A Case Study on Applying the Systems Engineering Approach: Best Practices and Lessons Learned from the Chattanooga SmartBus Project

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16. Abstract

This report presents the results of a review of the systems engineering processes used during the Chattanooga Area Regional Transportation Authority's (CARTA) SmartBus Project. The Smartbus Project is a comprehensive transit ITS program for the city of Chattanooga, Tennessee involving deployment of a wide array of transit ITS technologies. This review was part of the national evaluation of the SmartBus Project, a project that is being implemented in part with fiscal year (FY03) ITS Integration Program earmark funding and is being evaluated by the US Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) and the Federal Transit Administration (FTA).

This review highlights a number of features of CARTA's approach to systems engineering that helped lead to the success of its ITS deployments. Some of these features were: (a) documenting their long-term vision for ITS, (b) avoiding the temptation to do too much too fast, (c) testing systems thoroughly before introducing them to operation, and (d) being willing to accept schedule delays when needed to help manage deployment risks. In the end, CARTA's ITS program helped them evolve from an organization relying on manual processes and compartmentalized software systems to one with integrated applications and automated processes.

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GLOSSARY OF ACRONYMS

AAS	Automated Announcement System
APC	Automatic Passenger Counter
AVL	Automatic Vehicle Location
AVM	Automated Vehicle Monitoring
CAD	Computer-Aided Dispatch
CARTA	Chattanooga Area Regional Transportation Authority
DMS	Dynamic Message Sign
EVDO	Evolution-Data Optimized
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GPS	Global Positioning System
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
MDC	Mobile Data Computer
MOE	Measure of Effectiveness
TSP	Transit Signal Priority
TVM	Ticket Vending Machine
USDOT	United States Department of Transportation
WLAN	Wireless Local Area Networks

EXECUTIVE SUMMARY

The purpose of this document is to present the results of a review of the systems engineering processes used during the Chattanooga Area Regional Transportation Authority's (CARTA) SmartBus Project. This review was part of the national evaluation of the SmartBus Project, a project that is being implemented in part with fiscal year (FY03) ITS Integration Program earmark funding and is being evaluated by the US Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) and the Federal Transit Administration (FTA).

BACKGROUND ON CARTA AND THE SMARTBUS PROJECT

Chattanooga, Tennessee is a city of about 170,000 people (about 500,000 in the metropolitan area) located near the Tennessee-Georgia border. CARTA serves this community by providing fixed-route bus service (16 routes), curb-to-curb transit for people with disabilities (Care-A-Van), a free electric shuttle in the downtown area, an incline railway up historic Lookout Mountain, several parking garages, and management for much of the on-street parking in the downtown area. It is a moderate-sized transit organization in a moderate-sized community.

The CARTA SmartBus project is a comprehensive transit ITS program for the city of Chattanooga, Tennessee. It involves deployment of a wide array of transit ITS technologies deployed over a long period of time, including:

- Data warehousing and reporting software to accumulate data from different CARTA applications and provide reports to support CARTA operations (completed in 2004).

- New operations management software to support fixed-route scheduling and demand response scheduling and dispatch (completed in 2006).

- Ticket vending machines (TVM) for the Incline Railway (completed in 2006).

- Network connectivity to CARTA vehicles via cellular Evolution-Data Optimized (EVDO) network, along with wireless public Internet access on CARTA buses (completed in 2007).

- A diagnostics maintenance system that collects vehicle diagnostic data (completed in 2006), systems to automatically collect the data each night (completed in 2008), and systems to deliver the data in real-time to CARTA maintenance personnel (scheduled for late 2010).

- A next stop automated announcement system, real-time arrival time estimation system, bus stop signs, and a website for real-time arrival times (completed in 2008). This included deployment of in-vehicle hardware (e.g., mobile data computers, GPS receivers, automated passenger counters), but without full integration of this hardware into working systems.

- New fareboxes and a revenue management system (completed in 2008).

- Automatic Passenger Counter (APC) central management software, integration of the APCs with that software, and calibration of the system (scheduled for 2009).

- Computer-Aided Dispatch/Automatic Vehicle Location (CAD/AVL) system, the deployment of flexible-route scheduling and dispatch management software and integration with the demand-response scheduling and dispatch management software (scheduled for 2009).

- Bus security systems, such as a covert alarm and on-board video surveillance (scheduled for 2010).

BACKGROUND ON THE EVALUATION

The goal of the evaluation is to determine the impacts of these various technologies in performing daily functions such as operations, scheduling, service planning, and maintenance and to gather and document any lessons learned by the project team throughout the deployment and evaluation process. One set of lessons learned relates to the systems engineering processes used by CARTA. This report describes that systems engineering process and the lessons learned during CARTA's ITS deployments.

CONCLUSIONS OF THE EVALUATION

Making the transition from an organization that made limited use of technology to one in which technology was an integral part of its operations was challenging for CARTA. There were a number of activities that appeared to be key to CARTA's successfully meeting these challenges:

- *Documenting the long-term vision for ITS*. CARTA developed documents that described its long-term vision for ITS, and these documents helped keep the agency on track in its deployments. The documents also helped ensure that long lead-time activities were completed in time to support future plans.

- *Avoiding the temptation to do too much too fast*. CARTA sequenced its deployments so that systems were deployed sequentially, avoiding deployment of dependent systems at the same time. For example, one reason the CARTA data warehouse was the first ITS deployment was that so many other systems would need to integrate with it. Deploying it first meant that it could be operating stably before these other integrations occurred.

- *Being willing to accept schedule delays when needed to help manage deployment risks*. When changes to CARTA's deployment schedule were needed, CARTA was willing to accept delays in order to control risks. For example, when the bus arrival time prediction system was deployed early to take advantage of an outside funding opportunity, CARTA delayed other deployment activities so as not to overburden its limited IT resources.

- *Using a data warehouse*. The presence of a data warehouse at CARTA simplified other deployments in two ways. First, the data warehouse provided reporting tools, which eliminated the need for sophisticated reporting tools in other CARTA applications. Second, applications could be integrated with the data warehouse, reducing the total number of interfaces that were required.

- *Testing systems thoroughly before introducing them to operations*. CARTA displayed a strong commitment to thoroughly testing all systems before accepting them as complete and introducing them to operations. CARTA found and corrected many problems during final testing. If these problems had occurred in an operational system, they could have caused operational problems that could have reduced the confidence of the public and CARTA management in the ITS plans.

As CARTA completes the last steps of its ITS deployment plans, it appears that CARTA's approach to these deployments has been a success. Most of the technologies the agency hoped to deploy in 2003 are now in place, with the final technologies scheduled for deployment by the end of 2010. Those whose jobs have been impacted by the technologies speak favorably of them. Following a systems engineering approach helped CARTA successfully deploy its ITS technologies and become a transit agency in which the careful application of technology improved operations across the agency.

1 INTRODUCTION

The United States Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) has established a National ITS Evaluation Program to determine the impacts of federally funded ITS deployments across the country. The objective of this evaluation program is to document findings from ITS deployments that can be useful to a wide variety of external audiences, including planners, engineers, and managers. The results of these evaluations are intended to assist agencies in planning and implementing future ITS projects by providing information about lessons learned from systems that are already implemented.

One of the projects selected for a national evaluation was the Chattanooga Area Regional Transportation Authority's (CARTA) SmartBus Project. This project involved the application of new technologies across the full spectrum of CARTA's operations:

- Various network technologies were deployed to provide connectivity across CARTA's fixed and mobile assets.

- Technologies were deployed to help automate and modernize many field operations, such as APCs and new bus fare boxes.

- Technologies were deployed to help automate and modernize many back office operations, such as new dispatch and revenue management systems.

- A data warehouse was developed to consolidate data collected during CARTA operations, and reporting tools were created to take advantage of this data warehouse.

Managing a deployment that required the introduction of so many interdependent technologies across the entire range of CARTA operations was challenging and provided many opportunities for failure. There was a risk that a too-rapid introduction of a new technology would negatively impact the simultaneous deployment of a second, dependent technology. Rapid deployment of multiple technologies could also make it difficult for the organization to adapt to the changes. Alternatively, deploying a series of new technologies over a longer period of time could make it more likely that the technologies deployed earlier in the deployment cycle would fail to provide the immediate benefits that would justify its deployment because of the lack of other, supporting technologies. An inability to demonstrate benefits can result in a drop in support for the technology deployment process.

Proving its ability to manage these risks, CARTA has been successfully deploying the SmartBus technologies over a period of 6 years, from 2003 to the present, with most of the deployment now completed. This report describes the technologies being deployed and the systems engineering processes that were used to manage the deployment.

The remainder of this document is organized as follows:

- **<u>Section 2 – Background on CARTA and the SmartBus Deployment</u>.** This section provides background information on CARTA and the SmartBus project.

- **<u>Section 3 – The CARTA Systems Engineering Process</u>.** CARTA's experience with ITS can be traced back to 2002, when CARTA applied for and received a grant under the ITS Integration Program. Since that time, the agency has introduced new technologies across its operations, from TVMs for the Incline Railway to maintenance monitoring equipment on most CARTA vehicles. This section of the report describes the systems engineering process used by CARTA as it adopted these technologies. It ends with a section summarizing some of the keys to CARTA's successful deployment program.

- **<u>Section 4 – A Case Study of a CARTA ITS Deployment.</u>** This section of the report exemplifies the CARTA systems engineering process by describing the experiences during one of CARTA's ITS deployments: the data warehouse.

- **<u>Section 5 – Summary and Conclusions</u>.** This section provides a summary of the report and highlights the key lessons learned in reviewing the CARTA systems engineering processes.

2 BACKGROUND ON CARTA AND THE SMARTBUS PROJECT

2.1 OVERVIEW OF CARTA OPERATIONS

CARTA provides transit services for the City of Chattanooga in southeastern Tennessee and portions of nearby counties. Transit services include: fixed route service within the City of Chattanooga and Hamilton County; complementary demand-response paratransit service for citizens with disabilities within the City of Chattanooga and the Town of Signal Mountain; a downtown shuttle and parking system; and the Lookout Mountain Incline Railway (the Incline). CARTA operates 13 main line fixed routes, 3 neighborhood flex routes, the Care-A-Van demand responsive service, parking facilities in downtown Chattanooga, and a free shuttle service in downtown Chattanooga. Figure 1 shows a system map of CARTA's main line and neighborhood fixed routes.
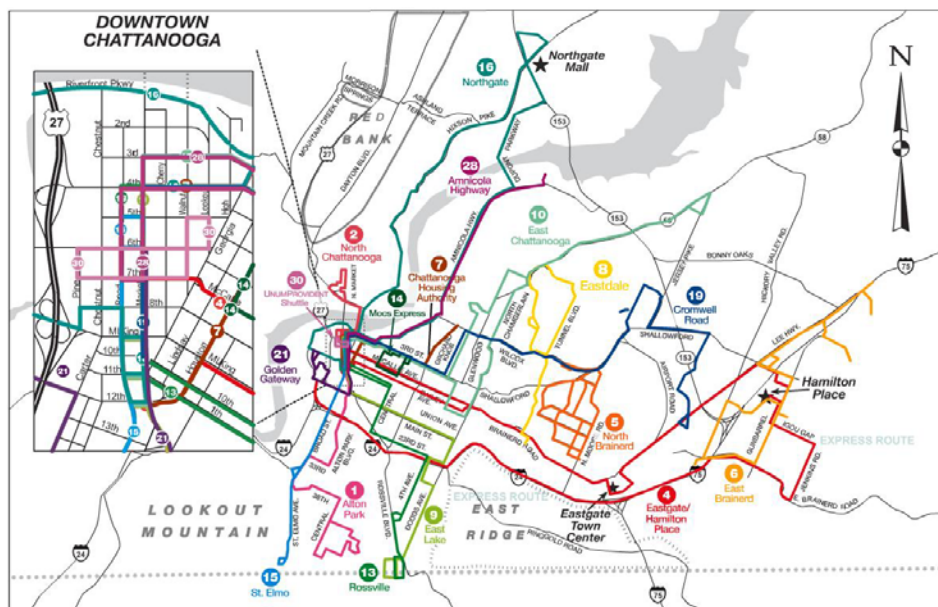
Figure 1. System Map of CARTA's Fixed Routes

CARTA's fixed and flex route services operate seven days per week using a mix of conventional diesel buses and electric shuttle buses. Buses on the fixed route service make stops on a fixed route at fixed times. Buses on the flex route service make stops at a shopping mall every 30 minutes, driving through nearby neighborhoods to pick up and drop off passengers in the intervening periods. Passengers can call in to schedule a pick up at any location in the neighborhood serviced by the bus. The CARTA Care-A-Van demand response service also operates seven days per week.

2.2 OVERVIEW OF CARTA ITS DEPLOYMENTS

CARTA's experience with technology deployments dates back to 1996, when it began using maintenance planning and tracking software for vehicles and facilities. In 1998, it began using GIS network software to support ADA paratransit operations. In 2001, it deployed a parking garage security system, established a system-wide network for CARTA fixed facilities, and integrated the CARTA network with the City IT network. The agency's experience with technology took an important step forward in 2003, when it applied for and was awarded an ITS Deployment Program earmark. With long-term funding for ITS technologies secured, CARTA began deploying a series of technologies that would integrate technologies across its operations.

Table 1 summarizes these deployments, and each of the technologies deployed is summarized in the following sections.

Table 1. CARTA ITS Deployments.

Year	Activity
2004	Deployed data warehousing and reporting software.
2005	Deployed handheld system ("tricoder") for recording vehicle fuel, oil, and other liquid usage.
2005	Deployed TVMs for the Incline Railway.
2006	Deployed new fixed-route scheduling software and new scheduling and dispatch management software for demand-response service.
2007	Deployed onboard components for an Automatic Vehicle Monitoring (AVM) system on fixed route vehicles, including wireless local area networks (WLAN) communications at both vehicle storage facilities to enable bulk data transfer with vehicles. The WLAN was also needed to download the onboard run schedules database for various onboard systems.
2007	Provided network connectivity to CARTA vehicles via cellular EVDO network to enable real-time data collection from vehicles for the upcoming next arrival predictions and CAD/AVL systems. Further leveraging this broadband data connectivity, CARTA also began offering wireless public Internet access on CARTA buses.
2008	Deployed a new revenue management system and new electronic registering fareboxes in fixed route vehicles. This included introducing the use of smart cards for fare payment, including onboard smart card revaluing capability (initially as a replacement for monthly passes and to enable a transition from transfers to a day pass).
2008	Deployed onboard audio and visual next stop automated announcement system (AAS) as well as a headsigns interface (to automatically change the headsign as the vehicle approaches the end of a trip).
2008	Deployed a public website with bus next-arrival-time prediction system based on real-time schedule adherence data gathered from the fleet over the mobile data communications system.
2008	Deployed bus arrival signs at eight bus stops — three at University of Tennessee – Chattanooga (UTC) campus stops, two on Market Street, one at Brainerd and Germantown, one at Hamilton Place Mall, and one at Eastgate Mall as an additional channel to disseminate to the public the next arrival predictions for these specific locations.
2009	Implemented daily upload via WLAN of bus diagnostic information collected onboard to the AVM server, making this data available to maintenance staff.
2009	Deployed APCs on fixed- and flex-route vehicles, with APC data uploaded daily via the WLAN, and the APC central management software to manage and analyze the collected APC data.
2009	Will complete deployment of the CAD/AVL dispatcher software initially for operations management on the fixed route fleet. This will include integration with the onboard systems to enable real-time fleet status data and new communications tools. It will also enable sending critical AVM alerts to dispatchers over the mobile data communications system.
2010	CAD/AVL deployment will be extended to the flex-route and demand-response fleets, including the deployment of flexible-route scheduling and dispatch management software and integration with the demand-reponse scheduling and dispatch management software.
2010	The smart card fare collection system will be extended to support stored value as an additional alternative to cash payment and web-based smart card revaluing.
2010	Fareboxes will be interfaced with the onboard systems for CAD/AVL to enable a single point login, additional data for the fare transactions database, and real-time access to farebox alarms data.

2.2.1   Data Warehousing and Reporting Software

CARTA understood that many of the activities needed to support its operations relied on information managed by different software applications. For example, reports needed to support tire lease payments relied on combining data from mileage logs with maintenance data that identified the tires mounted on each bus. Assessments of the cost-effectiveness of

alternative fuels required a combination of fuel usage and maintenance cost data. CARTA also noted that some of its existing applications were not capable of producing necessary reports. For example, the maintenance system could not produce the annual parts inventory audit reports needed for end-of-year accounting.

Recognizing these needs, CARTA decided to deploy data warehousing and reporting software. This data warehouse combined data from all CARTA software applications and was the central repository that supported key CARTA operational reporting. Making the CARTA data warehouse the first ITS application deployed enabled CARTA to include integration with the data warehouse as a requirement for future ITS deployments at CARTA.

2.2.2   Ticket Vending Machines

In the spring of 2005, CARTA deployed five TVMs along with a central TVM management server application to support the Incline Railway operation. The TVMs accept both cash and credit cards. The use of TVMs allowed CARTA to migrate from its former paper-based system for tracking Incline Railway ticket sales to an automated system that integrated with its data warehouse.

2.2.3   Remote Diagnostics Maintenance System

Beginning in 2006, CARTA required the inclusion of a multiplex system on all buses purchased. This system connected to the J1939 data bus; monitored common engine, transmission, and braking faults transmitted on the data bus (e.g., high engine oil temperature, low oil pressure, high transmission oil temperature); and logged the data for later retrieval. The main purpose of this system was for integration with other planned in-vehicle equipment to eventually provide CARTA with a full remote diagnostics maintenance system. (The system is now operational.)

2.2.4   Operations Software

In April 2006, CARTA completed the deployment of new fixed route scheduling software and new scheduling and dispatch management software for demand-response operations. Although the new software provided some immediate benefit, the full benefit for demand-response operations will not be achieved until the various onboard technologies are installed and integrated with the computer-aided dispatch/automated vehicle location (CAD/AVL) system and with the mobile data computers. The fixed-route scheduling software immediately supported more efficient development of the blocks, runs, and rosters for fixed-route schedules and allowed the user to explore various alternative scenarios. The paratransit scheduling and dispatch management software supports paratransit booking, scheduling, manifest generation, and completed trip validation, invoicing, and reporting. Once integrated with the CAD/AVL system and the demand-response fleet MDTs, this paratransit software will be better able to support same day scheduling adjustments and implement an electronic manifest and the real-time collection of data for completed trips.

CARTA had intended to use the same software to support the operation of the flexible neighborhood routes using real-time scheduling and manifest updating in response to telephone requests from passengers. However, it discovered that, without real-time location information from CAD/AVL, the software was not effective for this type of operation. For this reason, CARTA decided to delay this part of the software deployment

2.2.5   Fareboxes and Revenue Management System

CARTA's fareboxes were replaced with newer models that support a transactional database (i.e., with a time-stamped record created for each fare transaction indicating the amount collected and the fare type) and contactless smart card readers. As part of this deployment, new revenue management software was also deployed. This software included support for

the initial role of smart cards in the system as both monthly and day passes and with onboard smart card revaluing. In the future, CARTA may extend this capability to allow the use of smart cards as debit cards to pay fares.

2.2.6   Onboard Systems and Fixed Route CAD/AVL Operations Management Software

CARTA has implemented onboard systems including mobile data computers (MDC) for run login and real-time reporting of location and schedule adherence. These technologies already support the onboard next-stop announcements, APC, automated vehicle monitoring (AVM), and next arrival predictions. The dispatcher fixed-route CAD/AVL operations management software is being implemented beginning in late 2009.

- *Mobile data computers.* Mobile data computers on the vehicles will provide operators with text messaging capabilities, voice radio call management, and navigational assistance and will provide feedback to the operator regarding route/schedule adherence and remote diagnostics. It is important to note that the full impacts of many of the technologies already discussed are not expected to be fully realized until the onboard systems have been integrated with the CAD/AVL software. An example of this is the MDCs. These are expected to enhance the paratransit software by providing features such as paperless manifests, real-time manifest updates, automated reporting of date/time/location for pick-up/drop-off trip events, and location-enhanced, same day scheduling.

- *Computer-aided dispatch / automated vehicle location software*. The CAD/AVL software will receive location and schedule adherence data from the onboard MDCs and will provide dispatchers, customer service, and maintenance management staff with a map and tabular display of the vehicle locations and status (e.g., whether the bus is behind schedule) for the entire fleet including fixed-route, paratransit, and non-revenue vehicles.

- *Covert alarm.* A covert alarm switch will be incorporated into the MDCs to allow operators to send an emergency alarm message to dispatch through the CAD/AVL system.

- *Automated passenger counters.* APCs will count the number of passengers boarding and alighting at each stop and will display this information on the operator's MDC. This data will be archived onboard and uploaded using the bulk data transfer system when the vehicles return to the garage.

- *Next stop automated announcement system*. An automated announcement system (AAS) will announce each bus stop as the vehicle approaches (e.g., stop name, cross street, landmark). An LED display inside the vehicle will simultaneously display a corresponding text message.

3 THE CARTA SYSTEMS ENGINEERING PROCESS

3.1 A BRIEF HISTORY AND TIMELINE OF CARTA'S ITS

Prior to 2002, CARTA did not employ significant ITS assets. Although the agency used computerized systems for accounting, timekeeping, and payroll and a GIS software application to manage paratransit operations, these systems were not integrated. Operating fareboxes and headsigns required manual input from drivers, and Incline Rail ticket sales were still recorded in manual logs. This situation began to change in 2002 when CARTA began to plan their use of ITS.

3.1.1 Defining the Vision

In 2002, CARTA prepared a grant application under the ITS Integration Program. This resulted in grants under the FY 2002 and 2003 ITS Integration Programs. The grant application identified a long-term vision for ITS at CARTA that considered the needs that could be met through the deployment of proven ITS technologies. The planned deployments included:

- An AVL system for transit, paratransit, and shuttles.

- Mobile data terminals for CARTA vehicles.

- Scheduling and dispatching software for general public and paratransit routes.

- On-bus stop announcement (visual and voice) for transit and shuttle vehicles.

- Automatic passenger counters.

- Web-based traveler information.

- Integration with traffic signal priority.

- Digital recording system on all revenue vehicles recording views of the steps, driver, and other important areas of the bus.

- Bus monitoring systems that track coolant temperature, oil pressure, speed, interior temperature, and related indicators.

The grant applications identified the general scope of ITS plans for CARTA, established funding for deploying that ITS, and established a milestone for completing the deployment by March 2009.

In 2003, CARTA reviewed the existing Regional ITS Architecture and mapped its needs to the User Services and Market Packages defined in that architecture. CARTA used a regional stakeholders workshop to begin prioritizing its needs. This workshop helped identify the existing organizational practices at CARTA, the infrastructure in place to support those practices, the outstanding needs that could be met using ITS, and the priorities for meeting those needs. This workshop helped finalize the vision for ITS at CARTA by defining the capabilities that would be provided by ITS technologies. CARTA next conducted a review of available ITS technologies that could be used to meet those needs and documented the results of this review in a November 2003 report. At about the same time, CARTA elected to hire a Manager of Technology. The Manager of Technology would be dedicated to the development, operation, and maintenance of ITS at CARTA.

After reviewing both the agency's needs and the technologies available, CARTA identified the technologies to include in its ITS program and documented this in the System Overview Update – 2004 report completed in January 2004. A key feature of this report was the system overview diagram (see Figure 2), which depicted how the various technologies would be integrated into an overall system. It was this diagram that summarized CARTA's

long-term vision for its ITS program. This diagram identified the following as existing technologies deployed at CARTA:

- *Radio Communications*. All CARTA fixed route, paratransit, and supervisory vehicles were equipped with voice radio supported by the City-operated 800 MHz trunked voice radio system. The City radio network also supported 19.2 kbps data communications.

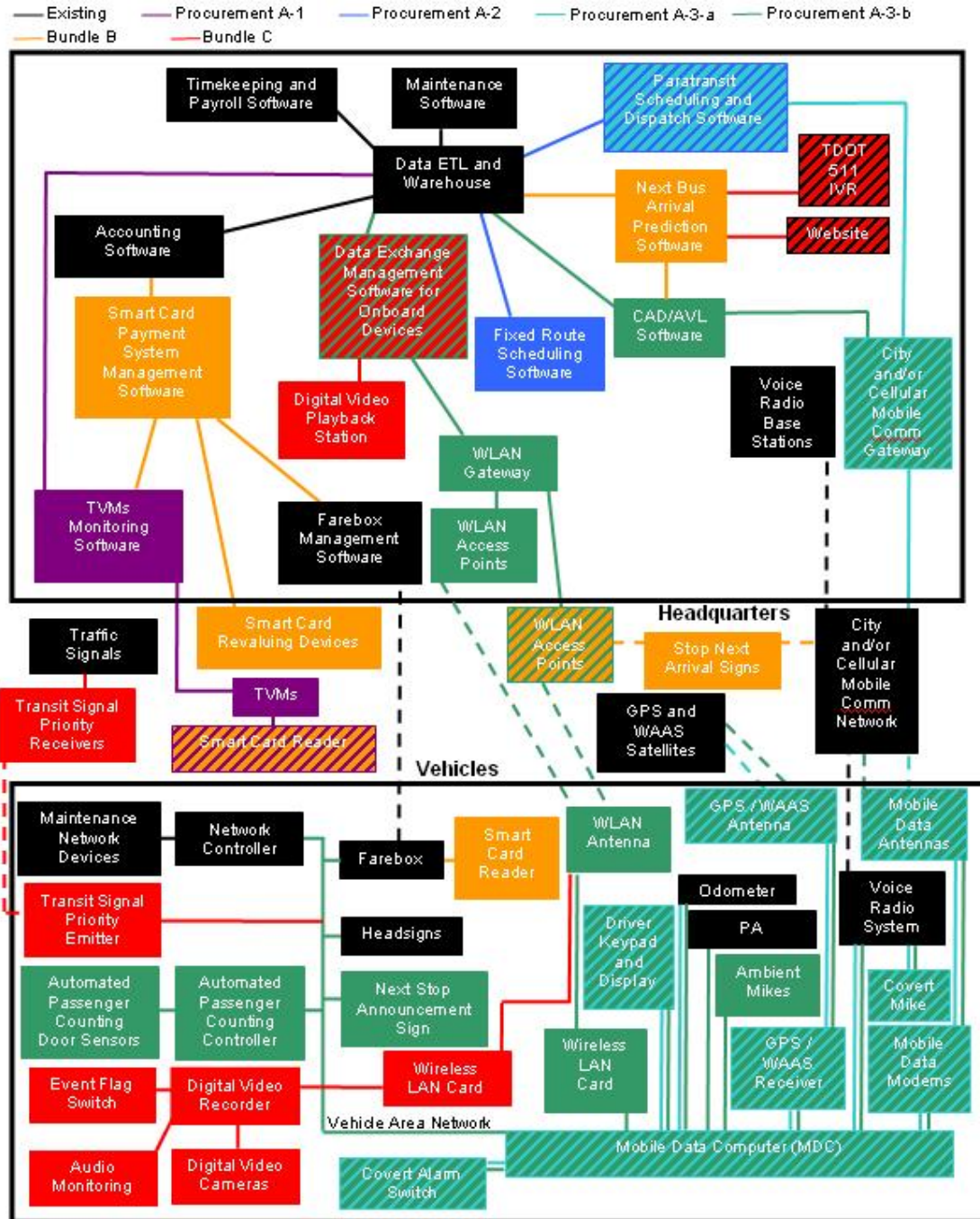- *Onboard Systems*. CARTA buses were equipped with headsigns and a public address system.

Figure 2. CARTA 2005 ITS System Overview Diagram

- *Fareboxes*. Fixed route vehicles were equipped with a 12-year-old farebox system. This system was limited to providing only fare tallies (i.e., number of fares by fare category).

- *Maintenance Software*. CARTA maintenance operations were supported by maintenance software that generated and tracked work orders and provided bar-coded parts management capabilities.

- *Timekeeping and Payroll Software*. CARTA had recently deployed a new timekeeping and payroll management system which tracked work shifts, time worked, and pay rate for all CARTA hourly employees.

- *Data Warehouse*. This system, the first CARTA ITS element, was deployed in 2004 and integrated with several existing CARTA applications.

This diagram also depicted two government-owned systems with which CARTA's ITS would integrate – the city traffic signal (for transit signal priority) and the GPS (for AVL). The other elements of this diagram identified CARTA's long-term vision for its ITS program.

3.1.2   Planning the Deployments

The System Overview Update also defined the plan for deploying the technologies it described. It grouped the technologies into a collection of individual deployment projects and defined the general strategy for the deployment procurements. In April 2004, CARTA identified the sequence in which the ITS projects would be deployed, and also identified infrastructure enhancements (e.g., network upgrades) needed to support the projects. CARTA established the deployment schedule for these projects in May 2004, along with the procurement procedures they would follow in pursuing these deployments. CARTA also began updating the System Overview Update report annually, describing the existing and planned ITS projects.

- Short term projects included:

  - *Include Rail Ticket Vending Machines*. TVMs would be installed to support the Incline Railway.

  - *Fixed and Flex Route Operations*. New operations management software would be deployed to support fixed route and flex route scheduling. New paratransit software would support booking, scheduling, manifest generation, invoicing, etc. Both applications would integrate with the data warehouse and with future ITS applications, such as mobile data computers.

  - *Paratransit Operations*. Paratransit MDC deployment and integration would deploy the in-vehicle devices needed to support CARTA's long-term ITS plans. This included deploying MDCs, integrating MDCs with the paratransit operations software, and deploying covert alarms.

  - *Networking*. CARTA identified four possible approaches to meet its mobile communication needs: 1) an expanded City mobile communications network (if deployed), 2) cellular data communications, 3) extended wireless local area networks (WLANs), and 4) a WLAN at the CARTA garage. No procurement package was defined for this deployment pending determination of the best approach.

  - *Onboard Systems*. The deployment of onboard systems for fixed and flex route vehicles would include automated passenger counters, next stop automated announcement system, covert alarms, MDCs, an on-board vehicle area network, and integration of these and other onboard systems (e.g., to support AVM) with the MDC.

- Medium-term ITS projects included:

    ▪ *Next Bus Arrival Prediction*. Software to estimate next bus arrival times based on data received from AVL systems.

    ▪ *Smart Card Fare Payment System*. This would include fareboxes for accepting smart card fare payment on fixed route vehicles and smart card management software integrated with the farebox management system, the TVM, and the data warehouse.

- Long-term ITS projects included:

    ▪ *Traveler Information Enhancements*. Integration of next-bus arrival prediction software with CARTA's web server and Interactive Voice Response (IVR) systems to provide next-bus arrival time information via the web and phone.

    ▪ *On-board Video Monitoring*. Onboard video monitoring with digital and audio recording systems and integration with the MDC for distribution across CARTA's communication network, when desired.

    ▪ *Transit Signal Priority*. Integration of transit signal priority equipment with the MDC to support TSP at City traffic signals.

CARTA also developed an ITS implementation schedule in 2005 and integrated this schedule into the System Overview document, beginning in 2006.

3.1.3   Deploying Technologies

CARTA's first step in its ITS program was to upgrade its infrastructure to prepare for the ITS deployments. This included deploying the CARTA Data Warehouse, deploying new timekeeping and payroll software, and integrating the new software with the data warehouse. With each deployment, CARTA developed a project deployment plan (refer to Figure 2), which included the following non-technical topics:

- A project overview that described the project.

- Description of how the system will operate and be maintained once deployed.

- Project stakeholders and their roles in the deployment.

- Approaches for monitoring and evaluating the performance of the deployment.

- Suggestions for outreach activities to accompany the deployment.

The technical topics related to each project were addressed through a series of standard systems engineering documents – a specifications document, a design review, test procedures, test results, etc.

3.1.4   Maintaining the Vision

As technologies were deployed, CARTA's vision for its ITS program evolved. As a result, CARTA updated its System Overview annually to reflect (a) technologies that were already deployed and (b) changes to the technologies that were planned for deployment. Maintaining this document helped CARTA ensure that its vision for ITS remained consistent with evolving technologies and that its ITS deployment activities remained consistent with its vision for ITS.

3.2 CARTA'S SYSTEMS ENGINEERING PROCESS AND THE "V" MODEL

FHWA has noted that the "V" model, as shown in Figure 3, is a standard way to represent systems engineering for ITS projects.[1]
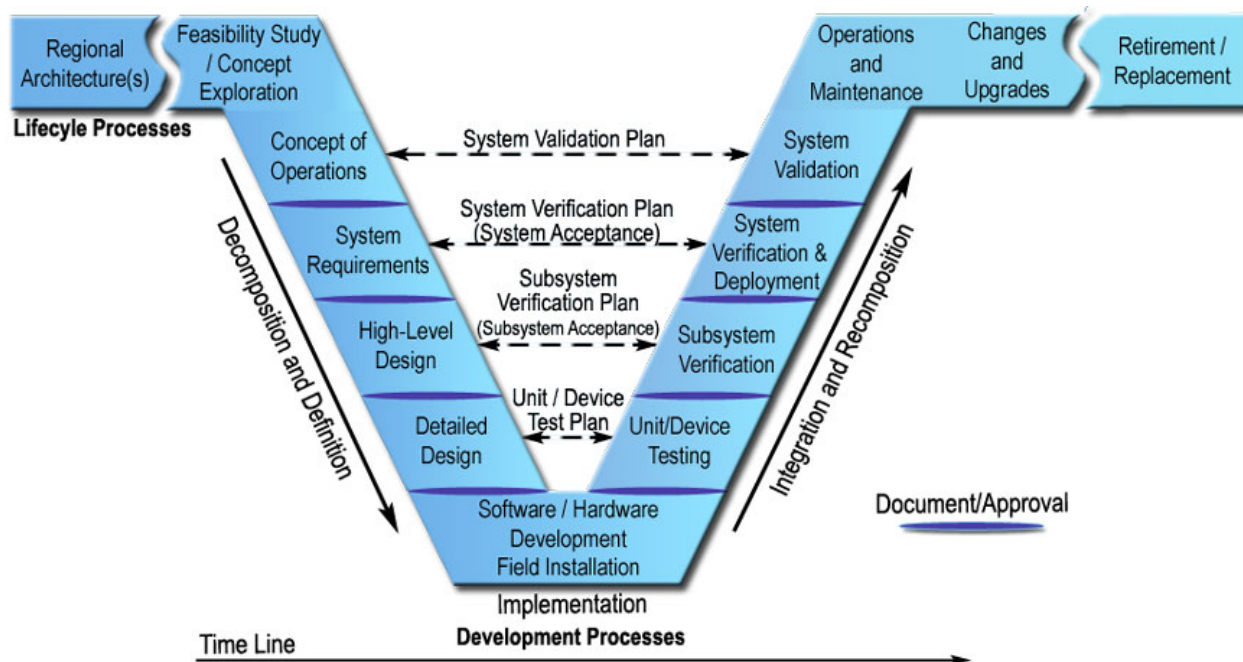
Figure 3. The Systems Engineering "V" Diagram

CARTA followed this general approach, but tailored the approach as indicated in Figure 2 to better suit the scale of their organization and the incremental approach used to develop the overall ITS program through a sequence of individual project deployments. For example, the subsystem and system verification steps were combined in an overall acceptance testing process based on the modest scope of each individual deployment project. There were also opportunities to involve key CARTA end users throughout the project development and implementation process to validate that the system would meet their needs. The concept of operations was incrementally updated when needed to reflect the specific effects of individual projects as they were deployed.

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[1] Federal Highway Administration, *Systems Engineering for Intelligent Transportation Systems*, "Chapter 3, What is Systems Engineering?" FHWA-HOP-07-069 (Washington, DC: January 2007). http://ops.fhwa.dot.gov/publications/seitsguide/index.htm (Accessed 10/5/2009)

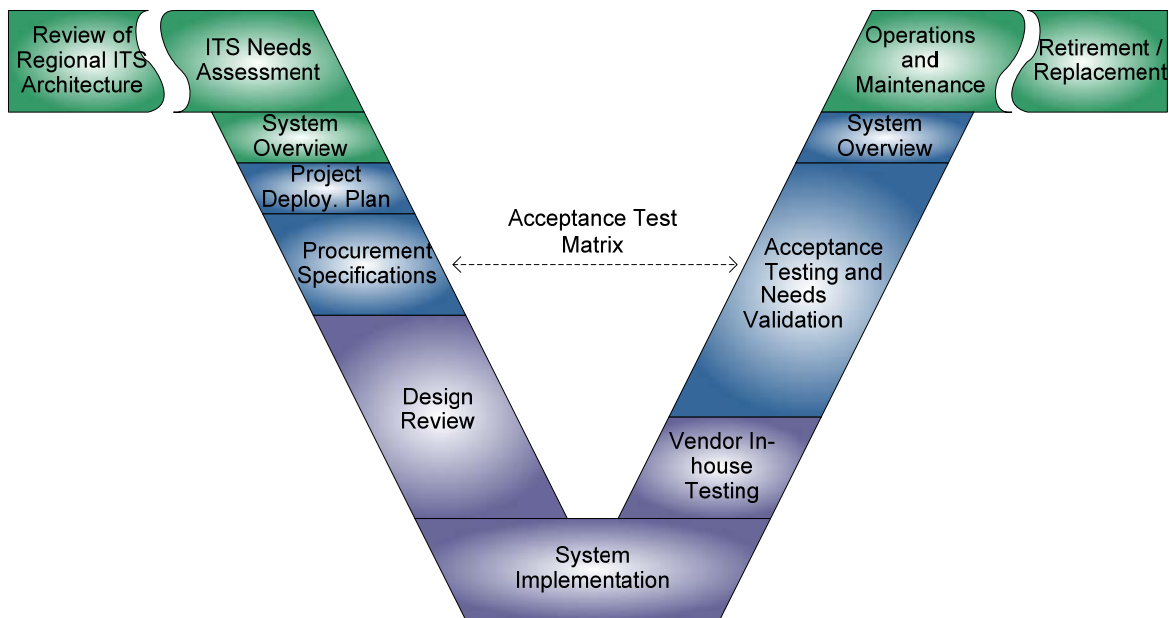Figure 4. CARTA's Implementation of the Systems Engineering "V" Diagram

In Figure 4, green shading indicates activities that were conducted for their entire ITS program and blue shading indicates activities that were conducted for each project. Purple shading indicates activities performed primarily by project implementation contractors in a collaborative approach involving CARTA review and feedback.

CARTA began its process with a review of the existing Regional ITS Architecture. This included a review of CARTA operations/organization/infrastructure to help identify needs that could be addressed through the deployment of proven ITS technologies and related these needs to the User Services and Market Packages in the ITS Architecture. These efforts helped CARTA explore and define an overall ITS program vision – a system concept overview for how existing and additional technologies could be best integrated to address the agency's needs and situation over the course of developing the overall ITS program. This system overview document defined the ongoing and near-term procurement packages and provided general descriptions of medium- and long-term plans for procurement packages. It also served as both a concept of operations for CARTA ITS and a planning document.

As individual project procurements were being initiated, CARTA developed a project deployment plan. These plans defined the scope of the individual projects and helped CARTA prepare to successfully transition each project into revenue service once the deployment was completed. It addressed aspects such as organizational impacts, operations and maintenance, monitoring and evaluation, and outreach. The project requirements were documented in the procurement package for the project, including an acceptance matrix that served as the basis for the design review and acceptance testing.

The selected project implementation contractor completed a collaborative design documentation and review process with CARTA, prior to developing and deploying the system hardware, software and integration. The project implementation contractor was responsible for in-house testing prior to the start of formal acceptance testing, which was witnessed by CARTA for each subsystem and the overall system. The testing followed procedures that were collaboratively planned in advance with the vendor so as to formally verify all acceptance matrix requirements.

CARTA also involved its end users throughout the process, in developing procurement specifications, contractor selection, design review, acceptance testing, review of training materials and documentation, and the transition into operations and maintenance. This all served to help validate that the project was being developed and implemented so as to address CARTA's needs. As each project was completed, the System Overview was updated to reflect the post-deployment situation. This provided another form of validation, as the review of CARTA's post-deployment situation helped CARTA assess the extent to which the project had helped it move towards the vision described in that document.

This step and the process of regularly updating the system overview also helped CARTA prepare for eventual changes, upgrades, retirements, and replacements that may be necessary. The process of preparing the annual updates to the system overview will provide CARTA with the opportunity to identify the need for such activities and include those needs in their long-term ITS plans. As with their ITS deployments, CARTA's needs for changes, upgrades, retirements, and replacements to their IT systems would be documented in the system overview and, from there, would follow the path of their ITS deployments.

3.3 KEYS TO CARTA'S SUCCESS

CARTA faced many challenges while deploying ITS technologies to support its operations. Some projects were delayed and others did not meet expectations and required rework. When new opportunities arose, CARTA had to re-plan its deployment schedule to accommodate the opportunities. Despite these challenges, CARTA remained focused on the ITS deployments and continued to deploy ITS technologies that had positive impacts on its operations. This section of the report describes approaches CARTA used to manage its systems engineering processes that helped lead to the success of its ITS deployments.

3.3.1   Developing and Maintaining a Long-Term Vision for ITS

As summarized in the previous section, one of the most important steps CARTA undertook for the ITS program was development of a System Overview Update report in 2004 to document a long-term vision of how CARTA wanted to use ITS. The report included:

- A Chattanooga Regional Transit ITS Overview Diagram that depicted the current and planned ITS technologies.

- Descriptions of deployed ITS technologies.

- Descriptions of ongoing and planned procurements.

- An implementation schedule.

The table of contents from this document is shown in Figure 5.

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Figure 5. The System Overview Update Table of Contents

CARTA updated this report annually to reflect changes that occurred in the previous year and plans for the upcoming years, so that this document always provided CARTA with a road map of where the agency was and where it was headed with its ITS program. This provided CARTA with some notable benefits.

First, understanding the long-term goals helped CARTA ensure that all the necessary preliminary activities were completed to support the long-term goals. This was particularly important with regard to long lead-time items with a long lifetime, such as bus purchases. For example, in 2006 CARTA added requirements that bus purchases include multiplex systems to better support the agency's plans for AVM. (The multiplex system allows the AVM to perform enhanced monitoring of more devices than a bus without a multiplex system. The AVM system on older CARTA buses monitors fewer devices than the system on those purchased after 2006.)

Documenting the long-term vision for ITS helps ensure that long lead-time activities are completed in time to support future plans.

Figure 6. A CARTA Bus Arrival Time Sign

A documented long-term vision also helped CARTA take advantage of short-term opportunities that arose. For example, CARTA was approached by the University of Tennessee at Chattanooga with funding to support the installation of arrival time signs at several bus stops on CARTA routes on the UT Chattanooga campus. At the time that this opportunity became available, CARTA did not have all of the systems in place to support

> *Taking advantage of opportunities that arise may require being flexible regarding the deployment schedule.*

real-time bus arrival time information. Realizing that real-time arrival time information was consistent with its long-term plans, CARTA re-organized its planned deployment activities to fast-track those items needed to support arrival time signs. (More information on this re-organization is in the next section.)

3.3.2   Proper Sequencing of ITS Deployments

CARTA also strove to introduce changes incrementally, avoiding the temptation to do too much too fast. Doing too much too fast can

> *Avoid the temptation to do too much too fast.*

increase the deployment risks because problems in developing one system can impact development of a second system dependent on the first. A review of the CARTA deployment schedule indicates that CARTA avoided simultaneously deploying systems that included strong dependencies between them.

- The first system deployed was the data warehouse, which pulled data from a number of existing systems. Since most other systems in CARTA's ITS plans would integrate with the data warehouse, deploying it first helped ensure that the data warehouse was operating stably when new systems that integrated with it were deployed.

- TVMs and the demand-response and fixed-route operations software were deployed in 2006. These systems integrated with the data warehouse, but required little additional integration when they were deployed. By the time CAD/AVL systems were deployed and

integrated with the operations software in 2009, the operations software was tested and stable.

- In 2007, CARTA provided network connectivity to CARTA vehicles. This ensured that the network connectivity needed to support CAD/AVL was in place in advance of the CAD/AVL deployment.

An exception to this rule occurred in 2008, when CARTA fast-tracked several system elements needed to support the real-time bus arrival time signs. At the time that the University of Tennessee at Chattanooga approached CARTA with the real-time bus arrival time sign opportunity, many system elements necessary to support real-time bus arrival time information were already in place; onboard location and route tracking equipment, ability to load the onboard run databases from Trapeze FX via the WLAN, and network connectivity to the buses. Other needed system elements were not in place, however. For example, the CleverCAD system was going to be used to access bus location archives needed to estimate run times and the real-time bus schedule adherence data needed to estimate arrival times. Also needed were elements from the BusTime system, including the arrival time website server and the signs themselves.

So, in this particular case, CARTA elected to deploy the BusTime system, the arrival time website server, and the bus stop dynamic message signs in 2008 despite the original intention to deploy these elements after the CAD AVL software deployment was well

> *Be willing to accept schedule delays when needed to help manage deployment risks.*

underway. To offset the risks from accelerating the deployment on specific elements of the program, CARTA deferred the rollout of the AVM and APC and slowed the CAD/ AVL deployment to allow the agency and its contractors to focus on elements needed for the bus arrival time predictions system. Thus, even when CARTA needed to adjust the schedule to accelerate some elements, it simultaneously accepted delays on other elements to help offset the risks of simultaneous deployments.

The early deployment of the data warehouse provides another example of sequencing projects to reduce complexity. Early in its ITS deployment process, CARTA recognized the need to integrate data from different sources

> *Using a data warehouse can reduce overall system complexity by reducing the number of systems that must be integrated.*

to support CARTA operations. An example of this is integrating fuel and maintenance cost data to report on the total cost of vehicle operations in order to identify the most cost-effective vehicles. One approach for doing this would have been to interface each of the ITS applications with every other ITS application for which integration was needed. Deploying a data warehouse allowed CARTA to achieve the same capabilities by integrating each ITS application with only a single other application – the data warehouse.

3.3.3   Manage the Limited IT Resources

CARTA's IT resources were limited – the agency had a Manager of Technology who was responsible for most IT functions at CARTA, from maintaining desktop computers to overseeing ITS deployments. With limited IT resources, CARTA took steps to control the maintenance burden that would be placed on the Manager of Technology as systems were brought online. The following list summarizes some of the steps CARTA used to help ensure that the Manager of Technology did not become overburdened as new ITS applications were deployed.

- *Virtual servers were used to reduce the number of physical servers at CARTA*. In general, the presence of more physical servers implies the requirement to perform more maintenance. There are more systems to back up and more pieces of hardware that might fail. For most of its projects, CARTA required that applications run on virtual servers hosted on a single physical server housed at the CARTA facility. This approach allowed CARTA to reduce the number of physical servers required to support its IT processes.

> *Using virtual servers and ensuring that all applications use a single database engine can reduce time required to maintain the IT infrastructure.*

- *Restrict applications to the use of a single database engine*. Each database requires configuration and maintenance. If multiple database engines are used, then the IT staff will need to be familiar with the configuration and maintenance tools for each type of database in use. The tools to support data integration with the Data Warehouse could also differ for different database engines. With this in mind, CARTA required that all newly acquired CARTA applications use the same database engine.

- *Limit the number of active deployments*. CARTA's Manager of Technology was responsible for overseeing all ITS deployments as well as maintaining already deployed systems. Thus, each active deployment placed an additional workload on the Manager of Technology. To alleviate the burden, in the cases where some deployment activities were moved forward in time (e.g., deployment of the bus arrival time system), other activities were delayed.

- *Thoroughly test applications before accepting them*. Developing and documenting a thorough testing process can be a time consuming activity. However, the process of fixing a problem in a production system can be even more time consuming. Also, the time required for testing can be scheduled. When problems occurred, they typically disrupted schedules and required immediate attention. With limited resources, identifying and correcting problems during scheduled testing periods is much less disruptive than correcting problems as they occur in a system that is already in use.

- *Make appropriate use of consultants to assist with the deployment process*. At the start of CARTA's ITS deployment, a Manager of Technology was hired whose primary responsibilities were the deployment and maintenance of technologies at CARTA. CARTA supplemented this person with an outside contractor who provided additional resources when needed, and contributed a complementary set of skills to that of the Manager of Technology. For example, from 2003 through 2009, CARTA used its consultant primarily to provide systems engineering, specifications development, and testing processes services. This allowed the Manager of Technology to focus on other areas where his strengths and experience were concentrated.

Taken together, these approaches allowed CARTA to effectively deploy and maintain its ITS technologies with the limited IT support staff that was available.

3.3.4   Involving Stakeholders

CARTA recognized the importance of stakeholder involvement early in its ITS program. One of the most vital phases in each ITS deployment was development of a project-specific deployment plan, with the last chapter of each plan devoted to outreach. In general, the outreach chapter for each project addressed the following three stakeholder groups:

- *The Council of Managers*. The Enterprise Center and its Council of Managers are responsible for the Chattanooga Regional ITS Architecture. CARTA regularly participated in meetings with the Enterprise Center to coordinate CARTA ITS plans with the regional plan.

- *CARTA Staff*. For each ITS Deployment, CARTA formed a team with representation from all departments that was involved with operating and maintaining the system once deployed. This team helped provided information about current processes and procedures, defined requirements for the deployment, and helped identify how current processes and procedures would be modified after the deployment.

- *The General Public*. While CARTA did not typically directly involve members of the general public in its development process, the agency did recognize the need in its deployment plans to publicize the changes to passengers and to educate passengers on how to use new services and features provided by the ITS technologies.

A good example of CARTA's concern for stakeholder involvement was the formation of ITS Oversight Committees to provide feedback on plans for the deployment of onboard systems, which included paid time for

> *Including a broad range of stakeholders, including those skeptical of ITS, can improve the final product and its level of acceptance.*

employees to participate in committee meetings. These committees included union representatives and many drivers, as well as several employees who had preconceived negative opinions regarding these particular technologies. These committees provided useful recommendations regarding the ITS rollout, and this approach also resulted in better buy-in for the ITS deployments among those employees.

Figure 7. CARTA Scheduler at Work

Another example of CARTA being sensitive to user needs was the change in plans regarding the timing for introducing the flex-route operations management software. CARTA originally planned to begin using the software to support these services in 2006, in conjunction with the rollout of new operations management software for fixed-route and paratransit operations. However, feedback from flex-route dispatchers indicated that the planned system could not efficiently support dispatch services until an overall CAD/AVL system was available to provide real-time bus location information. In response to these concerns, CARTA delayed this deployment and made plans to include acquisition of alternative flex-route operations management software incorporating additional software features to better satisfy user needs.

3.3.5 Planning for Demonstrations of Success

Another facet of managing stakeholders is planning projects so that successful demonstrations and observable benefits occur regularly. These demonstrations can help maintain program momentum in two ways. First, they build enthusiasm for ITS by regularly

providing benefits to stakeholders – stakeholders that are benefiting from ITS are more likely to continue to support it. Second, they help build confidence that ITS will be deployed successfully and, once deployed, will generate benefits. With this in mind, CARTA chose as its first ITS projects those that could be completed in a relatively short time and would generate easy-to-see benefits:

> *Search for easy-to-implement projects that will produce easy-to-see benefits.*

- The data warehouse project was completed in 2004 and immediately simplified a number of internal reporting functions. This was a particularly important step because the data warehouse benefited senior CARTA management by providing them with improved visibility into CARTA operations.

- The "tricoder" system for recording vehicle fuel, oil, and other liquid usage, deployed in 2005, saved time by simplifying a manual process. This system was relatively easy to deploy because it required little integration with other systems and it saved CARTA staff the time each day that had been used to transcribe manual fuel usage data.

- The CARTA EVDO network, deployed in 2007, was needed to support data communications between CARTA vehicles and CARTA headquarters. While designing this network, CARTA noted that it could purchase EVDO modems for vehicles with a built-in router and Wi-Fi. This allowed the agency to provide wireless Internet service to passengers at essentially no cost over the cost of the required data communications network. And, the benefit to passengers – free Internet service – was easily observable.

CARTA's ITS staff were aware of the need to demonstrate the benefits being achieved through the ITS technologies being deployed. The project-specific deployment plans included a section on monitoring and evaluation that described the types of benefits anticipated and how those benefits might be identified. And, CARTA ITS staff monitored the systems to identify benefits. For example, when the Evaluation Team discussed free Wi-Fi usage with CARTA, CARTA staff accessed monitoring screens that allowed them to identify the number of users presently accessing the Wi-Fi system.

3.3.6 Evaluation and Testing

Another feature of CARTA's systems engineering approach was a strong commitment to thoroughly testing the ITS technologies before introducing them to support operations. CARTA's general approach worked as follows. All the requirements for a system were documented in an acceptance matrix. This matrix included a requirement ID, the requirement description and amendments to that description, the requirement status, and any remarks related to the requirement and the verification and validation performed. For example, the acceptance matrix for the CAD/AVL deployment was maintained in an Excel® worksheet that included nearly 800 lines of requirements information.[2]

The deployments themselves were divided up into a series of incremental demonstrations, with each demonstration exhibiting more of the final functionality required. Before each demonstration, the contractor was required to submit for CARTA approval an acceptance test procedure that identified the requirements that would be met by that demonstration and the method used to verify the requirements were met. CARTA and the contractor would

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[2] This information included requirements, as well as header lines used to group related requirements and assumptions regarding the systems with which the new system would integrate.

follow the test procedures during the demonstration, and CARTA would update the requirements matrix with information about the results of the testing and the status of each requirement tested. This approach provided a mechanism for (a) ensuring that all requirements were satisfactorily met and (b) monitoring progress towards meeting the requirements.

But having a mechanism for testing is not sufficient without a commitment to thorough testing, and there were numerous examples that demonstrated CARTA's commitment to thorough testing. First was CARTA's recognition of the importance of testing. During discussions with the evaluators, CARTA identified testing as an important part of their system engineering process. Second was CARTA's willingness, if necessary, to change plans based on testing results. For example, during testing of the new operations software for its flex-route operations, CARTA determined that the planned new software would not provide the expected benefits. So, CARTA stopped the introduction of that software, selected an alternative that would better meet operational needs, and rescheduled the deployment to take place after the CAD/AVL system was in place.

An example of the thoroughness of CARTA's testing is related to the rollout of the next-stop announcement system in 2008. In late 2008, CARTA completed the onboard database and

> *Commit to thoroughly testing systems before introducing them to operations.*

was capable of activating onboard audio and dynamic message sign (DMS) announcements. Rather than proceed with operations after verifying the general functionality of the system, CARTA elected to conduct a comprehensive test of the system's functionality for of their routes. CARTA, using a test bus set up with the test database, drove each route variation in the system with an observer onboard to note any errors in the messages displayed and announcements made. During this testing, CARTA discovered and corrected several errors in the system, including incorrect announcements and announcements triggered at incorrect locations.

This end-use testing also allowed CARTA to identify enhancements to the system that would improve its operation. The system was originally configured to display a stop announcement then display the date/time on the interior DMS prior to displaying information about the next stop. During testing, CARTA discovered that the time spent displaying the date/time sometimes delayed the next-stop display, particularly when stops were closely spaced. Thus, performing end-use testing of the system prevented exposing the public to these errors, which could have reduced public confidence. It also enabled CARTA to identify ways to improve the way the system operated.

The 2009 roll out of the AVM system provided another example of CARTA's commitment to testing. The core infrastructure needed to support AVM – the onboard equipment, the WLAN for daily data uploads, and the AVM software – was in place early in 2008. However, it had been decided to focus 2008 ITS resources on implementing systems that would deliver the most direct and visible benefits most directly and visibly to riders, such as the next-stop announcements and the next-arrival-time predictions. After these systems came online in December 2008, CARTA shifted focus to rolling out AVM. By January 2009, the AVM system elements were integrated and the AVM system was receiving daily uploads of data from the buses. CARTA then conducted internal testing of the AVM system to confirm it was operating correctly before releasing it for use by the mechanics in March 2009.

Initially, some contractors were resistant to the extra time CARTA required for testing. This resistance was typically overcome during the initial subsystem implementations, when CARTA first applied its thorough testing processes with that contractor. CARTA required that test procedures fully demonstrate all the specified requirements for the systems and that these systems be planned in advance. CARTA reinforced its commitment to testing by

refusing to accept systems that did not pass the documented test procedures. After working with CARTA's testing process, most contractors recognized that this approach, while it might delay final acceptance, helped prevent errors from being found after the system was in use when corrections are more difficult and costly to make.

4 CASE STUDIES OF CARTA ITS DEPLOYMENTS

This section exemplifies CARTA's systems engineering approach by providing details about the data warehouse deployment.

4.1 DATA WAREHOUSING

The CARTA data warehouse was not on the initial list of systems identified on CARTA's

> *Deploying a data warehouse as the first ITS application can simplify future ITS deployments.*

2003 application for ITS deployment support. Despite this, CARTA elected to deploy the data warehouse as its first ITS deployment. There were several reasons for this choice:

- *The data warehouse would be integrated with most of the ITS deployments.* Deploying the data warehouse first helped ensure that this system would be operating stably before additional integrations were attempted.

- *The data warehouse provided a central source for sharing data between CARTA ITS applications.* Integrating the ITS applications through the data warehouse reduced the total number of interfaces that were required. It also insulated each ITS application from being impacted by changes in other ITS applications.

- *The data warehouse reduced the number of analysis and reporting tools that were required in each ITS application.* Analyses could be conducted and reports could be generated through the Data Warehouse. This also reduced the number of reporting tools that CARTA staff members were required to learn. Rather than learn a different reporting tool for each ITS application, CARTA could use the single data warehouse reporting tool to generated custom reports.

- *The data warehouse could provide immediate benefits in terms of simplifying existing CARTA reporting processes.* A number of reports that CARTA had been producing manually were produced automatically by the data warehouse.

TVM All in One Tickets Recieved Report All TVMs
TVM All in One Tickets Recieved Report TVM 1&3
TVM All in One Tickets Recieved Report TVM 2&4
TVM All In One Tickets Sold Report All TVMs
TVM All In One Tickets Sold Report TVM 1&3
TVM All In One Tickets Sold Report TVM 2&4
TVM Credit Card Detail Report
TVM End of the Month Revenue Ticket Sales Report All TVMs
TVM End of the Month Revenue Ticket Sales Report TVM 2&4
TVM End of the Month Sales Tax Report TVM 2&4
TVM Incline Ridership Report By Customer Type
TVM Passes Recieved Report All TVMs
TVM Passes Recieved Report TVM 2&4
TVM Payment Type Percentages All TVMs
TVM Revenue Service Report for All TVMs
TVM Revenue Ticket Sales Report All TVMs
TVM Revenue Ticket Sales Report TVM 2&4
TVM Station Attendant Transaction Report

Figure 8. Screenshot Showing TVM Reports Produced by the Data Warehouse

For planning purposes, the deployment of the data warehouse was described in the project-specific deployment plan for ITS infrastructure projects.

The initial deployment of the data warehouse was completed in 2004 including, involving the implementation of a database application to house the data warehouse, a data integration tool to facilitate extracting data from and providing data to other CARTA applications and generating reports, and a server to host the database and data integration application. This combination of hardware and software became a functioning data warehouse as CARTA data was integrated into it, with the order of integration driven primarily by two factors:

- *The availability of a reliable data source that could be easily integrated with the data warehouse*. The data supporting many of CARTA's existing processes could not be easily integrated with the data warehouse – Incline Railway tickets sales were tracked via paper logs, and the timekeeping and payroll system relied on a proprietary database from which data could not be easily extracted.

- *The opportunity to simplify onerous reporting processes*. A number of standard reports used by CARTA management were generated through manual or partially manual processes. The data warehouse allowed CARTA to design reports that exactly met its needs and that could be produced and distributed (via email) automatically.

The following list describes the data that was integrated into the data warehouse and the primary benefits associated with each data integration.

- *The timekeeping and payroll software*. CARTA upgraded the timekeeping and payroll software soon after installing the data warehouse application, making it a natural candidate for integration with the data warehouse.

- *The fuel and fluid usage and mileage data*. In 2005, CARTA deployed an electronic method for recording fuel usage, integrating the data collected into the data warehouse. The presence of the data warehouse allowed CARTA to use the data warehouse reporting tools for fuel usage reports, which simplified deployment of this system. The use of the data warehouse for reporting also allowed CARTA to take advantage of sophisticated reporting capabilities (e.g., automatically producing monthly reports) built into the data warehouse at no additional cost.

- *The maintenance management software*. Data from the maintenance management system was an important addition to CARTA's data warehouse because of the importance of the maintenance process in CARTA's overall costs. There were a number of reports involving maintenance management data that CARTA was producing manually, either because the maintenance management system did not produce an appropriate report or the report required data not included in the maintenance management system.

- *The Ticket Vending Machine system*. This system was deployed in 2005 with data warehouse integration being part of the requirements. As with the system for recording fuel and fluid usage data, using the data warehouse as the reporting tool for the TVM system eliminated the requirement for a sophisticated TVM reporting tool.

- *Fixed route and paratransit operation systems*. By the time these systems were deployed, it was standard practice at CARTA to include requirements to integrate new systems with the Data Warehouse during the deployment.

- *Fareboxes and the revenue management system*. In 2008, CARTA deployed new fareboxes and a new revenue management system that managed farebox data. This data was also integrated into the CARTA data warehouse.

In summary, CARTA's basic approach for integrating data into the data warehouse was to do so as part of the deployment of new applications. In general, the cost of this integration was at least partially offset by the lower costs from using the data warehouse as the reporting tool for these new applications.

More details on the CARTA data warehouse are contained in the document, *Chattanooga SmartBus Project Final Phase II Evaluation Report* (June 10, 2008).

5   SUMMARY AND CONCLUSIONS

Before the start of the SmartBus project in 2003, CARTA was not a heavy user of ITS technologies. The agency had computerized systems to support most back office operations – accounting, timekeeping, and payroll. The agency had a GIS software application to manage paratransit operations, though same-day reservations often had to be managed manually, and drivers used printed manifests to manage and record its routes. Fixed and flex route buses were equipped with fareboxes and headsigns, but operating these devices required considerable manual input from drivers. Incline Rail ticket sales were recorded in manual logs. Thus, a mixture of standalone applications and manual procedures were used to manage CARTA operations.

With the advent of the SmartBus project, CARTA envisioned an environment where manual processes were eliminated and data was shared freely between applications. This would allow CARTA to automate many activities that previously required many manual steps. It would also create a data-rich environment where CARTA could mine archived operations data to identify opportunities for improvement. For example, the integration of fuel usage and maintenance data in the data warehouse allowed CARTA to include both maintenance and fuel costs when assessing the cost-effectiveness of different fuels.

Making the transition from an organization that made limited use of technology to one in which technology was an integral part of its operations was challenging. There were a number of activities that appeared to be keys to CARTA's successfully meeting these challenges:

- *Documenting the long-term vision for ITS*. CARTA developed documents that described its long-term vision for ITS, and these documents helped keep them on track in its deployments. They also helped ensure that long lead-time activities were completed in time to support its future plans.

- *Avoiding the temptation to do too much too fast*. CARTA sequenced its deployments so that systems were deployed sequentially, avoiding deployment of dependent systems at the same time. For example, one reason the CARTA data warehouse was its first ITS deployment was that so many other systems would need to integrate with it. Deploying it first meant that it could be operating stably before these other integrations occurred.

- *Being willing to accept schedule delays when needed to help manage deployment risks*. When changes to CARTA's deployment schedule were needed, CARTA was willing to accept delays in order to control risks. For example, when the bus arrival time prediction system was deployed early to take advantage of an outside funding opportunity, CARTA delayed other deployment activities so as not to overburden its limited IT resources.

- *Using a data warehouse*. The presence of a data warehouse at CARTA simplified other deployments in two ways. First, the data warehouse provided reporting tools, which eliminated the need for sophisticated reporting tools in other CARTA applications. Second, applications could be integrated with the data warehouse, reducing the total number of interfaces that were required.

- *Testing systems thoroughly before introducing them to operations*. CARTA displayed a strong commitment to thoroughly testing all systems before accepting them as complete and introducing them to operations. CARTA found and corrected many problems during final testing. If these problems had occurred in an operational system, they could have caused operational problems that could have reduced the confidence of the public and CARTA management in the ITS plans.

As CARTA completes the last steps of its ITS deployment plans, it appears that CARTA's approach to these deployments has been a success. Most of the technologies the agency

hoped to deploy in 2003 are now in place, with the final technologies scheduled for deployment by the end of 2010. Those whose jobs have been impacted by the technologies speak favorably of them. Following a systems engineering approach helped CARTA successfully deploy its ITS technologies and become a transit agency in which the careful application of technology improved operations across the agency.