java applet, rather than just a Web browser.) When the user modifies the TSC data, then the modification request is passed on to the traffic signal control system, which modifies the data, returns a value indicating whether the modification succeeded, and notifies other applications that a modification occurred.

There are numerous other examples of using these three types of interactions to support application interoperability. Some of these are listed in the following paragraphs.

- In the Windows© family of operating systems, messages are used to notify applications of events (e.g., when the user clicks on a form, Windows sends a series of messages such as WM_LBUTTONDOWN to the application on which the click occurred). Also,, the Component Object Model (COM) is used by applications to expose procedures, which can process both data and service requests.
- In a classical Web Server, only service requests and responses are allowed and all service requests (i.e., download a selected Web page) originate from the Web browser. The displayed Web page is the response data to the service request.
- The Common Object Request Broker Architecture (CORBA) is a series of specifications that allow applications to request services from other applications.

So, examining how these three types of application interactions are managed is a good way to understand how a system provides application interoperability, and is the basis for much of the description of application interoperability in this appendix.

However, there is one other feature that should be considered because it is important for the robustness of a system. Consider the case described earlier in this section of a Web browser communicating with a traffic signal control system through a Web server, and suppose that the traffic signal control system is being upgraded. Even if the new traffic signal control system supports the same service requests as the previous one, it may run on a different computer. If this is the case, upgrading the traffic signal control system might necessitate changes to the Web Server software to allow it to connect to the new computer. If there are other systems that are also accessing traffic signal control services, each of those systems would have to be modified, too. This type of dependence between subsystems is undesirable because it makes it more difficult to maintain.

One method of alleviating this problem is for "broker" software to serve as a middleman connecting an application that is requesting a service with the application that provides the service. Each application that provides services registers with the broker application, which transmits service requests to a registered provider. In this way, migrating an existing application does not "break" other, interdependent applications; instead, the broker is simply updated to point to the new application, and all service requests are automatically routed to the new provider. The discussion of application interoperability in this appendix also considers how DelTrac manages service requests to help increase robustness.

A.1.2 An Overview of Integrated Web Services

One of the goals of the DelTrac program was to use Web browser technology to create a common transportation workstation that could support most DelTrac activities. To make DelTrac application services available through a browser, there must be a way for a DelTrac user to (a) identify the service (e.g., change signal timing) in which they are interested, (b) identify the thing to which that service applies (e.g., the signal controller at a specified intersection), and (c) interact with the DelTrac application that provides that service. The discussion of integrated Web services in this appendix focuses on how the DelTrac Server was designed to help facilitate these three types of activities.

A.2 Concept of Operations for the DelTrac Architecture

This section introduces the fundamental concepts behind the DelTrac architecture for providing application interoperability and integrated Web services. Figure B–1 is a simplified diagram that depicts the key elements of the DelTrac architecture.

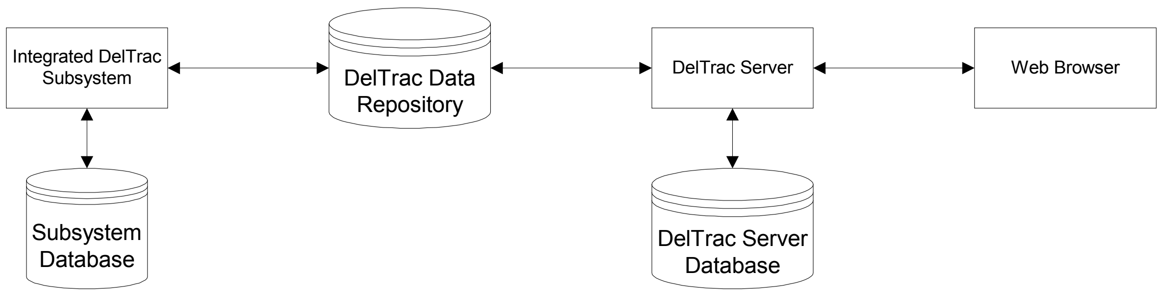


Figure B–1. A Simplified DelTrac Architecture Diagram

In this diagram, each **DelTrac Subsystem** is an independently operating application that shares data and services through the **DelTrac Data Repository**. This Data Repository serves as both a data reservoir and a broker for transmitting service requests between DelTrac subsystems. The **DelTrac Server** is a Web server that makes data from the DelTrac repository (along with other information) available to users with Web browsers.

For example, the DelTrac Traffic Signal Control Subsystem might publish a list of traffic signal controllers and the settings for each controller to the DelTrac Data Repository so that other DelTrac subsystems (such as the DelTrac Server) could use that information. The DelTrac Traffic Signal Control Subsystem would also make traffic signal control services available to other DelTrac Subsystems through service request messages passed through the DelTrac Data Repository. For example, if a traffic operator needs to modify traffic signal timings while in the field, they could request a modification to the signal timings using their Web browser. The DelTrac Server, on receiving this request, would pass it along to the DelTrac Data Repository, which would send it to the DelTrac Traffic Signal Control Subsystem. This subsystem would process the request and update the proprietary Actra database, then send a message to the Data Repository in order to update the repository with the new signal timings. Figure B–2 depicts the interactions that might occur between elements of the DelTrac architecture when a traffic operator uses a Web browser to update traffic signal control timings.

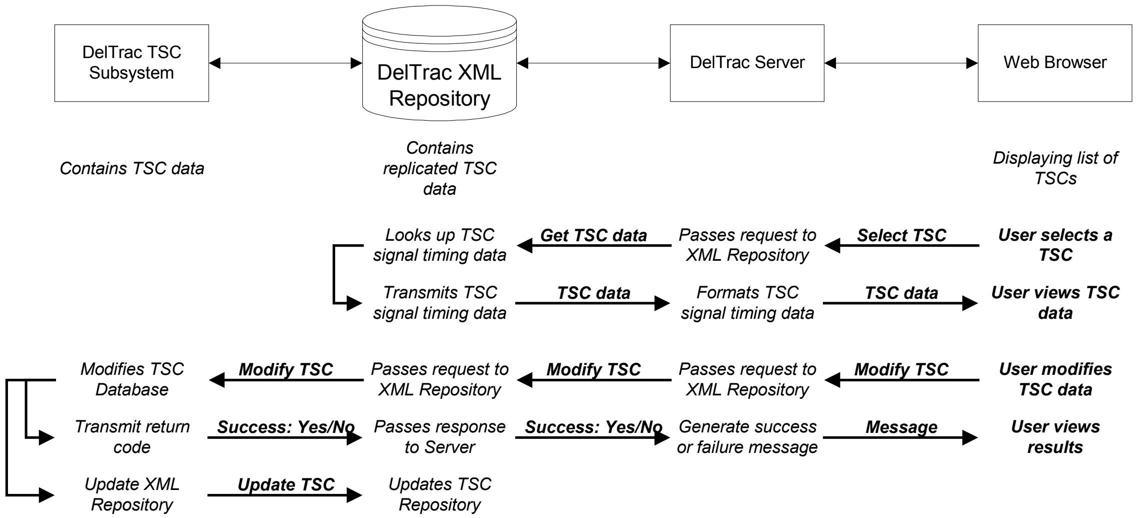


Figure B–2. Example of Interactions Within the DelTrac Architecture

The following list describes some important elements of this simplified architecture:

- Each DelTrac subsystem would be responsible for maintaining all of the data "owned" by that subsystem.
- Each DelTrac subsystem could select which data (if any) it would expose through the DelTrac Data Repository. For example, the DelTrac Traffic Signal Control Subsystem might publish the current signal timings for the traffic signal controllers, but not publish the traffic data collected from the loop detectors that are used to control signal-timing operations.
- Each DelTrac subsystem would be responsible for publishing to the Data Repository any changes that occur to data "owned" by that subsystem. For example, if a traffic operator used the Actra system to change signal timings for a traffic signal controller, then these changes would be published to the Data Repository.
- The Data Repository would contain only data that was replicated from data stored by the individual DelTrac subsystem. All requests for shared data would come to the Data Repository instead of to the individual DelTrac subsystems.
- The Data Repository would not directly support modifications to any data. Instead, it would pass along any data modification requests to the DelTrac subsystem that was responsible for maintaining that data. If a DelTrac subsystem needed to modify data owned by a different subsystem, then it would submit a modification request through the Data Repository.
- The Data Repository could support events by allowing DelTrac subsystems to register for events that would be broadcast from other subsystems and, when necessary, broadcasting those event messages.

The net result of applying this architecture would be that DelTrac subsystems could interact through data requests, service requests, and events that are managed via messages processed by the Data Repository. The DelTrac Server would be one of these subsystems, and would use the Data Repository to provide data for Web pages and to pass service requests back to the appropriate DelTrac subsystems.

A.3 High-level Architecture

While the previous section gives an accurate overview of the planned DelTrac architecture, it does gloss over a number of significant details. For example, the DelTrac Data Repository was to consist of two components: an Oracle database coupled with a Message Queue service and software for processing messages received from the Message Queue. Thus, DelTrac subsystems could maintain data in the Data Repository in at least three ways:

- By submitting data update messages passed through the Message Queue
- By submitting SQL statements directly to the Oracle database.
- By using the DelTrac Data Repository Oracle database as the subsystem database, so it would not be necessary to maintain parallel copies of subsystem data.

Similarly, the simplified architecture glossed over the details of how the DelTrac Server would process and format data retrieved from the DelTrac Repository. After all, the methods used to format traffic signal control data for display might not be the same as those for formating transit vehicle schedule information. The purpose of this section is to expand on the simplified architecture of the previous to give a more realistic overview of the complexities of the planned DelTrac architecture.

A more detailed view of the DelTrac architecture is depicted in Figure B–3

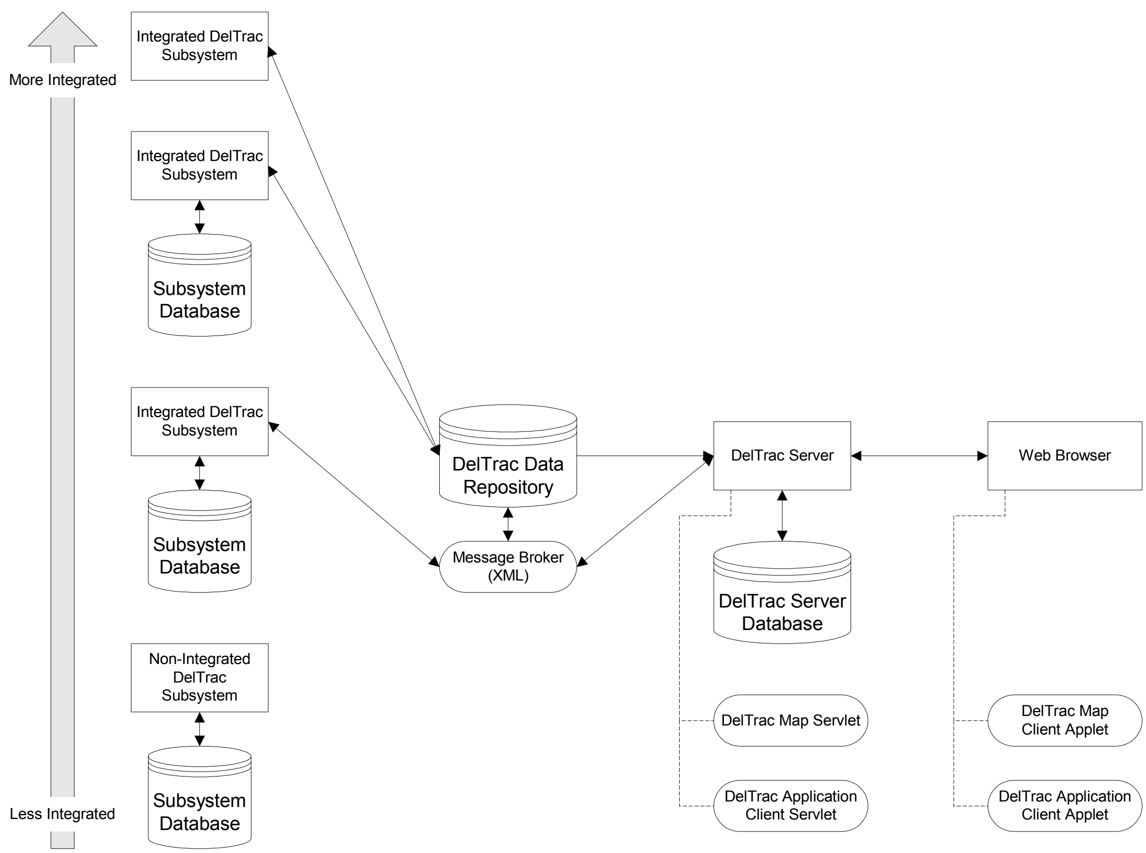


Figure B–3. The DelTrac Architecture

The following sections describe each of the four main elements (from left to right) in this diagram.

A.3.1.1 DelTrac Subsystems

Four different types of DelTrac Subsystems were planned, with each exhibiting a different level of integration with the DelTrac Repository.[b] The lowest level of integration would be a non-integrated DeTrac subsystem that does not provide any data to the DelTrac repository. An example of this type of system would be a legacy system that has not been integrated with the DelTrac repository.

At the next lowest level of integration, a DelTrac Subsystem could use the Message Broker to maintain consistency between the subsystem database and the DelTrac Repository. An example of this type of system is the DelTrac Traffic Signal Control subsystem. Application data for this system would be stored in a separate database from the Data Repository, and the built-in COM interface to Actra would be used to access Actra data and services. Wrapper functions would be developed that use this COM interface to integrate Actra with the DelTrac Data Repository. This architecture is depicted in Figure B–4.

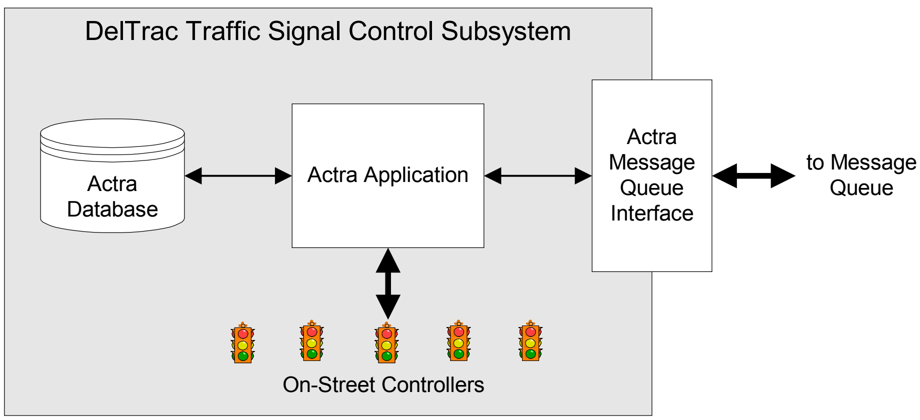


Figure B–4. The DelTrac Traffic Signal Control Subsystem

The next two levels of integration bypass the Message Queue altogether and connect directly to the database for the DelTrac Repository, either by replicating data directly into the database or by using the repository database as the database that maintains data for the subsystem. Although there are no current DelTrac subsystems that use either of these approaches, DelDOT did suggest that the approach would probably be used in the future.

In summary, the DelTrac subsystems that should share data and/or services with other DelTrac subsystems do so through the DelTrac Data Repository. Services would be provided by accepting and processing service request messages from the Message Broker. Data would be shared by populating the DelTrac Data Repository, either by submitting data update messages to the Message Broker or by directly accessing and updating the database supporting the DelTrac Data Repository.

At the time of the evaluation, the integration of the Traffic Signal Control subsystem was on hold while deployment issues were resolved and different tools for supporting the DelTrac infrastructure were considered. The police/fire CAD was using a similar approach to interact with the TMC.

[b] This diagram only depicts integration with respect to data supplied by a DelTrac subsystem to the DelTrac Repository. A similar set of relationships exists for subsystems using data from the repository, with a non-integrated data user not interacting with the repository, a partially integrated user retrieving data from the repository, and a full-integrated user retrieving and updating data from the repository.

A.3.2 The DelTrac Data Repository

The DelTrac Repository was to serve as a central access point for all shared DelTrac data and all shared services of DelTrac subsystems. In other words, the DelTrac Repository would be the central point for all communications between different DelTrac subsystems. As already mentioned, the need existed for three types of inter-subsystem communication: data requests, service requests, and events.

The design of the DelTrac Data Repository called for it to support all three of these types of interactions. The Message Broker would serve as the hub that received all requests and passed them on to the appropriate subsystem for processing the request. A data request would be passed on to the DelTrac Data Repository for processing. A service request would be passed on to the DelTrac subsystem that provides that service. A request to listen for an event would be handled by the Message Broker itself by registering the "listener" to receive messages directed towards an event queue.

As of the time when this report was developed, there were no subsystems integrated with the DelTrac Data Repository and the Data Repository was not being used. The police/fire CAD system was integrated with a temporary data repository, and DelDOT was considering plans to upgrade that temporary repository to serve as the DelTrac Data Repository.

A.3.3 The DelTrac Server

The DelTrac Server was intended to be a central, Web-based entry point to most TMC applications – in other words, the DelTrac Server would be the server-side of the DelTrac remote TMC. A DelTrac subsystem would be integrated with the DelTrac Server by (1) adding information to the DelTrac Server Database to indicate that the subsystem was available to provide Web pages, (2) providing a server-side application to serve up Web pages or provide data to a client-side applet for that subsystem, and (3) providing an optional client-side applet for greater subsystem functionality for users accessing that subsystem through the Web.

The original DelTrac deployment plans called for simultaneous development of the DelTrac Data Repository and the DelTrac Server as part of a project to deploy a new traffic signal control system. The new traffic signal control system would have been the first subsystem to integrate with the DelTrac server. Because of delays in the deployment of the TSC system and changes in available technology – most of the features of the custom DelTrac Server are now available in COTS Web Portal systems – deployment of the server is delayed and DelDOT is considering whether to change the server design to better use Web Portal technology.