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Greater Cleveland Regional Transit Authority Radio/ITS Project

Final Evaluation Report

MARCH 2016

FTA Report No. 0088
Federal Transit Administration

PREPARED BY

TranSystems Corporation

U.S. Department of Transportation
Federal Transit Administration

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Federal Transit Administration
Office of Research, Demonstration and Innovation
U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl z	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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ABSTRACT

This report presents findings from the evaluation of the radio and Intelligent Transportation System (ITS) deployments at Greater Cleveland Regional Transit Authority (GCRTA) in Cleveland, Ohio. GCRTA implemented an Enhanced Digital Access Communication System (EDACS) voice and data radio system and ITS technologies that include Computer-Aided Dispatch/Automatic Vehicle Location (CAD/AVL), Automated Vehicle Announcements (AVA), Automated Passenger Counters (APCs), and Vehicle Component Monitoring (VCM). The system was accepted in 2012 after a deployment process that spanned 10 years. These technologies were deployed to improve operational efficiency, enhance safety, and improve service reliability and customer satisfaction. Based on staff interviews, the evaluation team determined that the overall impact of the deployed technologies was positive. However, quantitative analyses conducted to test evaluation hypotheses were largely inconclusive due to limitations in archived data. GCRTA has taken several steps to improve the data quality since system acceptance in 2012, but the data quality was not adequate to conduct quantitative analyses at the time of evaluation. Thus, findings presented in the report are based primarily on staff interviews and review of historical project documentation provided by GCRTA.

EXECUTIVE SUMMARY

The Greater Cleveland Regional Transit Authority (GCRTA), established in 1974, is a multi-modal transit agency that serves Cleveland and surrounding suburbs in Cuyahoga County, Ohio. GCRTA serves 59 municipalities over a 457-square-mile area and a population of approximately 1.3 million and operates fixed-route bus, bus rapid transit (BRT), demand-response transit, heavy rail/subway, light rail, and downtown trolley service. Overall, GCRTA accounted for 49.2 million passenger trips in 2014 across all its service modes.

Background on GCRTA Radio/ Intelligent Transportation Systems (ITS) Project

GCRTA Radio/ITS system planning started in 1998. As a result of a competitive procurement process, a contract was awarded to Rockwell in 2000. However, during the span of the deployment, the ownership of the contract transferred several times, from Siemens to Siemens/VDO to Continental AG and finally to Trapeze ITS. Currently, GCRTA has a maintenance contract with Trapeze Group.

During the course of the 12 years since the contract was signed in 2000, a total of 14 change orders totaling $3,275,480 were issued by GCRTA (the original contract value was $16,928,679). This history of change orders is shown in Table 1-1 of the final evaluation report. To date, GCRTA has installed and accepted the following technologies:

- Voice and data communication system infrastructure, including towers
- In-vehicle equipment to support voice and data communication
- Computer Aided-Dispatch/Automatic Vehicle Location (CAD/AVL)
- Automated Vehicle Announcements (AVA)
- Automated Passenger Counters (APCs)
- Vehicle Component Monitoring (VCM)

A detailed description of each of these technologies is provided in the final evaluation report.

The original scope included approximately 1,000 fixed-route and paratransit vehicles, 108 rail cars, 100 non-revenue support vehicles, and 186 hand-held portable radios. Also, the radio system was expected to include 7 towers to provide coverage in the entire GCRTA service area. However, after scope adjustments, as mentioned in Table 1-1 of the final evaluation report, the current installation includes the following:

- 4 radio towers to provide Enhanced Digital Access Communications System (EDACS)[1] voice infrastructure, installed at Brunswick, Wickliffe, Schaff, and Embassy.
- 470 fixed-route vehicles, each equipped with an EDACS voice and data radio, and TransitMaster CAD/AVL equipment
- 84 paratransit vehicles equipped with an EDACS radio equipment and TransitMaster equipment
- 352 rail radios, distributed among heavy and light rail vehicles as follows:
- 2 voice radios and 1 data radio on each end of 20 double-ended heavy rail vehicles
- 2 voice radios and 1 data radio on 40 single-ended heavy rail vehicles
- 2 voice radios and 1 data radio on each end of 48 double-ended light rail vehicles
- 186 mobile handheld units.
- Additional equipment on non-revenue vehicles, which include maintenance vehicles and supervisor cars.
- Ruggedized laptops on supervisor cars.

Goals and Objectives of Radio/ITS Deployment

GCRTA identified its goals and objectives for the Radio/ITS system in the following two categories.

- **Overall ITS Project:** The focus of the overall ITS system was on increasing the overall quality of GCRTA's service delivery while minimizing the operating cost and increasing the safety. Specific goals include:
  - Make public transit more attractive to the general population.
  - Maximize passenger movements.
  - Reduce operational costs.
  - Reduce emission/energy use.
  - Improve safety of transit system.
  - Increase awareness of ITS benefits.

APC Package: The focus of the APC package, which includes APC technology, was on real-time service monitoring and archived data analyses for resource and capacity management, service adjustments, and efficiency in data reporting (e.g., National Transit Database [NTD] reporting). Specific goals in this category include:

[1]EDACS is a trunked two-way radio system that provides analog/digital voice and data communication and is implemented in several frequency bands, including very high frequency (VHF), ultra-high frequency (UHF), 800 MHz, and 900 MHz under both wide-band (25 KHz) and narrow-band (12.5 kHz) configurations. EDACS originally was developed by General Electric and was modified later by Ericsson. In 2000, EDACS became part of the M/A-COM and Tyco Electronics portfolio and is currently maintained by Harris. GCRTA's implementation of EDACS was completed using 900 MHz and some 450MHz frequencies.

- Real-time monitoring on at least 20% of service at all times.
- Monitor for passenger overloads.
- Resource to better manage special events.
- Management by fact-based service adjustments.
- Reliable statistics for service level management.
- Accurate Section15 reporting (NTD) with reduced staffing requirements.

Based on the review and assessment of above system goals and objectives, TranSystems developed a list of key and secondary hypotheses for this evaluation. Table 1-2 of the final report provides a list of these hypotheses, measures of effectiveness (MOEs), and relevant data sources. The table also identifies the key hypotheses and maps them to relevant goals.

Conclusions of the Evaluation

TranSystems conducted a preliminary analysis of archived ITS data for the timeframe from July 14 through August 5, 2014. The diagnostic analysis using data samples pointed to several data quality issues, as discussed in Section 4. Thus, the evaluation conclusions are based primarily on the qualitative assessments, which largely consist of GCRTA staff interviews and a review of other data/reports provided by GCRTA. Also, it should be noted that the evaluation team revised the original list of hypotheses based on the results of the preliminary data analysis since several hypotheses that are dependent on quantitative analyses could not be tested due to data quality issues.

The GCRTA radio/ITS deployment was planned primarily to replace an existing radio system that had become obsolete by 1998. However, the Request for Proposals (RFP) for the procurement included CAD/AVL functions since the new radio system was being designed to support data transport as well. Even though the bulk of the radio infrastructure installation was completed by 2002, it took additional 10 years to accept the system. While the report provides a detailed description of the events that led to the delayed acceptance, the issues can be summarized as follows:

- **Ambiguity in Requirements Language:** As stated earlier, requirements were written primarily for the radio infrastructure development. Thus, there was limited clarity in how CAD/AVL functions, such as vehicle tracking, route and schedule adherence, incident management, and single-point logon, should be verified in the field. Therefore, there were differences in the interpretation of requirements between the vendor and GCRTA.
- **Change in Vendor Management:** Vendor management changed several times throughout the course of the deployment. While the point of contact for GCRTA has not changed since 2002, changes in management caused several delays and renegotiations of contracts, resulting in several change orders.

- **Management of Contract Milestones:** Contract milestones were designed based on the radio and other hardware-related requirements. Thus, 80–85% of the total contract value was paid before any testing was performed on TransitMaster functions.
- **Lack of Effective Deployment Process:** The lack of a formal implementation process based on systems engineering was a key reason for the delays and current issues with the system. Sufficient checks and balances were not in place to determine the readiness to move forward with each stage in the implementation. Further, the radio and CAD/AVL systems were designed and implemented separately and sequentially even though both sets of hardware were procured at the same time. Most of the CAD/AVL system integration was performed a long time after the radio system was installed. Testing of the CAD/AVL system was not performed until 2009, but by then, the TransitMaster hardware was already 10 years old.
- **Inclusion of Rail Mode:** Rail was included in the CAD/AVL deployment because the radio equipment installed on rail vehicles had become obsolete. Since the radio RFP was going to procure new radio equipment for rail vehicles, requirements for CAD/AVL also were included. However, TransitMaster does not include functions that are typically required for the management of rail operations. Therefore, GCRTA still uses separate tools for Supervisory Control and Data Acquisition (SCADA) and signal control. TransitMaster is used only for operator logons and canned data message exchange. The announcement system installed on rail vehicles is not reliable since the system cannot determine the current location of vehicles when they do not have GPS coverage.
- **Project Staffing and Management at GCRTA**: There have been several changes in management at GCRTA since the project was commissioned. Original staff have either retired or left the organization, thus causing a loss of institutional knowledge. Also, the level of staffing dedicated to the project and interdepartmental communication have been limited. Typically, several full time equivalents (FTEs) are required to ensure a successful deployment and utilization of the product after the deployment. However, based on the discussions with GCRTA staff, it was discovered that the staffing level was not adequate.
- **Training and System Adoption:** The level of training provided by the vendor was very limited. Also, documentation was not developed specific to GCRTA. Further, due to initial issues with the system, users developed a low confidence in the system. Thus, the adoption of the system was not as expected.

Delayed acceptance and the current functional state of the system are a result of a combination of issues related to system planning, contract management, staffing levels, deployment process, and system functions. If GCRTA were to deploy a new system today, several of these factors should be taken into account very early in the planning process to ensure a successful implementation.

SECTION 1

Introduction

GCRTA Service Overview

The Greater Cleveland Regional Transit Authority (GCRTA), established in 1974, is a multi-modal transit agency that serves Cleveland and surrounding suburbs in Cuyahoga County, Ohio. GCRTA serves 59 municipalities over a 457-square-mile area and a population of approximately 1.3 million.

GCRTA operates the following modes:

- **Heavy rail/subway**, which includes the Red Line service that connects Windermere to the Cleveland airport via Tower City in downtown Cleveland. This service is provided on a 19-mile track and consists of 18 stations.
- **Light rail**, which consists of Green, Blue, and Waterfront Line services. The Green and Blue lines provide interurban rapid transit service between Cleveland downtown and Shaker Heights. The Waterfront Line, completed in 1996, extends Green and Blue line services from Tower City towards north to the Lake Erie waterfront. The light rail service consists of 34 stations.
- **Downtown trolley**, which includes 5 routes in the downtown area that are served by 11 vehicles.
- **Fixed-route**, which includes 63 routes and approximately 6,500 bus stops that are served by 470 vehicles.
- **Bus Rapid Transit (BRT)**, which includes the Health Line that runs on Euclid Avenue from Public Square in downtown Cleveland to the Louis Stokes Station at Windermere in East Cleveland. Health Line is a 9.4-mile route served by 24 articulated buses and consisting of 59 BRT stations and 3 platform stops.
- **Demand-response**, which includes complementary Americans with Disability Act (ADA) paratransit service that is provided with the help of 100+ vehicles that are both directly operated and contracted out. GCRTA delivered approximately 704,504 passenger trips in 2013.

Overall, GCRTA accounted for 49.2 million passenger trips in 2014 across all its service modes.

Background on Radio/ ITS System Deployment

Procurement

GCRTA Radio/ Intelligent Transportation Systems (ITS) system planning started in 1998. As a result of a competitive procurement process, a contract was awarded to Rockwell in 2000. However, during the span of the deployment, the ownership of the contract transferred several times, from Siemens to Siemens/VDO to Continental AG and finally to Trapeze ITS. Currently, GCRTA has a maintenance contract with Trapeze Group.

During the course of the 12 years since the contract was signed in 2000, a total of 14 change orders totaling $3,275,480 were issued by GCRTA (the original contract value was $16,928,679). This history of change orders is provided in Table 1-1.

Table 1-1

GRCTA Radio/ITS System Contract/Change Order History

Year	Contract Item	Amount	Cumulative Amount	Description
2000	Contract awarded to Siemens	NA	$16,928,679	Board resolution 2000-172. System (Radio and TransitMaster) was to be deployed on 533 fixed-route vehicles, 102 paratransit vehicles, 108 rail vehicles, and approximately 50 non-revenue vehicles. Central dispatch system was licensed for 30 concurrent users.
2001	Agreement finalized and NTP issued	NA	$16,928,679	Board resolution 2000-172.
2002	Change order 1	$8,300	$16,936,979	Approved by General Manager (GM). Change order involved procurement and installation of natural-gas-powered generators and gas lines instead of originally-proposed diesel-powered generators.
2002	Change order 2	$59,334	$16,996,313	Approved by GM. Additional 17 workstations for Integrated Communications Center (ICC).
2002	Change order 3	$2,906,751	$19,903,064	Board resolution 2002-33. Involved addition to original contract of: 1) 223 radios 2) 156 Automated Passenger Counters (APCs) 3) Cabling 4) Installation and engineering services
2002	Change order 4	$25,202	$19,928,266	Approved by GM. Additional 17 workstations for ICC.
2002	Change order 5	$371,393	$20,299,659	Approved by GM. Involved the following: 1) Additional licenses for TM 2) Automated Voice Announcement (AVA) and APC equipment 3) AVA memory upgrade 4) Equipment reallocation
2005	Change order 6	$(225,691)	$20,073,968	Approved by GM. Per change order, Midas interface replaced with 4 workstations and 4 licenses. Also, portable radios removed from scope.
2006	Change order 7	No cost	$20,073,968	Approved by GM. 4 radio sites instead of 2 as in contract; each site provides 5 channels—one TM data and 4 EDACS
NA	Change order 8	NA	$20,073,968	Not executed.
2007	Change order 9	$119,161	$20,193,129	Approved by GM. Exclusion of police vehicles.
2008	Change order 10	$12,000	$20,205,129	Approved by GM.
NA	Change order 11	NA	$20,205,129	Not executed.
2008	Change order 12	$(970)	$20,204,159	Approved by GM.
2009	Change order 13	No cost	$20,204,159	Replacement of UPS.
2012	Change order 14	$(17,300)	$20,186,859	Project closed on October 31, 2012.

The original scope included approximately 1,000 fixed-route and paratransit vehicles, 108 rail cars, 100 non-revenue support vehicles, and 186 hand-held portable radios. Also, the radio system was expected to include 7 towers to provide coverage in the entire GCRTA service area. However, the current installation includes the following:

- 4 radio towers to provide Enhanced Digital Access Communications System (EDACS)[2] voice infrastructure, installed at Brunswick, Wickliffe, Schaff, and Embassy
- 470 fixed-route vehicles, each equipped with an EDACS voice and data radio
- TransitMaster Computer-Aided Dispatch/Automatic Vehicle Location (AVL) equipment
- 84 paratransit vehicles equipped with an EDACS radio equipment and TransitMaster equipment
- 352 rail radios, distributed among heavy and light rail vehicles as follows:
- 2 voice radios and 1 data radio on each end of 20 double-ended heavy rail vehicles
- 2 voice radios and 1 data radio on 40 single-ended heavy rail vehicles
- 2 voice radios and 1 data radio on each end of 48 double-ended light rail vehicles
- 186 mobile handheld units
- Additional equipment on non-revenue vehicles, which include maintenance vehicles and supervisor cars
- Ruggedized laptops on supervisor cars

System Deployment Goals and Objectives

GCRTA identified its goals and objectives for the Radio/ITS system in the following two categories:

- **Comprehensive Goal and Objectives for Overall ITS Project** – The focus of the overall ITS system was on increasing the overall quality of GCRTA's service delivery while minimizing the operating cost and increasing the safety. Specific goals include:

  G1 Make public transit more attractive to the general population.
  G2 Maximize passenger movements.
  G3 Reduce operational costs.
  G4 Reduce emission/energy use.
  G5 Improve safety of transit system.
  G6 Increase awareness of ITS benefits.

[2]EDACS is a trunked two-way radio system that provides analog/digital voice and data communication and is implemented in several frequency bands, including very high frequency (VHF), ultra-high frequency (UHF), 800 MHz, and 900 MHz under both wide-band (25 KHz) and narrow-band (12.5 kHz) configurations. EDACS originally was developed by General Electric and was modified later by Ericsson. In 2000, EDACS became part of the M/A-COM and Tyco Electronics portfolio and is currently maintained by Harris. GCRTA's implementation of EDACS was completed using 900 MHz and some 450MHz frequencies.

- **Specific Goal and Objectives for APC Package** – The focus of the APC package was on real-time service monitoring and archived data analyses for resource and capacity management, service adjustments, and efficiency in data reporting (e.g., National Transit Database [NTD] reporting). Specific goals in this category include:
  - G7 Real-time monitoring on at least 20% of service at all times.
  - G8 Monitor for passenger overloads.
  - G9 Resource to better manage special events.
  - G10 Management by fact-based service adjustments.
  - G11 Reliable statistics for service level management.
  - G12 Accurate Section15 reporting (NTD) with reduced staffing requirements.

System Overview

The scope of the project included the following technologies:

- Voice and data communication system infrastructure, including towers
- In-vehicle equipment to support voice and data communication
- Computer Aided-Dispatch/Automatic Vehicle Location (CAD/AVL)
- Automated Vehicle Announcements (AVA)
- Automated Passenger Counters (APCs)
- Vehicle Component Monitoring (VCM)

The following subsections provide an overview of these system components.

Voice and Data Communication Infrastructure

The radio/ITS implementation project started in 2001 with planning, design, and deployment of radio infrastructure. The original scope of work required using 13 900MHz channels for voice and 3 900MHz channels for data using a total of 7 tower sites to ensure an appropriate level of coverage in the GCRTA service area. To meet this requirement, Siemens proposed two solutions as follows:

- Motorola Smartnet solution that offered to provide trunked simulcast[3] voice radio system using 13 900 MHz channels and 7 tower sites. Transit data transport would be provided using 3 900 MHz data channels that would be implemented using 2 tower site locations. Transit Police data transport was proposed using the 450 MHz spectrum. MCS2000 trunked analog mobile radios were proposed as in-vehicle equipment along with MTS 2000 portable equipment.
- EDACS solution from Ericsson (now part of Harris) that offered to provide a solution using new 900 MHz and existing 450 MHz bands as follows:

[3]Simulcast refers to the simultaneous broadcast of radio transmission signals from different locations (e.g., tower sites) using the same frequency at the same time. The implementation of a simulcast radio infrastructure allows seamless wide-area coverage. It is useful for a transit service environment that covers a large geographic area with a limited number of frequencies since vehicles can seamlessly move around in the service area without losing the radio coverage.

- 2-site multi-site[4] EDACS trunked voice communication. Schaaf road sitewas proposed to use 7 900 MHz channels and Embassy site was proposed to use 6 900 MHz channels.
- 4-site simulcast EDACS trunked voice radio system using 5 channels in 450 MHz band, primarily to support Transit Police data needs and voice communication needs for portable radios.
- 2-site, conventional 900 MHz data system using 3 channels to support transit data needs. The Schaaf site was assigned 1 channels and the Embassy site was assigned 1 channel.
- Conventional 450 MHz transitional system to support pre-1992 vehicles. At the time of the radio installation, vehicles purchased prior to 1992 had 450 MHz radio equipment installed and would not be replaced with new 900 MHz capable equipment. Siemens used the capability within the EDACS controller to use existing 450 MHz channels to provide simulcast voice infrastructure for these vehicles.

Towers in both cases were proposed to be linked through microwave in a loop configuration.

Siemens recommended the EDACS voice solution as the best value solution since it was able to utilize existing 450 MHz licenses. Also, the multi-site solution was capable of resolving interference issues caused by frequency overlap present in the 900 MHz simulcast system due to closely-spaced channels (i.e., 12 KHz channels). Also, channel interference was an issue since many of the frequencies in the GCRTA 900 MHz band are located next to each other in the spectrum. Since multi-site configuration allows selection of frequencies while assigning those to a tower site, the EDACS-based solution was preferred to resolve the co-located frequency as well.

Even though Siemens proposed only two towers, it was promised that the system would provide 95% coverage in the GCRTA coverage area. However, using the system in two-tower configurations for a few years, GCRTA realized that it was not adequate and the coverage requirement could not be proven in the field. Thus, GCRTA negotiated with Siemens in 2006 to install 2 additional towers at Strongsville/Brunswick and Lake County locations. Each of these tower sites was installed with 4 voice channels and 1 data channel to provide additional voice and data coverage. Those additional frequency licenses were obtained by GCRTA.

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[4]In a multi-site configuration, each site is assigned a list of frequencies but shares common talk group channels using channels from other sites in the system. Also, in this configuration, one channel at each site is a dedicated command and control channel. This channel keeps track of all voice calls on the radio system.

Thus, the current radio system configuration includes 21 900 MHz voice radio channels and 5 900 MHz data radio channels. Also, Transit Police has now migrated to the Ohio Multi-Agency Radio Communication System[5] (MARCS), so it is not using the 450 MHz EDACS system as originally implemented by Siemens.

Dispatch

In-Vehicle Equipment

In-vehicle installations included the following system components.

Mobile Radio

The EDACS voice and data wayside infrastructure implementation was followed by the installation of analog land mobile radios on GCRTA vehicles in 2001. Ericsson Orion mobile radios for 450 MHz and MDX radios for 900 MHz configurations were installed.

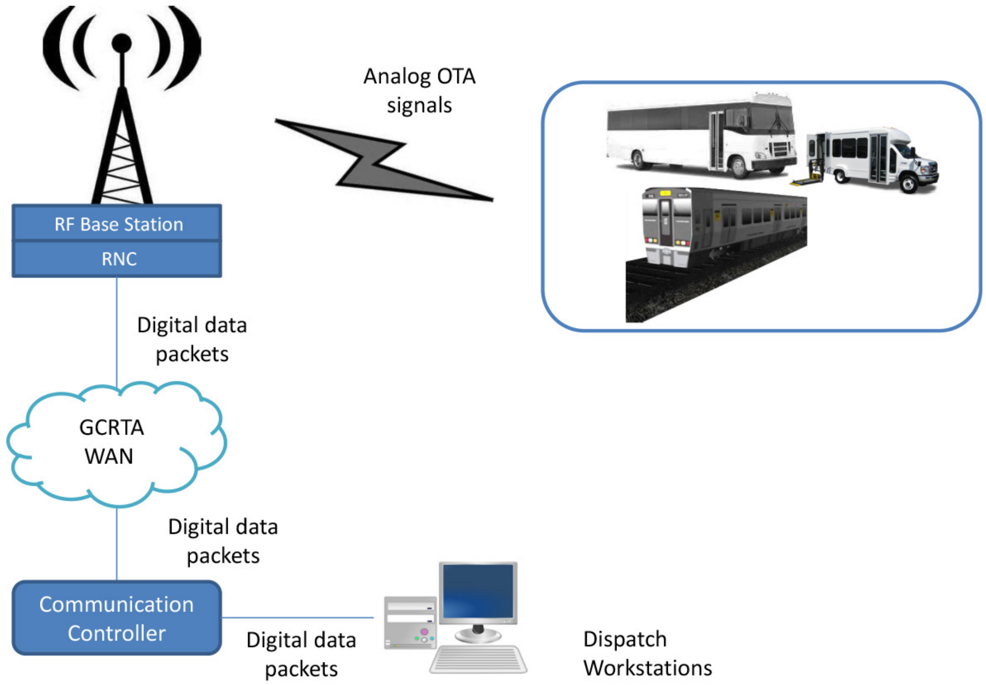
Each fixed-route, paratransit, and single-ended rail vehicle was installed with one EDCAS radio. However, double-ended rail vehicles were installed with one radio inside the cab on each end of the car. The radios were installed to provide integrated voice and data communication through integration with the TransitMaster vehicle logic unit. However, GCRTA was interested in an open-mic configuration for rail vehicles, so additional data radios were installed to provide this capability through a change order since both the open-mic configuration and data transport could not be provided using a single radio.

In-vehicle analog radios communicate with central dispatch workstations through the radio network controller (RNC) located at radio frequency (RF) base stations at tower sites. Any over-the-air (OTA) signals between vehicles and tower sites are exchanged in analog format, and any data exchanged between the tower site and the dispatch workstation (through the communication controller located in the data center) are in the format of digital data packets. Figure 1-1 provides an illustration of this process.

[5]MARCS is a statewide radio communication system developed by the State of Ohio for first responders and public safety/public service providers. This system was developed using 700/800 MHz digitally-trunked radio technology for voice and is capable of supporting data transport as well. MARCS is being considered as one of the future radio alternatives by GCRTA when it eventually switches from the current EDACS system.

Figure 1-1

Block diagram of communication between vehicles and control center



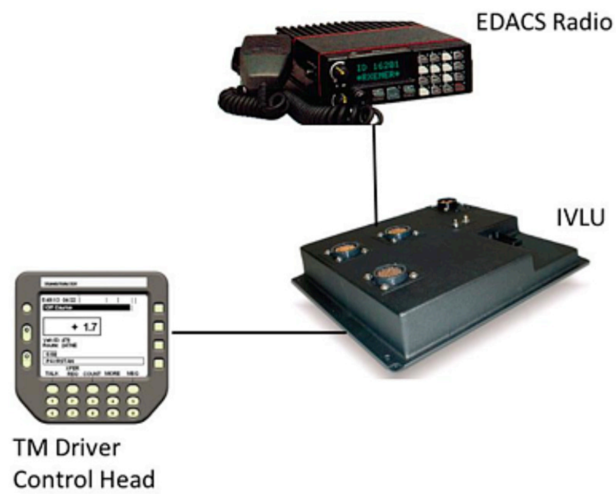
Vehicle Logic Unit and Driver Control Head

GCRTA vehicles are equipped with the TransitMaster integrated vehicle logic unit (IVLU) and driver control head, as shown in Figure 1-2. The on-board equipment uses DOS 6.22 with RTKernel Real-time Operating System (RTOS). Also, the IVLU is interfaced with an in-vehicle EDACS radio to perform the following actions:

- Command the radio to switch to voice communication mode when a voice call is initiated by a control center dispatcher.
- Exchange data messages with the control center software.
- At any given time, drivers can use the driver control head to request to talk (RTT) with the control center using the RTT button. In the event of an urgent communication need, drivers press the priority RTT button. Also, they can use the control head to send and receive canned data messages.

Figure 1-2

Basic configuration of in-vehicle dispatch equipment



Drivers use the driver control head to logon using their Driver ID and Run ID. Based on the driver logon, the system modifies the headsign on the bus and determines the trip (route and direction at a given time) that should be run by the driver using the schedule that is stored inside the IVLU. This schedule is downloaded to the vehicle using the wireless local area network (WLAN) (described later).

The IVLU is equipped with global positioning system (GPS) receivers that allow it to track current vehicle location. The GPS signals are corrected by using error correction data received from the central differential GPS (DGPS) reference stations (described later).

The IVLU uses current location and schedule information to determine any deviations from the route and schedule. Any route and schedule adherence exceptions are reported to the central TransitMaster dispatch software.

Also, the IVLU is connected with a silent/emergency alarm switch on the bus, which can be pressed by the driver in the event of an emergency. Once the vehicle is in emergency mode, dispatchers have the ability to remotely monitor the driver compartment audio through the radio.

Further, the IVLU is connected with discrete inputs such as doors, wheelchairs, and odometers. Also, on some vehicles, the IVLU is connected with peripherals such as electronic displays to announce/display the next stop and APCs.

Central System

The Integrated Communications Center (ICC) was created by consolidating fixed-route, rail, and Transit Police control centers and establishing a centralized control center at the GCRTA headquarters at the 6th Street building in Downtown Cleveland. However, the paratransit control center is not part of the ICC.

The central system environment includes the following components.

Radio Console

GCRTA dispatch uses a C3 Maestro radio console, a Microsoft Windows-based desktop product that allows monitoring of radio communication using a central graphical user interface (GUI). It is being used to access and select specific channels and communication modules. Also, the console allows the display of callers on the screen. Figure 1-3 shows the dispatch room configuration of the Maestro radio console.

Figure 1-3

Dispatch workstation configuration

TransitMaster Dispatch

The TransitMaster dispatch software consists of the following major components:

- **AVL Map Display** – provides the ability to view the current location of a vehicle on a map. Typical map functionalities such as zoom, pan, and distance measurement are available. Also, the map provides a color-coded indication of vehicle events such as current route and schedule adherence status, loss of communication, and loss of GPS. Further, the map interface provides additional capabilities such as initiation of communication with vehicles and geographic search of vehicles.
- **CAD** – provides the ability to view vehicle events (e.g., logons, incidents, vehicle alarms) and vehicle performance (e.g., route and schedule adherence) in a tabular format. Also provides the ability to communicate with vehicles using voice and data communication capabilities.

- **Playback** – provides the ability to view the historical records of driver and vehicle performance using map and tabular interfaces.

Figure 1-3 shows the display configuration of TransitMaster dispatch tools.

Currently, GCRTA is not using the built-in incident management module of TransitMaster. Instead, it has developed its own Microsoft Access-based database to track vehicle events (see Figure 1-3). Dispatchers record incidents in the Access database when any incident is reported by a driver over the radio or based on their observations on the TransitMaster display.

TransitMaster-PASS Interface

TransitMaster is integrated with Trapeze PASS for voice and data communication on paratransit vehicles. Data communication includes canned messaging and electronic manifest transmission.

Drivers logon into their manifests using the TransitMaster control head. Once successfully logged on, the interface allows drivers to view their trips scheduled for the vehicle during the day. Drivers perform pick-ups and drop-offs and notify the completion of those activities using the control head. Any exceptions such as no-shows are notified using the driver control head as well.

Voice Recording System

The NICE voice recording system is used to record any voice communication between central dispatch and vehicles.

Citrix Workstations

Remote connectivity to TransitMaster dispatch is provided by Citrix server farms. Staff located at the Districts offices or street supervisors in the field access the TransitMaster application via Citrix.

Bus-in-a Box

Bus-in-a-Box (BIB) (see Figure 1-4) is used to train drivers on the TransitMaster product. The BIB includes a driver control head, IVLU, radio, handset, and public address (PA) speakers and buttons.

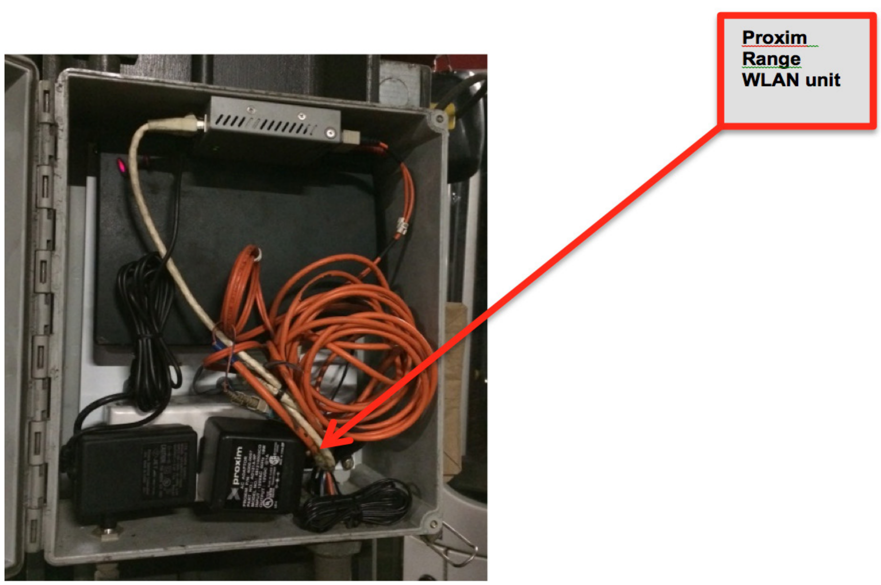
Figure 1-4
Bus-in-a-Box (training equipment)

Garage Equipment

The Hayden and Triskett bus districts and the rail district are equipped with wireless local area network (WLAN) access points. These access points, known as RangeLAN2, were manufactured by Proxim and use a proprietary WLAN technology for data exchange.

Several access points are installed inside each garage to provide adequate coverage to all vehicles inside that garage. Each access point is connected to a central file transfer protocol (FTP) server via the GCRTA LAN. The quality of installation of this equipment was found to be unsatisfactory during the evaluation team visit. These access points are used to download log files and APC data from the vehicles and also are used to upload route/schedule data, announcement files, and system configurations.

Figure 1-5
Sample installation of WLAN access point inside Triskett District garage



Also, garages are equipped with Differential GPS (DGPS) reference stations for making error corrections in GPS locations. Since the DGPS knows its location, it determines errors in the signals received from GPS satellites and transmits the error data to the IVLU inside vehicles. Of note is that DGPS correction is required since the receivers in the IVLUs are old are not wide-area augmentation signal (WAAS)-capable. Modern GPS receivers that are WAAS-capable do not require DGPS correction.

Interface with HASTUS

Schedule data generated in HASTUS are imported into TransitMaster every time there is a schedule change. Ideally, such updates occur four times per year. However, route segment detours and stop relocations cause data to be updated more often. Once the schedule is updated in HASTUS, an export is created for TransitMaster. TransitMaster uploads the modified schedule and route data to vehicles via FTP servers located at garages using the garage WLAN. Any relevant announcement files are updated as well.

The workforce management module of HASTUS, called Daily, is used by garages to manage driver schedules in real time (e.g., attendance management) and to assign vehicles to drivers. HASTUS Daily is a replacement of MIDAS-BD, the workforce management software that GCRTA was using earlier. However, the interface between TransitMaster and MIDAS-BD was removed from the scope through a change order, so there is no interface between HASTUS-Daily and TransitMaster.

Other Back-Office Products

Other back-office products are used to define geo-triggers for announcements and to track route and schedule adherence. Additionally, the reporting interface provides the ability to retrieve system performance information using canned reports in the system.

Automated Passenger Counters (APCs)

In-Vehicle Equipment

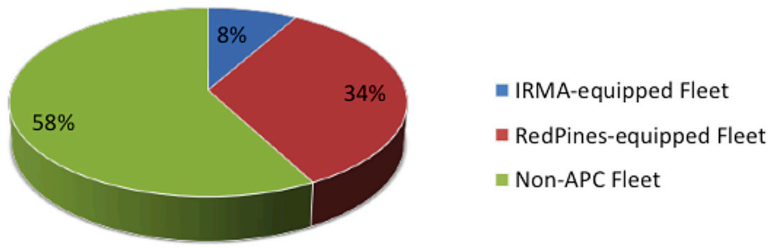
GCRTA vehicles are equipped with two different types of APC equipment:

- Side-mounted APCs from RedPines (now part of Trapeze)
- Overhead IRIS-IRMA sensors

IRMA sensors were installed only on Health Line BRT vehicles; the remainder of the fleet is equipped with RedPines sensors. Although 100% of the Health Line fleet is equipped with APCs, the percentage of APC-equipped vehicles is still less than 50% of the entire GCRTA fixed-route fleet. Figure 1-6 shows a breakdown of APC-equipped vehicles.

Figure 1-6

Breakdown of APC-equipped vehicles



Both types of sensors are connected to controllers. The controllers are connected to the TransitMaster IVLU via a Society of Automotive Engineers (SAE) J1708/1587 vehicle area network. Passenger counts recorded by sensors are transferred to the IVLU where they are stored in raw format in the local storage until downloaded by central servers. The IVLU tags those counts with the latitude/longitude, date/time, and other operational information such vehicle ID and run ID.

Central Software

Once vehicles are back in the garage, raw APC data are downloaded to the central servers. Then, the central system post-processes the raw APC data to correlate passenger counts to the appropriate stops using latitude/longitude information. This correlation exercise is heavily dependent on the accuracy of stop coordinates stored in the system database. Since the stop coordinates were incorrect in the TransitMaster database until Fall 2013, APC reports were not reliable since the rate of data errors during post-processing was extremely high.

Automated Vehicle Announcements (AVA)

The IVLU is equipped with a built-in PA amplifier and is connected to the vehicle's internal and external speakers to make automated next-stop announcements. These announcements are made by determining the upcoming stop based on the current location of a vehicle on a route.

During onsite visits, only audio announcements were observed, and no vehicle equipped with electronic displays to show visual announcements was found. However, GCRTA clarified that only 50 vehicles were equipped with electronic signs to provide visual announcements but are currently non-functional. The only vehicles that have visual announcements that are functional are run on the Health Line route. Also, external announcements are not functional system-wide.

Vehicle Component Monitoring

As stated earlier, the IVLU is connected with discrete signals inside the vehicle. Typically, the TransitMaster IVLU is integrated with vehicle components over SAE J1708/1587 or J1939. However, at this time, no other inputs from other vehicle components (e.g., engine, transmission, antilock braking system) are being monitored other than discrete inputs.

Real-Time Information

A real-time information system (RTIS) was not part of original ITS project. However, as part of BRT deployment, GCRTA procured dynamic message signs (DMS) to provide real-time vehicle arrival information at selected rail stations through an initial installation of 16 OnStreet[6] DMS. The initial installation was followed by the addition of 63 DMS in 2008 at the Health Line and renovated rail stations. Currently, the total number of installed DMS is 124. Figure 1-7 shows a test version of the signs installed at Health Line stations.

Figure 1-7
Sample GCRTA RTIS sign

Further, GCRTA purchased Trapeze's Web Watch application in 2011. Web Watch provides real-time prediction information at particular stops for the upcoming vehicles using a web-based interface. Web Watch is integrated with the GCRTA website. Figure 1-8 is an example of the GCRTA Web Watch interface.

Figure 1-8
Web Watch display

[6]OnStreet is the Trapeze ITS trademark for their DMS solution for real-time vehicle arrival information. WebWatch is Trapeze's web-based real-time information system product.

Each of the system components described previously is interconnected using either the radio network or GCRTA wide area network (WAN)/LAN. Figure 1-9 is an overview and the interconnect diagram for various GCRTA ITS components described earlier.

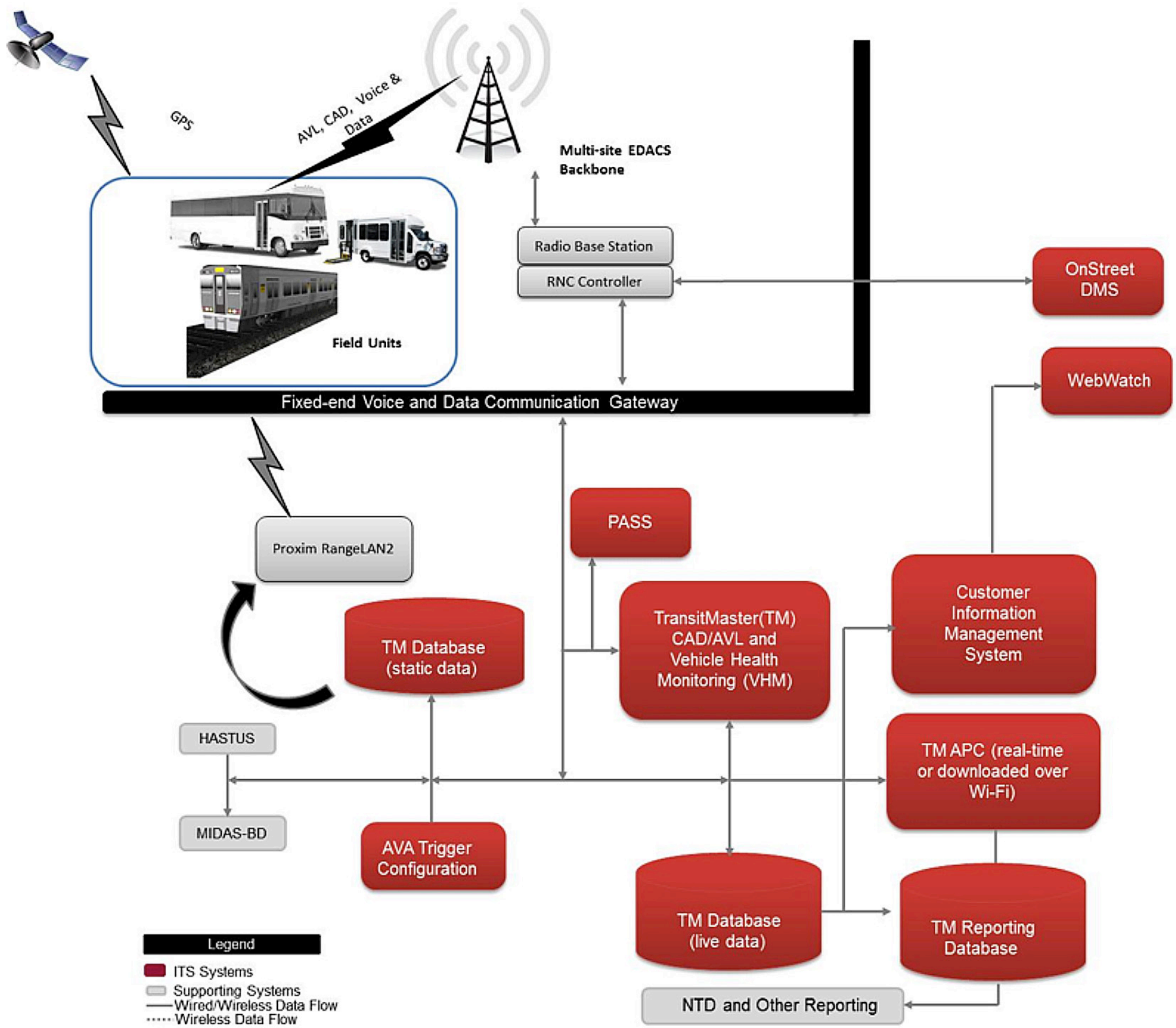


Figure 1-9

GCRTA ITS system overview diagram

Current Status of the System

The TransitMaster system was accepted by GCRTA on October 31, 2012. The system is currently under a maintenance and support contract with Trapeze for TransitMaster software. Hardware support is not available due to the age of the equipment.

Radio equipment maintenance is being handled by a local radio contractor, and the tower-site and other backbone maintenance is being handled by TransCore.

SECTION

2

Evaluation Plan

Evaluation Scope

The evaluation is being performed through the following six tasks:

- Task 1 – Assess agency goals and objectives – analyze the goals and objectives listed in Section 1.
- Task 2 – Document ITS system as installed – review system components installed as part of Transit Master Radio and APC package deployments.
- Task 3 – Document how systems are being utilized – conduct an assessment of the level of utilization of products by observing system impacts and through staff interviews.
- Task 4 – Collect information from stakeholders – conduct detailed interviews with GCRTA staff to obtain information on system planning, deployment, utilization, and maintenance.
- Task 5 – Document lessons learned – document key lessons learned through the system life cycle.
- Task 6 – Prepare a final evaluation report that documents the findings from the evaluation.

Figure 2-1 shows a workflow diagram with an overview of the tasks and key activities in the evaluation.

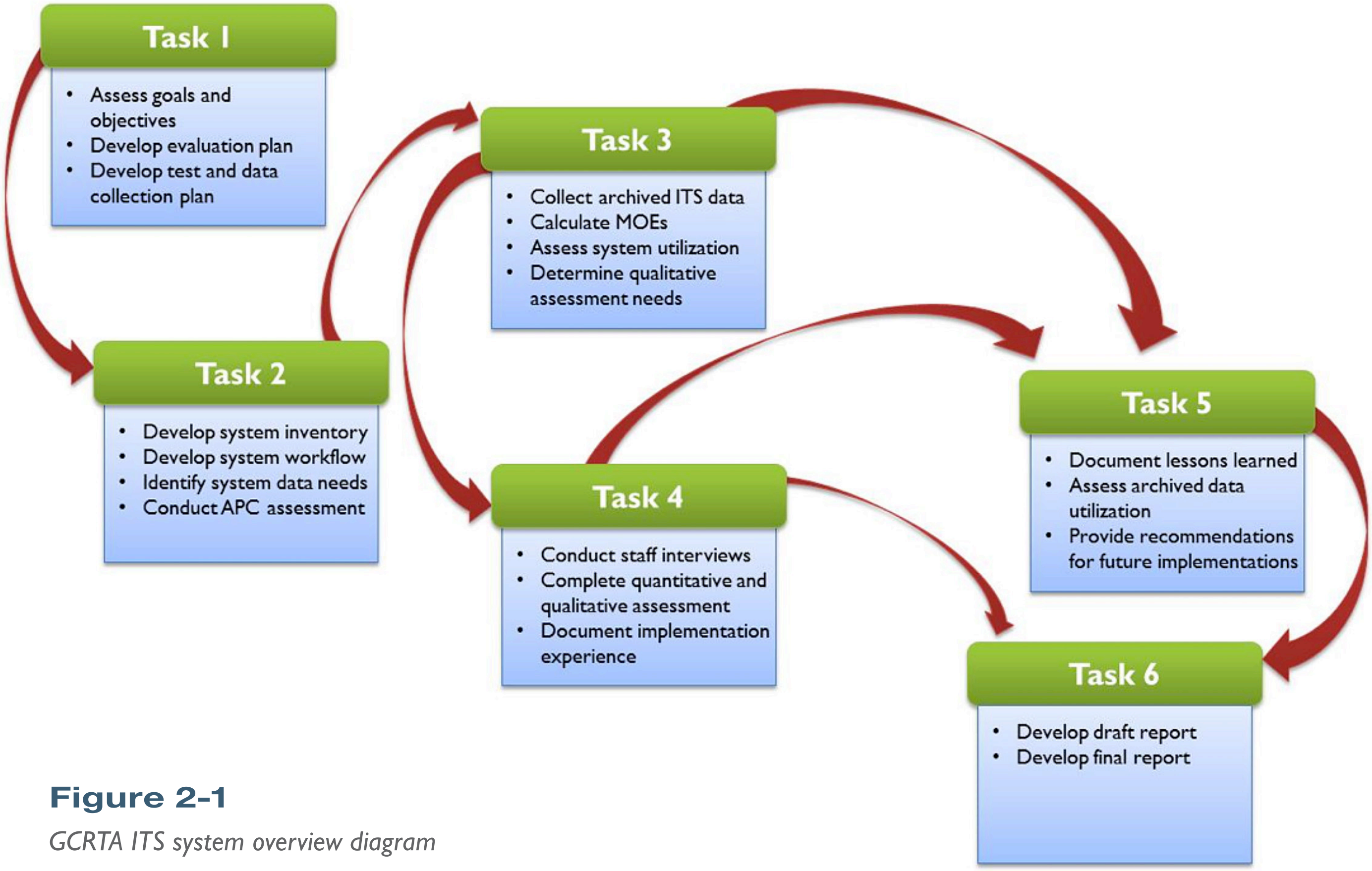


Figure 2-1

GCRTA ITS system overview diagram

Evaluation Objective

The key objectives of the evaluation as identified in the ITS implementation study scope of work are as follows:

- Document systems that are being used by GCRTA.
- Determine APC readiness for NTD reporting.
- Determine if systems have assisted in meeting goals.
- Determine and document system workflows between departments.
- Determine systems impacts and document lessons learned from the implementation.
- Assess archived ITS data utilization by GCRTA departments.
- Develop final evaluation report that can be shared with other transit agencies.

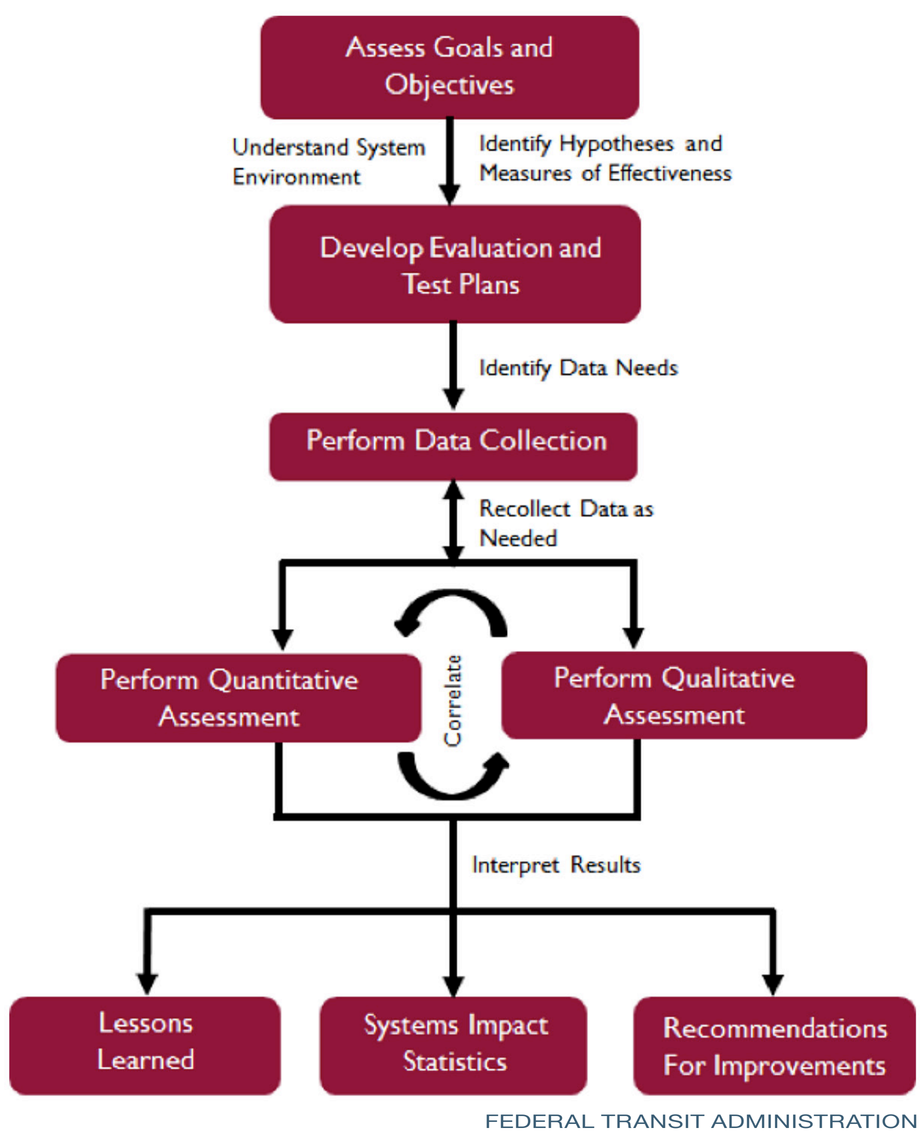
Evaluation Approach

The evaluation approach for project tasks, as illustrated in Figure 2-2, follows the guidelines provided in FTA Circular 6100.1C and the ITS Evaluation Guidelines. The approach can be summarized as part of the following five step process:

- Step 1: Conduct a comprehensive assessment of goals and objectives, and develop hypotheses to conduct the evaluation. Based on these hypotheses, determine measures of effectiveness (MOEs) and identify data sources to calculate these MOEs. The discussion associated with this step was documented in the Evaluation Plan and the Test Plan.
- Step 2: Complete a review of the state of the system deployment and collect archived ITS data.
- Step 3: Conduct data analysis and identify data gaps. These data gaps should be filled by either collecting additional archived ITS data or through staff interviews.
- Step 4: Correlate quantitative and qualitative assessment results to determine systems impacts and lessons learned from the system implementation.
- Step 5: Develop final conclusions for each hypothesis and provide recommendations for improvements for future implementations.

Figure 2-2

Evaluation approach



Based on TranSystems' experience, the critical path items associated with this evaluation approach are as follows:

- Finalization of key hypotheses and MOEs.
- Collection of required data for qualitative and quantitative analyses.
- Verification of data quality.
- Understanding of the correlation among the datasets used for the evaluation.
- Interpretation of the results of quantitative and qualitative analyses.

After the review of system goals and objectives, TranSystems developed a list of key and secondary hypotheses. Table 2-1 provides a list of hypotheses, MOEs, and relevant data sources. Also, this table identifies the key hypotheses and maps them to relevant goals listed in Section 1.

The hypotheses were developed for the Evaluation Plan document before a preliminary analysis of data was performed. However, the analysis approach was adjusted since this table was first developed. The approach was revised since a limited volume of data of reliable quality was available to conduct a conclusive quantitative analysis prior to Fall 2014. Even a two-week sample obtained to conduct a diagnostic analysis from late July 2014 highlights some of the quality issues associated with GCRTA's TransitMaster data, as shown in Section 4. Thus, the evaluation conclusions are based primarily on the qualitative assessment, which consisted largely of GCRTA staff interviews and a review of other data/reports provided by GCRTA.

Table 2-1 shows the revised approach by striking out the analyses that could not be performed due to lack of reliable data.

Table 2-1

Hypotheses, MOEs, and Data Sources[7]

S/N	Goal ID	Hypothesis	Key? (Y/N)	MOE	Data Source	Analysis
H1	G3	ITS implementation will result in reduced operational cost through automated data collection.	Y	• Reduction in need for field supervision • ~~Cost of field data collection~~ • ~~Number of drivers and vehicles required in peak hours~~ • Amount of voice traffic between vehicles and dispatcher	~~CAD/AVL,~~ Staff interviews	Qualitative & ~~Quantitative~~
H2	G7	ITS implementation will assist in monitoring of on-time performance.	Y	• On-time Performance • ~~Running time~~ • ~~Actual versus scheduled headway~~	~~CAD/AVL~~, Staff interviews	Qualitative & ~~Quantitative~~
H3	G1, G2	ITS implementation will result in increased passenger movement.	Y	• System ridership • ~~System revenue~~	APC, ~~Farebox,~~ Staff interviews	Qualitative & ~~Quantitative~~
H4	G3, G7, G9	ITS implementation will result in improved service reliability.	Y	• ~~Stop arrival and departure variability~~ • ~~Travel-time variability~~ • ~~Headway variability~~	~~CAD/AVL~~, Staff interviews	Qualitative & ~~Quantitative~~
H5	G10	ITS implementation will result in improved service adjustments.	N	• ~~System productivity~~ • ~~Trip running times and cycle times~~ • ~~Vehicle platform hours~~ • ~~Cost per revenue miles~~ • Route on-time performance • Driver on-time performance	~~CAD/AVL~~, Staff interviews	Qualitative & ~~Quantitative~~
H6	G2, G8, G9, G10	ITS implementation will result in improved management of passenger loads.	N	• ~~Crowding or peak load variability~~ • ~~Dwell time variability~~ • Number of customer complaints regarding crowding	~~APC~~, Staff interviews	Qualitative & ~~Quantitative~~
H7	G1	ITS implementation will result in improved customer satisfaction.	N	• Number of customer complaints/ commendations • System ridership improvement	Staff interviews, ~~APC, Farebox~~	Qualitative & ~~Quantitative~~
~~H8~~	~~G4~~	~~ITS implementation will result in reduced emission/energy use.~~	~~N~~	• ~~Undesired vehicle idling time~~ • ~~Non-revenue vehicle miles traveled (VMT)~~ • ~~Required fuel in gallons per vehicle miles~~ • ~~Required number of vehicles per route~~	~~CAD/AVL~~	~~Quantitative~~
H9	G5	ITS implementation will result in improved safety.	N	• Number of customer complaints • Number of incidents and accidents per mile	Staff interviews, (Claims, Legal, Marketing)	Qualitative & ~~Quantitative~~
H10	G10, G11, G12	ITS implementation will result in improved reporting.	N	• Number of staff hours for custom reports • Number of staff hours for ad-hoc reporting • Number of staff hours for NTD reporting • Issues with data reporting	Staff interviews	Qualitative
~~H11~~	~~G10, G11, G12~~	~~APC implementation will result in accurate and reliable passenger count data.~~	~~Y~~	• ~~APC data accuracy~~ • ~~APC data reliability~~	~~APC Data, Manual observations, Service monitor records~~	~~Quantitative~~

[7]Analyses that cannot be performed due to lack of data are struck out in the table. Further, rows representing hypotheses that could not be tested at all are highlighted in grey.

SECTION 3

Hypothesis Test Plan

This section provides the technical approach and required data and data analyses to test each of the hypotheses identified in the Evaluation Plan (see Section 2).

Operational Cost (H1[8])

Overview

One of the key objectives of implementing the GCRTA radio and CAD/AVL system was to reduce the overall cost of transit operations. Typically, radio/CAD/AVL systems impact the operational cost as follows:

- Reduced need to deploy field staff for monitoring on-time performance.
- Reduced number of road calls through proactive maintenance of fleet.
- Increased capability to collect field data electronically and avoidance of data duplication.
- Availability of tools to manage operational resources in real-time and assess actual demand, particularly in peak hours.
- Reduced need for voice communication between dispatchers/street supervisors and drivers.

Data and Data Analysis

The evaluation team's conclusions are based on input from GCRTA's operations staff, who are part of the Service Quality and Service Management groups.

Service Monitoring (applies to H2 and H4)

Overview

CAD/AVL systems provide the ability to continuously track vehicle locations and monitor route and schedule adherence of vehicles/drivers. Further, CAD/AVL systems provide both drivers and dispatchers with the ability to communicate via voice and data messages. These features enhance the service monitoring capability of a transit operation and help gain efficiencies.

Data and Data Analysis

Due to the lack of reliable data for a quantitative analysis, the evaluation team's conclusions are based on input from GCRTA's operations staff that are part of Service Quality and Service Management groups.

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[8]Corresponding hypotheses for each topic area are mentioned in parentheses next to the topic area.

Service Management and Adjustments (applies to H5)

Overview

As mentioned in Section 1, one of the goals of the APC package implementation was to provide the ability to make fact-based service adjustments and better use available resources. Typically, a trend analysis of the following key indicators can be performed to evaluate whether or not improvements made based on CAD/AVL data/reports helped improve the service:

- System productivity
- Trip running times and cycle times
- Vehicle platform hours
- Cost per revenue miles
- On-time performance by driver, vehicle, and route

Data and Data Analysis

The evaluation team's conclusions are based on input from GCRTA's Service Quality and Service Management departments. Also, Service Quality provided on-time performance statistics for the 2012–2014 timeframe.

Passenger Counting and Load Management (applies to H2, H6 and H11)

Overview

Task 2 of the evaluation required the evaluation of the current process for NTD reporting at GCRTA and assessment of whether the archived ITS data can be used for this purpose. Based on the review of vendor documents, it is understood that the currently-installed APC system guarantees 95% accuracy. However, the field accuracy for the APC system may be less than 95%. Based on experience, it is understood that APC accuracy depends on a variety of factors, and vendor-quoted accuracy is guaranteed only under "ideal" circumstances. Some of the issues associated with APC accuracy and reliability are as follows:

- Inaccurate counts at terminals due to the high number of boardings and alightings.
- Inaccurate counts due to objects carried by passengers such as shopping bags.
- Issues with dark clothing and other ambient light/color issues.

- Issues with the correlation of boarding and alighting counts with the appropriate stops (e.g., vendor products cannot correlate passenger counts with stops when vehicles do not stop at designated stop locations as configured in the system).
- Propagation and balancing APC errors over a vehicle block (vendors often balance errors during post-processing of data over a vehicle block to filter erroneous data from trip-level counts).

Since none of the above anomalies can be captured and corrected as part of the electronic data collection, APC sensors are required to be calibrated at required intervals. Overall, in TransSystems' experience, depending on the technology (e.g., normal vs. active-passive beam configuration), installation configuration (e.g., overheard vs. door-mounted), level of analysis (e.g., trip level, block level, or stop level) and sample size (e.g., typically 1,000–1,500 counts are needed at vehicle block level for accuracy over 95%), APC accuracy may vary from 85% to 95% with +/-5% error.

Data and Data Analysis

TranSystems had planned to collect two samples of 700 passenger counts with the assistance of GCRTA service monitors to validate the accuracy of APC data. The purpose of collecting data was to validate the passenger counts reported by APC sensors with respect to manual observations using the following equation:

$$\frac{\sum_{j=1}^{S} |\sum_{i=1}^{D} In\ (APC - Manual)| + \sum_{j=1}^{S} |\sum_{i=1}^{D} Out\ (APC - Manual)\,|}{\sum_{j=1}^{S} |\sum_{i=1}^{S} In + Out\ (Manual)\,|}$$

where,

S = Total number of stops
D= Total number of doors

However, based on the preliminary analysis, it was concluded that the APC data quality was not good enough to complete the accuracy analysis. In discussions with GCRTA staff, it was discovered that the issue with the APC counts is related to both hardware and software configurations (i.e., stop database). The biggest issue with the hardware is that it was never maintained after purchase. As stated earlier, GCRTA purchased both the Red Pine and IRMA sensors. IRMA sensors have relatively less calibration/maintenance needs, but APC sensors have never been through a preventive maintenance (PM) process. Also, during a sample verification exercise, GCRTA staff recently discovered that many of the Red Pine counters were not connected to the door discrete. The sensors themselves might work, but since they are not connected, count data may not be reliably recorded. For this reason, several sensors are reporting zero counts.

Conclusions with respect to APC accuracy have not been included in the report since GCRTA is working with the vendor to resolve ongoing issues. However, further details on APC accuracy is expected to be included in the final report.

Customer Satisfaction (applies to H7)

GCRTA has implemented on-street and Web Watch real-time information systems from Trapeze. Typically, improvement in service reliability due to effective service monitoring and implementation of accurate and reliable real-time information tends to have a positive impact on customer satisfaction. As indicated in Table 2-2, customer satisfaction can be measured by the following indicators:

- Number of customer complaints and commendations; and
- System ridership.

Due to lack of sufficient datasets to assess the customer perception of current service (primarily, customer survey data) customer satisfaction is measured primarily based on the findings from staff interviews.

Emission/Energy Use (applies to H8)

One of the goals of the CAD/AVL system implementation was to strive for environmental benefits. Key environmental benefits that can be obtained from CAD/AVL implementation are related to the reduction in non-revenue vehicle miles and reduction in revenue miles through efficient route planning. The key indicators mentioned in Table 2-1 to evaluate environmental benefits are:

- Undesired vehicle idling time
- Non-revenue vehicle miles traveled (VMT)
- Required fuel in gallons per vehicle miles
- Required number of vehicles per route

No results for emission/energy use analysis have been included due to the unavailability of the data required to conduct such analyses.

Data Reporting (applies to H10)

The purpose of this evaluation was to determine the benefits of ITS implementation at GCRTA in terms of indicators related to transit operations and maintenance functions. These indicators include on-time performance, off-route vehicle statistics, ridership by routes and stops, peak-hour load, and number of incidents per route/block. GCRTA staff were interviewed to collect information on the reporting capabilities and resulting benefits of the ITS system.

As indicated in Table 2-1, the following aspects of the reporting capabilities were evaluated:

- Data quality impacting accurate data reporting
- Vendor assistance needs for custom reports
- Reporting gaps fulfilled by external systems (e.g., spreadsheets and Access databases)
- Number of staff hours spent in reformatting standard reports
- Flexibility in the reporting tool

SECTION 4

Data Quality Assessment

As stated in Section 2, some of the hypotheses were to be tested by analyzing results of a quantitative analysis to be performed on TransitMaster AVL and APC datasets. However, before proceeding with data analysis, "data diagnostics" were conducted using a sample AVL and APC dataset for two weeks, July 14 through August 5, 2014.

Extracting any data prior to July 2014 was deliberately delayed since GCRTA was in the process of correcting geo-coordinates of stops and timepoints in the system. Stops, timepoints, and route traces were incorrect in the TransitMaster database since a route survey, which is a critical requirement for the performance of TransitMaster system, was not performed during the deployment. Thus, the information in the system was based on baseline information as initially supplied by GCRTA. This initial information became irrelevant over the years due to periodic changes in system route and stop configurations.

Of note is that the issues identified in this section are based on data available in the reporting database. It is likely that raw data, which is stored in a separate database, does not have some of these issues.[9] However, processing raw data with respect to route, stop, and schedule data requires a significant amount of time and resources. Thus, the scope of analysis for the evaluation was limited to the reporting database only.

AVL Data Analysis

Missing Timepoint Crossing Records

Route-Level Analysis

Examination of the AVL data revealed that numerous timepoint crossing records had missing arrival/departure and schedule deviation information. The number of missing records as a percentage of the total number of adherence records was calculated for each route direction and day to quantify the extent of this problem. Table 4-1 provides such information for key routes that include routes 1, 10, 22, 26, and 81.

[9]Raw AVL and APC data records from vehicles are sent over the air in near real-time and consist of latitude/longitude, odometer readings, run/block ID, vehicle ID, driver ID, and other relevant information. These raw data are used to display information on CAD/AVL workstations. However, raw data are processed prior to storing that information in the reporting database. During this processing, if reference data such as route and stop data are inaccurate, the reporting database will either discard raw data or perform an incorrect correlation.

Table 4-1

Missing AVL Data for Key GCRTA Routes (2014)

Route and Direction	7/20	7/21	7/22	7/23	7/24	7/25	7/26	7/27	7/29	7/30	7/31
1 East	41%	28%	30%	28%	23%	33%	11%	9%	17%	26%	28%
1 West	46%	25%	31%	34%	25%	34%	10%	10%	20%	28%	33%
10 North	39%	22%	21%	13%	42%	39%	3%	66%	42%	5%	15%
10 South	49%	35%	33%	28%	53%	48%	17%	69%	50%	20%	28%
22 East	31%	40%	34%	31%	31%	23%	36%	2%	24%	23%	2%
22 West	33%	41%	33%	33%	31%	20%	36%	0%	23%	23%	3%
26 East	52%	26%	34%	24%	21%	48%	27%	5%	32%	31%	48%
26 West	50%	25%	32%	25%	18%	46%	27%	8%	29%	28%	45%
81 East	39%	10%	20%	22%	24%	40%	42%	34%	21%	35%	32%
81 West	40%	9%	21%	25%	30%	43%	42%	35%	21%	32%	33%

Other routes not displayed in Table 4-1 show a similar pattern of making data unsuitable for any conclusive analysis without conducting extensive and sophisticated data filtering. Route 67 had the lowest level of reliability, with 99% or 100% of its records missing every day during the timeframe. Route 66 was similarly unreliable, with 85%+ records missing on any given day. However, routes 5 and 54 appeared to be the most reliable, with typically less than 10% of the records found to be missing on any given day.

Stop/Timepoint-Level Analysis

To understand the patterns better with missing records, a timepoint-level analysis was conducted to determine any direct correlations with the incorrect stop database in the system. Visual inspection of the results suggests that, in general, the system more reliably recorded timepoint records closer to downtown and Southwest Cleveland. However, AVL data reliability by timepoint did not appear to be limited to one transit route or roadway corridor.

On-Time Performance

GCRTA calculates on-time performance using the following standard for schedule deviations:

- Deviation of less than 0 minutes is marked "early"
- Deviation of greater than 0 minutes and less than or equal to 5 minutes is considered "on-time"
- Deviation of greater than 5 minutes is considered "late"

On-time performance was analyzed at the route and timepoint levels to understand any anomalies in the data. In general, the analysis did not reveal any abnormal patterns with the data. However, daily variability in schedule deviations was unexpectedly high. Some of the key routes show variability in daily on-time performance by 8%. One of the reasons for such variability could be vehicle equipment, since different vehicles could be dispatched on the same route across various days in a week. Figures 4-1 through 4-5 show daily variability in on-time performance between July 14 and 31, 2014.

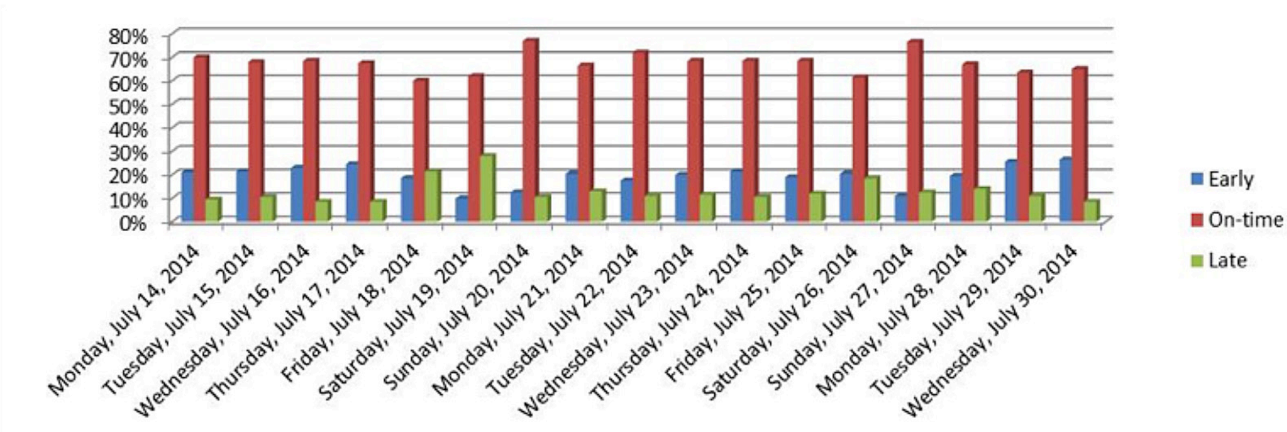


Figure 4-1

Daily variability in on-time performance on Route 1

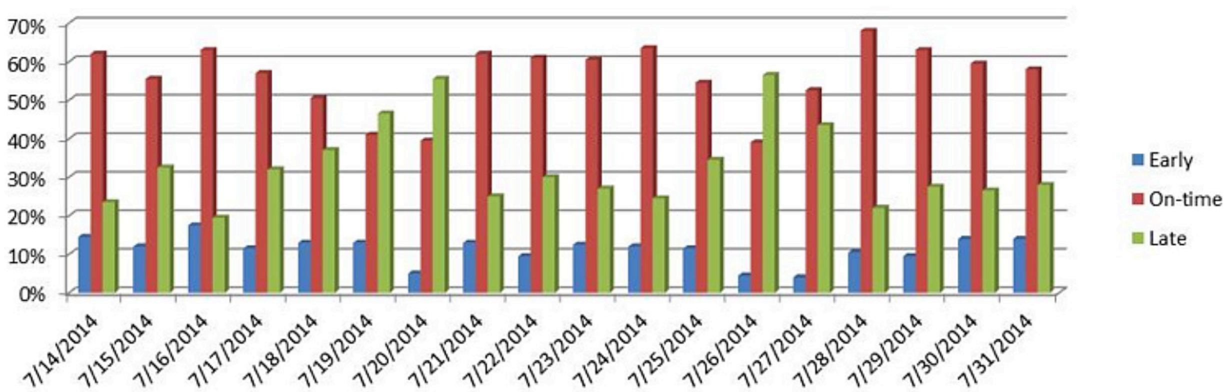


Figure 4-2

Daily variability in on-time performance on Route 10

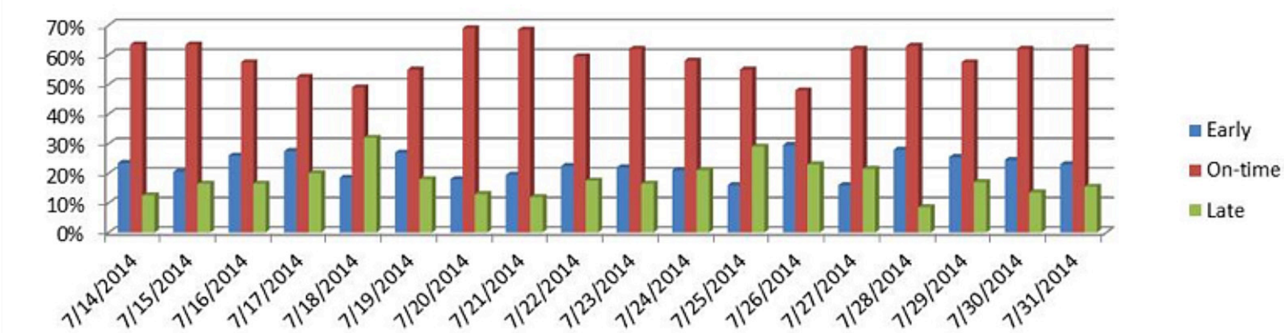


Figure 4-3

Daily variability in on-time performance on Route 22

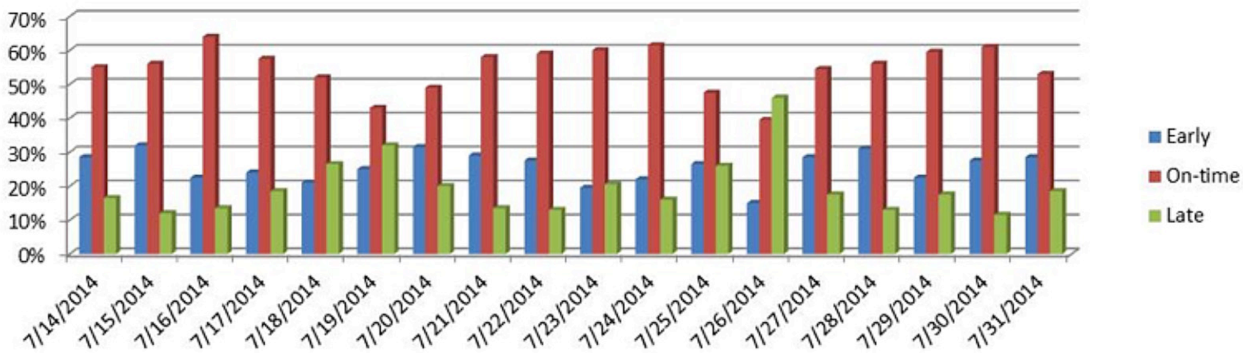


Figure 4-4

Daily variability in on-time performance on Route 26

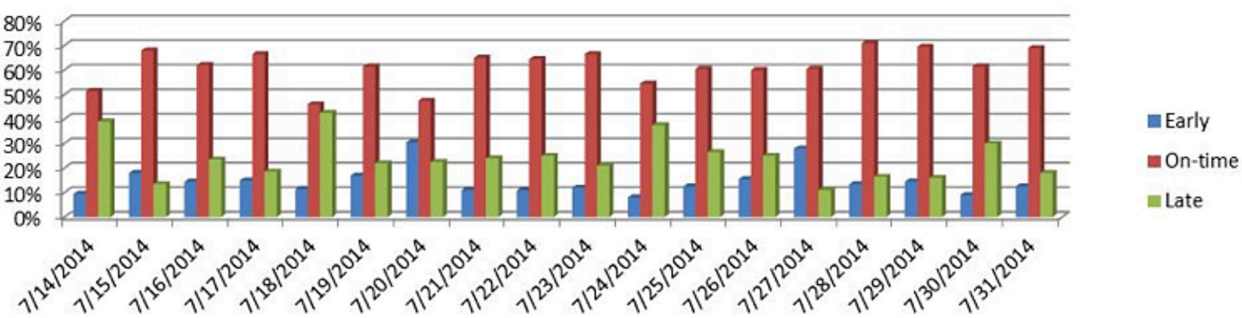


Figure 4-5

Daily variability in on-time performance on Route 81

APC Data Analysis

APC data were found to be unreliable due to the amount of discrepancy in boarding and alighting data. Generally, the deviation in boarding and alighting data should be within 5%. However, as shown in Figure 4-6 and Table 4-2, there was difference of more than 50% in most cases. There was significant variability in daily counts as well, as shown in Table 4-2. However, it cannot be attributed to error in the APC system since not all vehicles are equipped with APCs. It is possible that the number of APC-equipped vehicles on a route may vary across days in a week.

As stated earlier, Health Line vehicles are equipped with relatively more accurate APCs. However, preliminary analysis found several anomalies. In some cases at terminal points, extremely high boardings (>200) and alightings were noted.

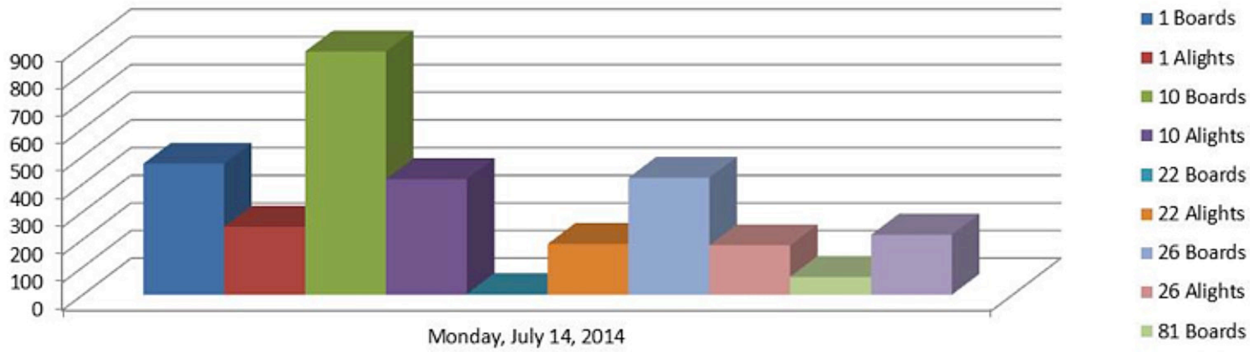


Figure 4-6

Discrepancy between boarding and alighting on key routes

Table 4-2

Boarding and Alighting Data for Key Routes

2014	Route 1		Route 10		Route 22		Route 26		Route 81	
	Boards	*Alights*	*Boards*	*Alights*	*Boards*	*Alights*	*Boards*	*Alights*	*Boards*	*Alights*
7/14	474	246	879	418	3	184	423	179	65	217
7/15	97	279	22	102	209	201	371	754	4	255
7/16	160	74	400	185	41	11	177	336	228	249
7/17	11	124	640	640			490	578		
7/18	4	0	788	734	192	321	144	111	156	240
7/19			804	286	39	72				
7/20	217	106							4	53
7/21	660	475	681	597			731	494	352	380
7/22	63	66	125	66	14	31	602	514	651	804
7/23	885	662	118	143			732	692	468	162
7/24	1126	772	0	4	247	238				
7/25	98	95	375	166			222	95	0	152
7/26			3	326			111	541		
7/27	0	2								
7/28	474	540	1	12	235	181	409	384		
7/29	339	154			193	68	0	42	253	99
7/30	427	298								
7/31	160	176	2	2			460	456		

SECTION

5

Impact of Radio/ TransitMaster on GCRTA Business

Service Development

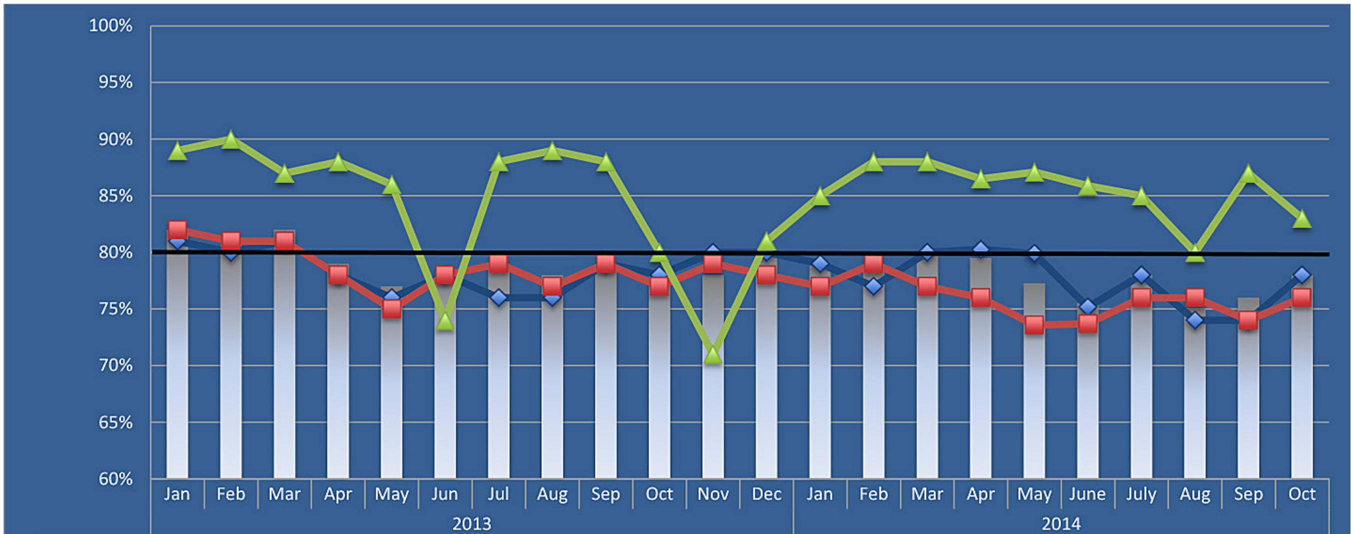
The HASTUS scheduling software includes an "ATP" module for automating running time analysis and schedule optimization. GCRTA is beginning to use this feature by importing AVL data from TransitMaster to analyze running times. The purpose of this analysis was to evaluate the running times in the schedule at route, trip, and route segment levels with respect to actual running times as observed in the field. Results of this analysis will allow HASTUS to optimize running times so sufficient time is available for drivers to perform their runs and layovers between trips.

Given that GCRTA has started conducting this analysis recently, the impacts of such analysis and service adjustments on GCRTA route performance are not available.

Operations

The Operations division is a key stakeholder of the TransitMaster system. In particular, the Service Quality department within the Operations division (that includes dispatchers at the ICC), uses the system daily to communicate with drivers, track their locations, and send instructions in the form of data messages when necessary. Further, the system determines the schedule and route adherence of vehicles based on the schedule of the vehicle, allowing Service Quality staff to take appropriate actions as necessary in real-time. Also, in the event of an incident or accident, dispatchers can send street supervisors to assist drivers or take other actions such as replacing the vehicle. GCRTA road supervisors have remote access to TransitMaster as well on laptops (through Citrix) and can coordinate with ICC dispatchers when necessary.

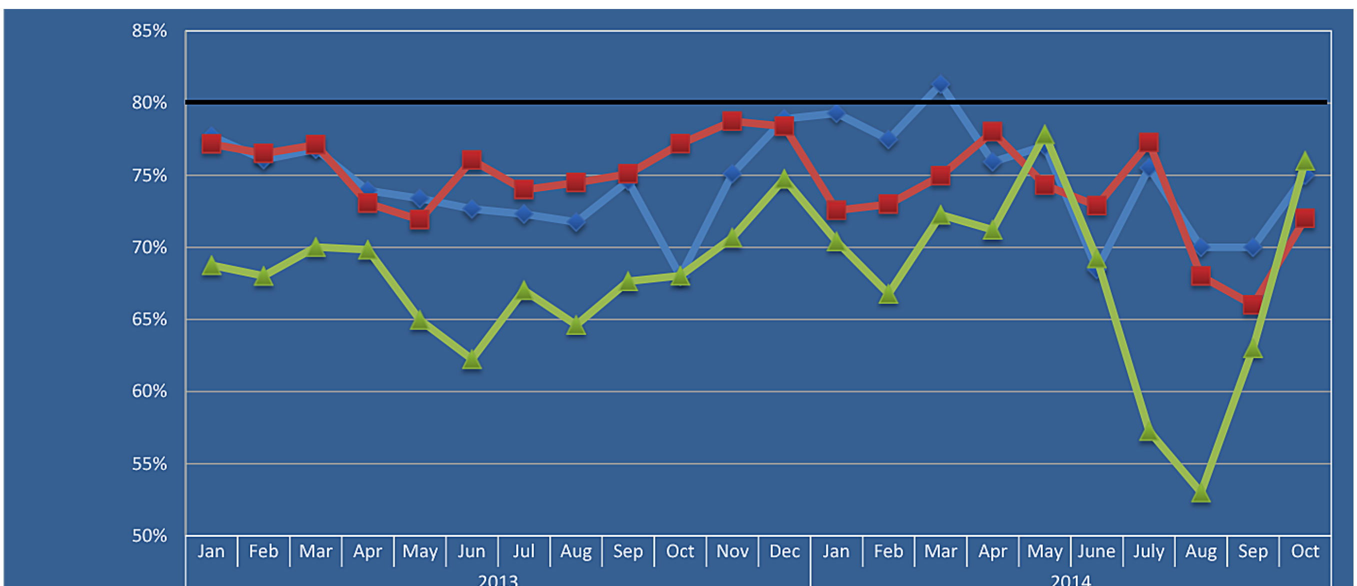
Further, Service Quality staff track on-time performance using TransitMaster data and develop daily, weekly, and monthly reports for senior management staff. Figure 5-1 provides an example of such a report, which presents systemwide on-time performance from January 2013 to October 2014. Also, the on-time performance breakdown is provided by bus and rail districts. As shown, the overall system performance varied between 75% and 80%. The target on-time performance set by GCRTA is 80%. Service Quality conducts a separate analysis for target routes by district. Figure 5-2 provides a sample chart for such an analysis for the Hayden District.



	2013												2014									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct
Overall	82%	81%	82%	79%	77%	78%	79%	78%	79%	78%	78%	80%	79%	79%	80%	80%	77%	76%	78%	75%	76%	78%
Hayden	81%	80%	81%	78%	76%	78%	76%	76%	79%	78%	80%	80%	79%	77%	80%	80%	80%	75%	78%	74%	74%	78%
Triskett	82%	81%	81%	78%	75%	78%	79%	77%	79%	77%	79%	78%	77%	79%	77%	76%	74%	74%	76%	76%	74%	76%
Rail	89%	90%	87%	88%	86%	74%	88%	89%	88%	80%	71%	81%	85%	88%	88%	87%	87%	86%	85%	80%	87%	83%

Figure 5-1

Systemwide monthly on-time performance report, January 2013 to October 2014



	2013												2014									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct
9	78%	76%	77%	74%	73%	73%	72%	72%	75%	68%	75%	79%	79%	77%	81%	76%	77%	68%	76%	70%	70%	75%
15	77%	77%	77%	73%	72%	76%	74%	74%	75%	77%	79%	78%	73%	73%	75%	78%	74%	73%	77%	68%	66%	72%
Health Line	69%	68%	70%	70%	65%	62%	67%	65%	68%	68%	71%	75%	70%	67%	72%	71%	78%	69%	57%	53%	63%	76%

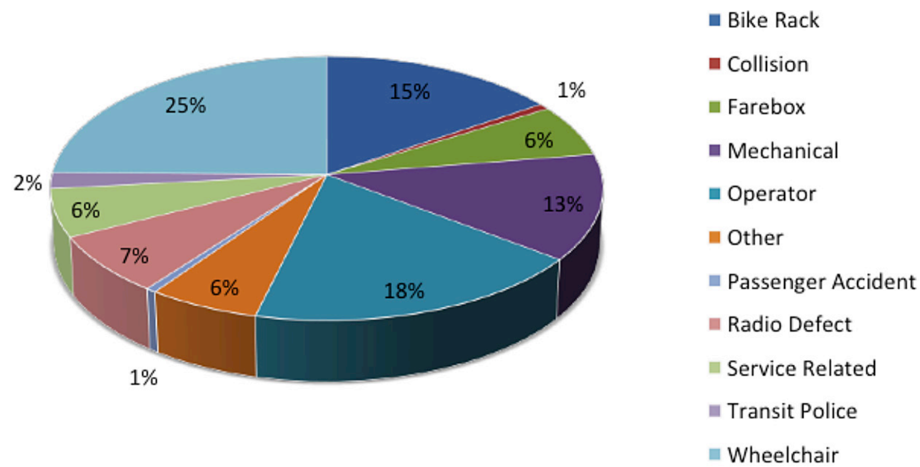
Figure 5-2

On-time performance for Hayden target routes, January 2013 to October 2014

Currently, dispatchers are not using the incident management feature within TransitMaster, but they use the information received in calls from drivers to input information into a Microsoft Access-based tool developed in-house. GCRTA developed this tool because some of the information needed regarding an incident on the same day (e.g., for daily reporting) is not available from TransitMaster until the data are ingested into the reporting database. Typically, there is a lag of 24–48 hours before the data are available from the reporting database. The data stored in the MS Access database are used to analyze daily issues by category. Figure 5-3 shows a distribution of issues recorded in the incident database as observed in a sample dataset from December 2014.

Figure 5-3

Distribution of issues based on data in access-based incident database



Another key aspect of the TransitMaster system is automated announcements. The system makes automated announcements in the vehicle to alert riders about upcoming stops so that drivers do not have to make the announcements manually. There have been some issues with the announcements due to system configurations, which GCRTA is resolving with the help of Trapeze through the maintenance contract. The Service Management department, which supports the back-office setup and data configurations for TransitMaster (e.g., development of schedule, preparation of route/run files for vehicle upload and respond to data request), is working with Trapeze to initiate and finish stop and route surveys, which were excluded during system deployment. Given that TransitMaster relies on the location of stops for announcement triggers and the distance between stops for determining approach distances, improvements in these data through surveys will improve the accuracy of the announcements.

Driver and Vehicle Resource Management

Driver and vehicle resource management, handled by the District Management department, is performed using HASTUS-Daily, so District Management is not a direct user of TransitMaster. However, it sometimes uses TransitMaster to determine the current location of a driver/vehicle since HASTUS-Daily is not integrated with TransitMaster. Also, District Management uses TransitMaster to investigate any issues reported by Customer Service.

Maintenance

The Electronic Repairs group within the Fleet Management department is in charge of maintaining electronic equipment inside vehicles. Electronic Repairs troubleshoots radios, IVLUs, driver control heads, and any other equipment related to TransitMaster. In the event that an issue cannot be fixed in-house, Maintenance staff contact vendors for replacement parts. Given the age of the equipment, GCRTA has a limited number of spare parts available in-house. In the case of some equipment, such as Proxim RangeLAN2, even the vendor has very limited replacement parts available. As stated earlier, hardware is not supported by Trapeze as part of the maintenance agreement.

During the interviews, GCRTA reported that the IVLU failure rate is very high, with 40% of the current problems are related to IVLUs. Other problems are related to handset wiring, the radio antenna, and other radio-related components in the vehicle. Since the repair turnaround time for IVLUs is 4-6 weeks, it is difficult to maintain equipment with an extremely low spare ratio. Generally, ITS equipment maintenance is handled through "remove and replace" actions, but, due to a low spare ratio and the unavailability of equipment in the marketplace, GCRTA has started to repair equipment such as IVLUs with the help of a third-party contractor by using parts from older equipment and spares.

Equipment on rail vehicles has several issues due to high voltage conversion requirements (i.e., 600V to 12V since TransitMaster operates at 12V). Also, there are issues with wiring that cause issues with TransitMaster on rail vehicles. TransitMaster equipment generally is not installed on rail vehicles, and GCRTA was the first agency to do so. Given the amount of equipment (4 radios and 2 IVLUs per car on some rail vehicles), maintenance is difficult on those vehicles. Further, the Electronic Repair staff have very limited documentation to help troubleshoot equipment in-house.

Until the system was accepted in October 2012, GCRTA did not have an in-house inventory of TransitMaster and radio parts. Since the acceptance, parts and their utilization, failure, and repair history are being tracked in Ultramain, GCRTA's fleet management software. This change has helped GCRTA be proactive about running spare parts with low inventory and repeat failures.

Customer Service

Customer Service has been using TransitMaster since it was accepted in 2012. Earlier, the Customer Service department used to call Service Quality to determine the location of a vehicle to respond to a customer request. Now, with the help of TransitMaster AVL, Customer Service staff can answer those questions directly without much delay.

Customer Service uses Trapeze COMM as its complaints management tool, inputting customer complaints related to vehicles. These complaints are investigated by District Management staff by using the TransitMaster Playback feature or other tools such as the incident management database.

During the interviews, it was discovered that Customer Service staff do not have access to the Playback tool. It is likely that they will not have time to use the tool due to time constraints since the Customer Service department gets up to 2,500 calls per day and each representative handles up to 250 calls a day. However, it would be useful to have access to the Playback tool if quick historical information on a driver/vehicle is required to address a customer question or concern. Further, Customer Service staff mentioned that they would like to have access to information on service anomalies ahead of time (e.g., detours and vehicle breakdown).

Customer Service staff believe that the number of calls has been reduced by 30% over the years since the real-time information went live. Now, customers can obtain information via the GCRTA website or interactive voice response (IVR) as well, so Customer Service staff do not have to answer those calls. Particularly, the number of queries related to timetable information has been reduced.

Reporting

Reporting is available from TransitMaster in the form of standard reports for on-time performance, route adherence, driver activity, and passenger counts. Based on staff interviews, it appeared that the reporting feature has not been used much due to the unreliability of data. Thus, no conclusions can be drawn on the benefits of the reports.

Additional reports are available from the in-house incident database. Also, the Service Management department provides data support to other departments that need information on system performance. These reports are developed in-house using Crystal Reports.

SECTION 6

Deployment Experience

As stated earlier, the Radio and TransitMaster systems were accepted approximately 12 years after the contract was awarded. Even though the Radio and CAD/AVL systems are two completely independent systems, neither was accepted until 2012. However, both systems were procured as part of the same contract. This section provides further information on some of the key aspects of the deployment experience as reported by GCRTA staff.

Overall Experience: Success and Challenges

GCRTA believes that this project played a critical role in "pushing the technology IQ into the organization." Prior to the implementation of the technology, dispatchers relied on two-way radios and their knowledge of the GCRTA system service area. TransitMaster provides dispatch staff with the ability to view current vehicle locations on a map and make informed decisions in the event of incidents. For example, GCRTA reported that, very recently, a driver who was attacked by a rider was helped by police because he was able to press the covert alarm button.

Also, this project provided GCRTA an opportunity to identify the process, resources, and tools necessary to successfully manage large technology deployments. GCRTA believes that even though there were several issues during the initial years of the deployment, the approach adopted to close the project and maintain the system has been satisfactory. Also, the successful collaboration among various departments has been helpful in recent years. The lack of interdepartmental communication and collaboration was one of the reasons behind the initial delays in system deployment. Given the renewed positive environment, GCRTA is making every effort to ensure that system life can be extended[10] through appropriate software and hardware maintenance.

One of the key concerns related to this deployment has been the long deployment timeframe. Unfortunately, by the time system was accepted, the hardware had become obsolete. Current TransitMaster hardware on vehicles is first-generation, and radio equipment is no longer supported. Other equipment such as the garage WLAN is not supported either. In the event that the garage WLAN becomes non-functional, GCRTA will have to manually install any updates to vehicles, which will be a highly time-consuming exercise.

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[10]CAD/AVL system life cycle is considered to 7–10 years, and radio equipment is expected to last longer (10–15 years). In this case, both radio and CAD/AVL equipment are almost 15 years old and already past their useful life.

Further, the key reasons behind the unsatisfactory results and delays is the level of requirements definition in the RFP, contract terms and conditions (e.g., payment milestones), and treatment of the project as a hardware deployment project. Based on the agreed-upon payment milestones, a large percentage of the contract was paid to the vendor upon hardware delivery. Generally, it is advised that milestones be split such that payment is held until software functionalities (e.g., CAD/AVL data transmission over radio) are demonstrated.

Pre-deployment

The system requirements were first developed around 1998. At the time of RFP development, GCRTA was using an old Motorola radio system that was procured in 1981 and implemented using 10 450MHz frequencies. Given the age of the radio system at the time, the RFP focused primarily on the radio communication backbone and other aspect of the radio system. CAD/AVL was included in the project as "add-on feature" to the radio system. Thus, the number and extent of requirements related to CAD/AVL and related transit management systems were limited and ambiguous. Even though agencies take a different approach today (e.g., the communication infrastructure is developed separate from CAD/AVL system procurement), the approach taken by GCRTA was very typical in at the time due to the limited flexibility with communication alternatives. CAD/AVL systems used to be closely coupled with radio systems, even though the level of actual integration between CAD/AVL and radio systems was the same as today.

During the initial years of deployment, GCRTA experienced service cuts, and the number of vehicles and staff was reduced. This had an impact on the radio/ITS system implementation since some of the components were de-scoped. For example, the gyroscope, which is required to help in dead reckoning along with the odometer, was excluded and not installed. Since the system relies on the odometer to track its path between GPS synchronizations, some of the errors in the system are due to this exclusion since the system is not aware of its heading when in motion. Also, only two towers were included in the scope as recommended by Siemens, even though the RFP required seven towers. GCRTA had to add additional towers to ensure desired coverage in the service area.

Vendor Management

The initial contract was with Rockwell in 2000. However, the ownership of the contract was transferred immediately to Siemens who bought the CAD/AVL business from Rockwell. Then, Siemens sold the business to Continental. The current owner of the business is the Trapeze Group, who bought it from Continental. Although the vendor project manager has been involved with the deployment since 2002, project managers have changed several times internally at GCRTA over the years.

As stated earlier, contract milestones were heavily skewed towards hardware delivery and radio infrastructure installation, so 70% of the contract value to date (approximately $20 million) was paid to the vendor by 2002 when those milestones were complete. None of the functionalities of the central CAD/AVL system were demonstrated by that time even though major purpose of establishing the radio infrastructure was to provide CAD functionality to dispatchers.

Since 2000, GCRTA has issued 14 change orders. One of the biggest change orders was issued in 2002 as part of the APC package, in which additional radios were purchased for new vehicles. As part of the final change order in October 2014, the project was closed. GCRTA agreed to a maintenance and warranty agreement to maintain the software and hardware after the project closeout with Trapeze Group.

Deployment Process

Due to limited documentation, very few details are available on the deployment process steps such as design and testing. TranSystems received a copy of the acceptance testing that was performed in 2009 but the information recorded about test results is limited.

A systems engineering-based approach should be followed for a project of such complexity and magnitude. There is not enough documentation to prove that a systems engineering process was performed during the deployment. In particular, there is no change log of requirements to show which requirements were taken out during negotiations. For example, test procedures that were run by GCRTA during testing in 2009 have marked several requirements as “de-scoped.” Further, it is not clear if the typical deployment management approach for ITS deployment (that includes steps such as design review, factory test, pilot test with a subset of fleet, and system test) was followed.

Another critical issue with the deployment process was knowledge transfer. GCRTA staff who worked on the project during the initial years of the deployment are no longer there. The level of documentation is limited for the current staff to understand the complexities associated with the deployment and to assist with ongoing efforts to extend the life-span of the system.

Training

Training was not adequate for any of the components of the system. Also, staff that were trained have either left the organization or retired. Thus, the system knowledge with in-house staff is very limited. GCRTA currently is going through an extensive training process as part of a TransitMaster upgrade to the latest software version. In fact, the ongoing training process has helped GCRTA discover incorrect configurations in the system that have been causing system performance issues.

Hardware training was limited as well. Electronic Repairs staff rely on their experience and on-the-job training to troubleshoot issues and perform any necessary repairs. Even though manuals are available, they are not specific to GCRTA and, thus, are not useful for anyone with limited background information on the project.

Staffing

As stated earlier, due to limited budget and staffing, the level of staffing on the radio/ITS deployment was not adequate. GCRTA had a designated project manager to coordinate with the vendor on issues, but additional in-house staff (e.g., planning, scheduling, maintenance, customer service and operations), who typically are needed on a CAD/AVL deployment project, may not have been available, particularly since the project was considered hardware-oriented. Unfortunately, detailed information on the level of staffing during deployment is not available.

Other Issues

Several other technical and non-technical issues were faced during the deployment. Some of key issues are follows:

- Route surveys were not performed as required by the TransitMaster system. Since route/stop information is extremely critical for the system to determine announcement triggers or route adherence, the lack of accurate route/stop information has been one of the major reasons behind a large number of off-route messages and inaccurate APC counts. Due to the lack of survey data, GCRTA is relying on the geographic data from HASTUS.
- There were some issues in coordinating infrastructure-related needs with the Information Technology (IT) department. Sometimes, issues were caused due to a discrepancy in software versions. For example, the vendor was using MS Access 2000 for the announcement database, but GCRTA's IT group was using MS Access 2013. Also, at times, detailed instructions were not communicated, resulting in incorrect configurations. For example, some announcements were being played at incorrect locations since the software was changed to read from the Windows registry setting instead of from INI files.
- Radio coverage issues are still faced by the agency. Currently, there are four towers—two in the east side, one in the west side, and one in the southwest side of the service area. However, coverage still seems to be inadequate in the eastern part of the service area. GCRTA currently has 24/7 support from TransCore to provide tower maintenance and believes that it has helped in ensuring system restoration in the event of a failure.
- The CAD/AVL solution for rail vehicles was incomplete. While TransitMaster allows GCRTA to track vehicles and communicate with drivers via data messages (radio is open mic so it is not integrated with TransitMaster),

GCRTA uses separate tools for SCADA and rail signal management. Ideally, a train control system with vehicle tracking capabilities should have been selected for rail vehicle management.

- GCRTA staff have learned most functionality on-the-job. Training materials provided by the vendor are either obsolete or not specific enough. Lack of a data dictionary for TransitMaster databases is a concern as well, since GCRTA has to "reverse-engineer" to discover table attributes that are readily-available in a data dictionary. Driver training seems to be an issue, as evident from missing driver logons or mishandling of the voice communications protocol (e.g., reseating handset properly once the call with Dispatch is over [in response to a RTT/PRTT]). Drivers either forget to logon or cannot logon when they are outside data coverage, which results in the system not recording the data for that run/route. Sometimes dispatchers notice this and either notify drivers to logon or perform the logon for them remotely.
- There are several issues associated with the APC equipment due to lack of maintenance and the age of the equipment.
- The current equipment is first generation (2000) and has been around since the original installs. This is a concern for GCRTA going forward, since replacement parts are not available. Also, the on-board system is DOS-based and has only 512MB memory, which is not enough to store schedule data, announcement files, and APC data.
- Siemens identified in its proposal that, generally, agencies reduce their reliance on voice communication by 75%, but it appears from the discussions that GCRTA that drivers and dispatchers still rely on radios for most of their communications. This practice may be either due to a lack of training or the unreliability of the data communication. Currently, GCRTA dispatchers spend 70% of their time on radios.
- IT had a limited role in the deployment, being involved only to provide network connectivity between sites. Ideally, IT should have been involved in all computer infrastructure-related discussions so the durability of the software and hardware could have been assessed from a GCRTA standpoint. In fact, radio/ITS servers were stacked in a completely different server rack than the rest of the servers in the agency.

Post-deployment Experience

Maintenance was neglected until project close-out in 2012. Trapeze has been helpful now that GCRTA is in the Customer Care phase. Earlier, during implementation, only one vendor resource was available, but other resources from Trapeze Customer Care are now available. However, Trapeze support is for software only. GCRTA is using a local contractor for radio support. The radio towers are under a maintenance agreement with TransCore.

As part of software maintenance, GCRTA is upgrading to the latest version of TransitMaster. Trapeze has made some modifications to the software to ensure that it works with the current version of the hardware and radio infrastructure. Further, GCRTA is upgrading the computer/server hardware as part of the current system upgrade since the current hardware that is running TransitMaster software is very old and past its useful life.

SECTION

7

Lessons Learned

System Planning

The appointment of a project champion and project manager should be the first step in any project planning process to ensure that a project is successful. Although the appointment of a champion may not be necessary for every project, a project manager should always be appointed. The project manager should work closely with the vendor to ensure that knowledge transfer to the agency is appropriate and complete.

The project team must conduct a thorough needs assessment with key stakeholders to ensure that all aspects of the existing conditions are identified. Particularly, the IT department needs to be included in scoping future technology projects to ensure that the planned system will work with the current infrastructure. Going forward, GCRTA would prefer to install any new CAD/AVL system in a virtual environment to improve the maintenance process. Since there are more than 50 applications for an IT staff of 4 people, it is highly critical that maintenance needs are kept at a minimal level. Further, the needs assessment process should highlight any gaps between the existing conditions and the desired state.

In general, as part of planning process, a detailed deployment should be developed that focuses on the following:

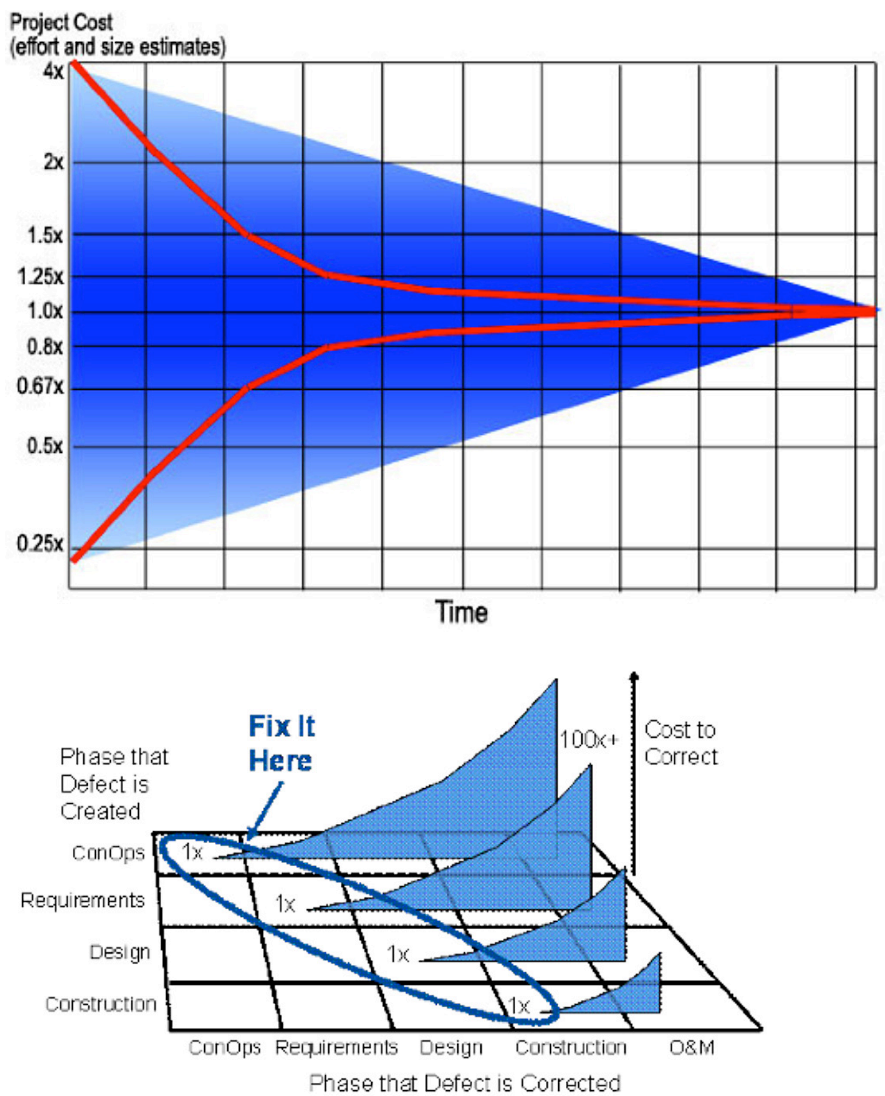
- Analyzing needs and identifying technologies/systems according to user needs.
- Developing high-level functional, performance, and interface requirements to address user needs.
- Identifying system integration needs to ensure that new/enhanced systems "fit" into the existing system environment at an agency.
- Assessing the technology infrastructure (e.g., hardware, data network configurations, wireless communications) impacts.
- Conducting a thorough analysis of the post-implementation environment and documenting the impact on the agency's business.
- Identifying staffing and training requirements.
- Estimating capital, and operating and maintenance (O&M) costs.
- Identifying a high-level technology implementation schedule and developing an action plan by timeframe (e.g., 0–2 years, 2–5 years, 5–10 years). The action plan should analyze the feasibility of grouping projects together and long-term risks associated with such groupings. GCRTA believes that radio procurement should have been done separate from the CAD/AVL since some of the current issues are related to the age of the in-vehicle hardware that was purchased at the beginning of the project.

Assessment of Total Cost of Ownership[11]

As shown in Figure 7-1, the uncertainty related to ITS project costs is very high and cannot be accurately predicted ahead of time for some projects. Thus, it is recommended that a contingency cost factor should be built into the overall project cost. Also, the focus should be on identifying and fixing issues in the initial phases (planning and design) of a project to lower the project cost.

Figure 7-1

Uncertainty in project cost



Source: *FHWA Systems Engineering Handbook*

[11]Cost estimates in this section are based on general assumptions and do not take into account concepts of Net Present Value (NPV) estimation or other methods that are used to determine realistic estimates of costs.

Typical project planning and execution costs should be determined as follows:

Cost of project planning and execution = (1.32[System Cost])*

This formula represents cost estimates for project planning and implementation oversight based on TranSystems experience. In TranSystems' experience, project planning and implementation oversight costs are typically 10–20% of the total project cost. Also, a 20% contingency should be added to account for project risks and uncertainties.

Further, agencies must calculate total cost of ownership of a vehicle for at least 10 years when planning a system. Based on observations at GCRTA and TranSystems' experience in general, O&M costs typically are overlooked by agencies at the time of planning. O&M costs typically vary in the rage of 5–25% of the capital cost depending on the nature of the system component (e.g., in-vehicle hardware or software). However, in our experience, the median O&M cost of any system typically is close to 15% of the capital cost. Of note is that cost of maintenance may increase as a system gets older. A conservative estimate of total cost of ownership of a system for 10 years can be defined as:

*Total Cost of Ownership for 10 Years= (1.32 [System Cost] + (10*0.15*System Cost])*
*= (2.82 *[System Cost])*

Thus, if a system costs $1 million, the cost of deployment and total cost of ownership for 10 years should be estimated as approximately $3 million.

Requirements Definition

Requirements for CAD/AVL system functions were limited in the RFP issued by GCRTA since the primary focus of the RFP was to procure the radio system. The lack of clarity with respect to the CAD/AVL and related system requirements was an issue during contract negotiation.

When developing the requirements, agencies should consider the following:

- Requirements must be concise and unambiguous.
- Requirements must be attainable (e.g., 99.9% reliability may not be practically attainable).
- Requirements must be able to be verified in the field (they must be "testable").
- Requirements must focus on system interoperability, scalability, and reliability.
- Requirements reflect the following:
  - What is the system supposed to do (i.e., functional requirement)?
  - How well is the system supposed to perform a required function (i.e., performance requirement)?

- How is the system required to exchange data with existing systems (i.e., interface/integration requirements)?
- What communication media will be used for inter-system communications (i.e., communication requirements)?

Further, non-technical requirements should be developed. These requirements include items such as project management (e.g., bi-weekly conference calls to discuss action items), documentation (e.g., manuals), design documentation and reviews, installation/integration, testing, training, and maintenance/support.

Procurement

ITS procurements should use the most appropriate procurement instrument, preferably an RFP, and should follow a diligent and structured process to ensure that a vendor is selected based on a range of criteria and not just cost.

Agencies should consider the following when going through an ITS procurement:

- **Maintain reasonable expectations by understanding what transit ITS product vendors have to offer.** Many transit systems depend heavily on vendors for specific information on transit ITS applications. In many cases, transit ITS solutions have been oversold or agency expectations have been unreasonably high. This can lead to agency ITS needs not being met by product vendors.
- **Procurements should cover optional items that an agency may wish to purchase in the future.** Often, it is a challenge to make decisions about every conceivable feature or element of technology that is desired. If there are open questions at the time of procurement, agencies should include a description of potential future requirements and request that each proposer provide a price for those items or services. This will ensure that the agency can exercise that option at a later date for a reasonable price.
- **Consider performance-based contracts, including incentives and penalties.** One way of avoiding problems later in an ITS deployment is to write performance-based contracts with vendors. For example, agencies can develop project milestones, for which payment is made to vendors only when the milestone is completed successfully. In this way, vendors have an incentive to do a good job and meet the project schedule.
- **Sequence deployments with consideration to the dependencies among applications and avoid the temptation to do too much too fast**. Some transit agencies schedule their ITS implementations so that systems are deployed sequentially, avoiding deployment of dependent systems haphazardly or simultaneously. Agencies should have a clear understanding of their staff's capacity and should schedule deployments based on realistic expectations rather than political interests if at all possible.

- **Be flexible to accept schedule delays when needed to help manage deployment risks**. Delays are an inevitable aspect of large-scale technology projects. It is often desirable to accept changes in the deployment schedule in order to mitigate the risks.

Contract Negotiation

Contracts between an agency and vendor must be developed keeping the agency's best interest in mind. Often, vendors will propose using their own agreements, which are skewed toward the agency taking a majority of the risk in a project. Further, many vendor-developed agreements do not include reasonable payment milestones and other language that ensures vendor performance. Obviously, any agreement with a vendor must be reviewed thoroughly to ensure that GCRTA's interests are protected by the final contract language. At a minimum, the following documents must be included in the contract to ensure vendor performance:

- Compliance requirements matrix with vendor responses to each requirement
- Final cost proposal (could be as a result of a BAFO response)
- Maintenance and warranty agreement
- Software license agreement
- Tentative project schedule, which will form the basis of the selected vendor's System Implementation Plan

Effective Process Management

An agency should establish a formal and effective process for systems planning, design, procurement, implementation, and maintenance/support incorporating the best practices. In particular, the process should emphasize the documentation of activities at every step, from project planning through maintenance and support. However, not all steps may be necessary for each project. A customized systems engineering process may be used by the agency depending on the scale of the project (see Figure 7-2 for an example of a customized systems engineering process for GCRTA).

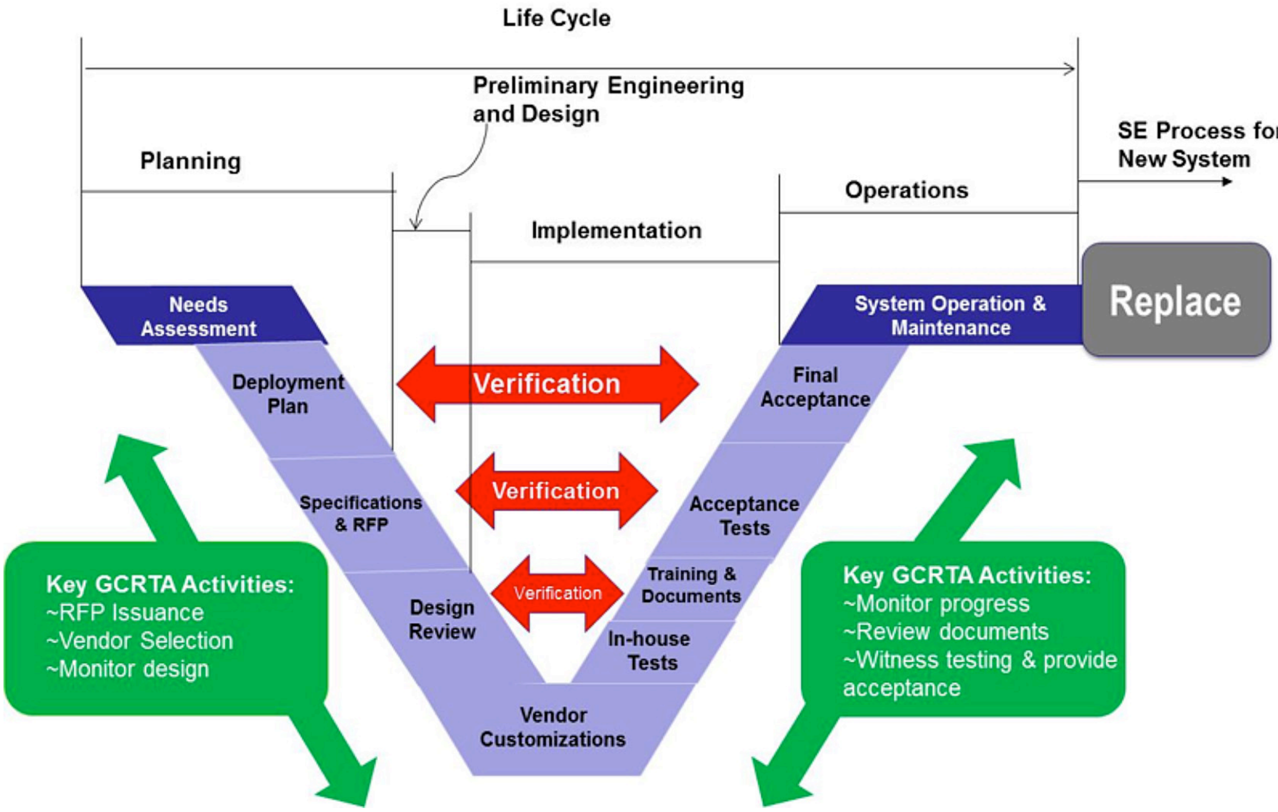


Figure 7-2

Systems engineering approach for ITS deployment

The planning and design stages must focus on systems integration to avoid the development of information silos within the organization. The adoption of standard interfaces to avoid interoperability issues must be considered. Also, the implementation should follow the systems engineering approach. Further, final system acceptance must be based on the results of several testing phases (e.g., lab and field tests) during the implementation process, as shown in Figure 7-2.

GCRTA believes that appropriate staff should have been involved at each stage of the deployment to ensure knowledge transfer after the system was accepted. In the case of GCRTA, the vendor was in charge of leading the deployment process and, due to the lack of documentation and limited staffing during deployment, knowledge transfer was very limited. GCRTA suggested that the actual users of the systems and the staff that would be in charge of maintaining the system should have been involved from the requirements definition stage of a project.

Documentation

Documentation during any stage of deployment is extremely important to enhance the level of communication among the project team members. Also, documentation is necessary to mitigate risks related to the continuity of the deployment process in the event a project member with key responsibilities is no longer involved with the project.

Further documentation should be compiled at every stage of deployment, including at least the following:

- Contract documents
- Final system requirements and change log
- System implementation plan (SIP) that describes the detailed project deployment approach
- Documentation of actions and their resolutions
- Design documentation that provides a detailed overview of how the vendor's system will meet the requirements
- System testing and test result documents
- Installation design document that provides detailed description of system component interconnects, wiring diagrams, system configurations and other installation related details
- Training materials and training manuals
- Various system and user manuals that are needed for operations and maintenance of the system
- As-built documents that provide the "as-is" description of the entire system at the time of acceptance

Also, TranSystems discovered several gaps related to the lack of documented data flows between GCRTA system components or departments. Identification and documentation of data flows is extremely critical for system maintenance (e.g., troubleshooting) and implementing changes to an existing system. Workflows must be identified by department or business function (e.g., scheduling, operations, and planning) by showing system interconnects between applications that are used by those departments/business units.

Training

Vendors must be required to provide a training plan that must be reviewed and approved by the agency prior to commencement of the first training session. The training plan must include at the least the following information:

- Description of each training course
- Number of classes per course
- Type of training (e.g., in person or webinar)
- Maximum number of attendees per training class

- Materials to be used for the training (e.g., demo equipment, whiteboard, projector and PowerPoint slides, course material)
- Instruments/techniques to be used to evaluate trainees (e.g., feedback form and team exercise)

GCRTA must ensure that the vendor's training plans include interactive sessions in their training curriculum as much as possible.

Timing of Training

Training sessions must be scheduled as follows:

- **Training Prior to Any Installation** – The focus of this session should be to provide familiarity to the top management and supervisors. Also, in some cases (e.g., during pilot/installation testing), other staff such as dispatchers and operators need to be trained ahead of time so that they can assist during testing. Training ahead of deployment can provide staff with knowledge to help others who are learning the system at a later stage in the system implementation process. This is typically referred to as the "train-the-trainer" approach.
- **"Just-in-Time" Training** – If there is a considerable delay between the first training session and the time of actual use of the installed system, vendors must provide additional training prior to the pilot/installation testing (i.e., during or after the installation).
- **Refresher Training** – Users encounter more questions and concerns once they have used the system for a certain amount of time (e.g., six months after the installation). Thus, vendors should be required to provide refresher training sessions a few months after the system has been accepted.
- **Follow-on Training** – Vendors should visit the agency periodically to retrain and evaluate how the system is being used. The evaluation should be done through manual observations or analysis of system usage logs. These visits should be scheduled only after the system has been in use for at least 6–9 months.

In-House Training

Training sessions alone cannot provide enough opportunity for staff to become familiar with new systems and subsystems. Thus, the agency should develop an in-house training plan for hands-on training of its employees by in-house trainers (trained under the train-the-trainer program) at regular intervals.

The agency should use hands-on training tools for operators and maintenance staff, such as:

- **Bus-in-a-Box (BIB) or Test Equipment** – A BIB (test bench configuration of the TransitMaster operator control head, IVLU, and voice and data radio for the CAD/AVL system) or test units (e.g., farebox test unit) can be extremely useful for operators to get a hands-on learning experience and review different operating scenarios (e.g., single-point logon, covert/emergency alarm situation, wheelchair cycle) with trainers during in-house training sessions.
- **Maintenance Test Bench (MTB)** – An MTB, which could be identical to a BIB or sometimes is equipped with additional vehicle equipment (e.g., heat ventilation and air-conditioning [HVAC] component connected with a TransitMaster IVLU over J-7108), is meant to be used as the test bench by maintenance staff. However, an MTB can be useful for electronics/maintenance technicians to familiarize themselves with on-board system configurations that might not have been covered in a vendor training session.
- **Software Environment with Training Data** – The TransitMaster system allows playback of previous operational situations. The agency should store such data representing unique operational scenarios in a training database that should be used to train dispatchers and operational supervisors about typical and emergency operational scenarios. Similarly, other ITS software products should be configured to have training environments which can be used by either trainers or software users for training purposes.

In addition to the above tools, the agency should arrange for or develop interactive tools for its employees (e.g., training videos, demonstration programs running on training data).

Installations

Factory installation quality for the new vehicles was unsatisfactory. APC equipment on some of the vehicles was not installed, and some vehicles did not have the PA connected with the IVLU. Almost 70% of the fleet had installation issues.

Agencies should ensure that installations are performed per approved installation design documents. Every vehicle installation should have a pre- and post-installation verification checklist that should be signed by agency maintenance staff. For an installation that is conducted at a vehicle manufacturer facility, agencies should visit the manufacturer facility to conduct installation quality checks.

System Maintenance

Transit ITS requires a certain level of system maintenance and vendor support to ensure the utility and performance of the system. Key lessons learned with respect to system maintenance are as follows:

- **Identify maintenance roles and responsibilities.** Identify what agency and staff will be responsible for in terms of monitoring and maintaining the system and what activities they should perform, and ensure that they are trained on how to use the equipment. If desired, it could be the contractor who designed and/or installed the system who is responsible for monitoring and maintaining the system. Alternatively, it can be project staff, but it is important that someone familiar with the equipment develop a maintenance schedule and train those who will be responsible for maintaining the system.
- **When an operational issue is reported, troubleshooting is commonly performed by in-house personnel.** This enables a comprehensive check that the transit technology functionality is fully restored while minimizing downtime. In-house personnel are supported with troubleshooting flowcharts and functionality checklists and with drop-in replacement using known-good components from a spare inventory. Although most transit ITS technology will require little preventive maintenance (e.g., vacuum dust, clean screens), these routine tasks should be completed in conjunction with regular maintenance work.
- **Develop a maintenance schedule and keep records of all maintenance.** It is important that the maintenance schedule clearly denotes where and how all maintenance activities should be conducted and documented. For example, transit agencies should develop a set schedule on when (and who) will clean and inspect cabinets and on-board vehicle systems. The schedule will help delegate responsibility and ensure the longevity of the ITS system. Repair history databases also should be developed. Periodic analysis may reveal recurring failures with a particular component for which the cause can be considered (e.g., supplier quality control, operator sabotage).
- **Expect that regular monitoring may be required to test manual settings.** For the system to continue to be reliable, manual settings and adjustments may be needed. Regular system checks (e.g., weekly) can be performed to validate that systems such as APCs are functioning as expected. Remote user interfaces can help validate information currently posted on each DMS as well as the configuration of lot assemblies. Also, remote user interfaces can facilitate the user updating or shutting off signs remotely as needed. While systems may not fail often, they will require frequent monitoring to ensure that accurate information is being transmitted.
- **Troubleshooting flowcharts are usually provided as part of the original maintenance manual**s. Flowcharts also can be developed later based on the initial maintenance experiences and should evolve as maintenance feedback is received. Some agencies establish maintenance forces that specialize in supporting their transit technology equipment (e.g., CAD/AVL, farebox, headsign, APC), but such specialization is not essential. Ideally, the entire repair process for a particular vehicle (i.e., getting the

vehicle back in service promptly with fully-restored functionality) can be made the responsibility of a single assigned employee who can then be accountable for how quickly and effectively the work was done.

- **A "golden" test bench environment (e.g., Bus-in-a-Box) with fully-functioning components is valuable when initially testing components**. The test bench enables maintenance personnel to test individual components off the vehicles, away from other potentially faulty components. A spare (proven out using the test bench before going into the spares pool) can be swapped in quickly to enable a current step in the checklist (i.e., if the functionality is not fully restored after swapping in the known good unit, then that component was not the (only) issue and the flowchart process would continue).
- **Equipment should be purchased from the supplier to replenish the spares pool on an ongoing basis**. A swapped-out component should be checked on the test bench to confirm whether it is faulty (if not, it can be returned to the spares pool). Once components are no longer being replaced under warranty, discussions should be initiated with the supplier as to whether they will offer to recondition faulty units at a reduced price in comparison to new units. This is more likely in the case of components with a variety of subcomponents such as an onboard computer or operator display, since, in many cases, reconditioning would require replacing only some subcomponents.

Apart from equipment maintenance, it is critical for agencies to ensure that vendors support software and databases per the agreed-upon terms and conditions in the software license agreement. Terms and conditions in the software license agreements should be unambiguous and must include specific activities that vendors are required to perform in the event of an issue. Escalation procedures must be specified as well.

Further, roles and responsibilities should be determined internally to ensure that the data required by software products (e.g., stop latitude/longitude, employee list, and system configurations) are accurate. It is extremely critical to determine the "master" data source where certain datasets reside and could be obtained from multiple sources (e.g., stop database could be in both a scheduling system and bus stop management system)

Typically, database maintenance (e.g., data archival, deletion/archival of database logs) is done by agencies with the help of in-house and/ or external resources. Periodic data maintenance is critical to ensure desired system performance and, thus, database maintenance schedule should be determined and followed by agencies.

Staffing

The staffing level and commitment of these resources is extremely critical at any stage of deployment and during system utilization. Key points related to staffing based on lessons learned from GCRTA experience and best practices are as follows:

- **Despite the structured systems engineering process and extensive communication and coordination among stakeholders, the ITS deployment potentially can lead to disruptive changes.** It is nearly impossible for a technical installation involving hundreds of vehicles, multiple communication networks, and dozens of computers to happen flawlessly. The agency project manager should prepare agency staff for the potential that installation may be disruptive and challenging. Champions for each transit ITS user group can provide a way to maintain enthusiasm throughout the deployment and communicate with the agency staff. Proper preparation will reduce potential staff frustration.
- **Prepare agency staff for implementation and acceptance of new ITS technologies.** In many agencies, some transit staff are reluctant to change their current practices, regardless of the potential benefits of a new system. When the system has shortcomings or failures, reluctant staff may become more hesitant to accept new technologies, even after they are working well. Preparing staff and making them aware that the system is likely to have some issues at startup will help to encourage staff acceptance.
- **Include staff as co-participants.** Initially, transit agency staff may not be accepting of the new transit ITS or resistant to organizational changes. By involving staff in the planning and procurement process and preparing them for potential issues, project managers can help achieve buy-in from management and staff while ensuring continuity once the system is fully deployed. Engaging staff early on facilitates training and overall system acceptance.
- **Solicit feedback from staff and heed their concerns, as issues will arise with the ITS system**. Providing staff with channels with which to voice their frustrations and document feedback will alleviate these issues while enabling the agency to troubleshoot issues with the system. Standard procedures with which to document system errors or functions should be developed and communicated with staff. These forms will facilitate the vendor and project manager's roles in documenting and resolving system configuration issues. Moreover, this process reinforces the staff's sense of ownership of the system and provides them with a structured process on how to improve it.

- **Build in-house capability by involving maintenance and IT staff in the installation process**. Active participation and support of the ITS system installation provides hands-on learning and familiarity of the system. Participating in the testing of hardware will provide agency staff with the tools to troubleshoot issues as they arise once the deployment is complete while reducing the agency's reliance on vendors to provide maintenance support.
- **Develop a partnership with the vendor.** Transit ITS systems are not turnkey systems. Many agencies expect a transit ITS system to be fully installed by the selected contractor. Working side-by-side with vendor will provide the agency staff with a greater understanding of the system and a greater sense of ownership and will streamline the design and implementation by allowing agency staff to diagnose and resolve issues as they arise with the support of the vendor. Over the long term, working hand-in-hand will the vendor will facilitate adoption of the ITS systems.

Data Quality Management

Since the ITS systems and their reporting functions are completely data driven, it is very important to validate data input and output at periodic intervals. This section describes the processes that achieve that goal by the type of data.

Table 7-1 provides a sample of issues with transit ITS datasets for applications installed at GCRTA. (An actual list of issues could be much more extensive.)

Table 7-1

Sample of Issues with Transit ITS Data

System/ Subsystem	Data	Issues
AVL	Logon/logoff	Incorrect driver logons/logoffs due to driver errors
AVL	Timepoint crossing	Missing timepoint crossing data due to incorrect configuration/ geocoding of timepoints
AVL	Schedule adherence	Incorrect reporting of schedule adherence due to incorrect geo-triggers or geocoding of stops
AVL	Automated announcement	Incorrect geo-triggers for announcements or incorrect geocoding of stops
APC	Passenger counts	Incorrect association of counts with trips for counts at terminal stops
APC	Passenger counts	Incorrect association of counts with stops due to incorrect geocoding of stops or incorrect driver activity (e.g., door open/close activity is too far from actual bus stop)

CAD/AVL, APC, and real-time information are the most critical datasets for agency operations, planning, and customer service. The following bullets describe the validation process for these datasets:

- **AVL**: Apart from conducting random ridechecks after a schedule change, GCRTA staff should regularly monitor the following reports in the CAD/AVL system to ensure that data is being reported as expected:
  - Driver logon/logoff
  - Terminal departure points
  - Missing timepoints
  - Actual vs. scheduled headway
  - Early/late events
  - Off-route events
  - Announcement summary and details (e.g., location where stop was announced)

Not all of these reports may be included in the standard report offerings. Thus, it may be necessary to develop custom reports to review the required information. Once the issues have been identified, the appropriate actions must be taken to fix the issues. As indicated earlier, most of the issues related to the CAD/AVL system stem from incorrect schedule data or geo-trigger configuration in the CAD/AVL system. Also, sometimes issues arise due to defects in the AVL/GPS hardware on the bus (or its connection with the GPS antenna) or due to issues with the interface between the odometer and IVLU.

- **APC**: Some of the issues associated with APC accuracy and reliability are as follows:
  - Inaccurate counts at terminals due to the high number of boardings and alightings
  - Inaccurate counts due to objects carried by passengers, such as shopping bags
  - Issues with dark clothing and other ambient light/color issues
  - Issues with correlation of boarding and alighting counts with appropriate stops (e.g., vendor products cannot correlate passenger counts with stops when vehicles do not stop at designated stop locations as configured in the system)
  - Propagation and balancing APC errors over a vehicle block (vendors often balance errors during post-processing of data over a vehicle block to filter erroneous data from trip-level counts)

Since none of the above anomalies can be captured and corrected as part of electronic data collection, APC sensors are required to be calibrated at required intervals.

- **Real-time Information:** It is critical to identify and resolve issues related to the underlying data for real-time information. Issues with real-time information can be generally categorized as follows:

– Incorrect prediction
– Incorrect dissemination

Issues with real-time information are typically due to:

– Incorrect run/block assignments for drivers/vehicles
– Variability in travel times
– Latency in location data refresh
– Lack of ad-hoc detour management capabilities

Issues associated with information dissemination are easier to resolve since they are related usually to hardware or software configurations. Prediction issues require system calibration over a longer period of time to become reliable. Agencies should conduct field observations to compare the predicted arrival information with the actual arrival information. After this, a report describing the accuracy and reliability of prediction information for a stop on a route should be generated, as shown in Table 7-2. Please note that observations in Table 7-2 can be improved by addressing some of the issues identified with the underlying data for real-time information.

Table 7-2

Sample Observations for Field Test of Prediction Accuracy

When Bus Is	Deviation of Predicted Arrival from Actual Arrival	% Observations
5 min away	+/-1 minutes	96%
5 min away	+/-2 minutes	98%
10 min away	+/-1 minutes	85%
10 min away	+/-2 minutes	90%

System Utilization

System Performance Measurement

At the time of systems planning, agencies should develop measures of effectiveness (MOEs) for a system. These MOEs should be based on the goals and objectives of the system deployment. Agencies should evaluate systems based on these MOEs once the system has been deployed and accepted for at least one year.

Organize Peer-to-Peer Learning Opportunities

GCRTA should provide employees with an opportunity and encourage them to interact with peers at other agencies to discuss issues and solutions. Such information channels could be developed either through direct contacts between peers or through facilitation from vendors (e.g., user conferences). GCRTA has started to discuss its issues and current practices with Kansas City Area Transit Authority (KCATA) and Dallas Area Rapid Transit (DART) to learn from their experiences.

Conduct Periodic Assessments of Systems Usage and Make Recommendations for Improvements

Agencies should conduct periodic evaluations of system users either with the help of vendors or through in-house efforts. These evaluations should focus on identifying issues in the following categories:

- Issues that persist due to lack of training
- Issues that persist due to user "ignorance" or "hostility" (e.g., vandalizing)
- Issues that require vendor and/or system administrator attention for reconfiguration
- Issues that require bug fixes from vendors
- Issues that require enhancements from vendors

Once the issues have been categorized, agencies should identify the severity of an issue and recommend proper actions with the help of senior management, as needed. This is necessary to ensure that the issues are addressed and user productivity is increased.

Interdepartmental Communication

An effective interdepartmental communication framework is the key to ensure successful planning, design and expected utilization of ITS systems.

In the pre-implementation phase and during implementation, the system implementation manager(s) should engage staff from relevant departments to ensure that their needs and concerns are addressed. Further, once the system is implemented, the end-users should have the ability to communicate issues and concerns to the system specialists using effective tools such as an electronic issues tracking system (e.g., a typical help desk system).

To ensure a continuous dialog regarding desired functioning of systems and needed improvements, the executive staff from various departments (as part of a working group) should participate in periodic meetings, conducted at least every month.

Even after a system is accepted, departments should still maintain a good level of communication to ensure that the system is properly maintained and utilized, and the overall goals of the system are achieved.

SECTION

8

Conclusions

The GCRTA radio/ITS deployment was planned primarily to replace an existing radio system that had become obsolete by 1998. However, the RFP for the procurement included CAD/AVL functions since the new radio system was being designed to support data transport as well. Even though the bulk of the radio infrastructure installation was completed by 2002, it took an additional 10 years to accept the system. This report provides a detailed description of the events that led to the delayed acceptance, and the issues can be summarized as follows:

- **Ambiguity in Requirements Language** – Requirements were written primarily for the radio infrastructure development. Thus, there was limited clarity in how CAD/AVL functions, such as vehicle tracking, route and schedule adherence, incident management, and single point logon, should be verified in the field. Therefore, there were differences in the interpretation of requirements between the vendor and GCRTA.
- **Change in Vendor Management** – Vendor management changed several times throughout the course of the deployment. Although the point of contact for GCRTA has not changed since 2002, changes in management caused several delays and renegotiations of contracts resulting in several change orders.
- **Management of Contract Milestones** – Contract milestones were designed based on the radio and other hardware-related requirements. Thus, 80–85% of the total contract value was paid even before any testing was performed on TransitMaster functions.
- **Lack of Effective Deployment Process** – The lack of a formal implementation process based on systems engineering was a key reason for the delays and current issues with the system. Sufficient checks and balances were not in place to determine the readiness to move forward with each stage in the implementation. Further, the radio and CAD/AVL systems were designed and implemented separately and sequentially even though both sets of hardware were procured at the same time. Most of the CAD/AVL system integration was performed a long time after the radio system was installed. Testing of the CAD/AVL system was not performed until 2009, but by then, the TransitMaster hardware was already 10 years old.
- **Inclusion of Rail Mode** – Rail was included in the CAD/AVL deployment because the radio equipment installed on rail vehicles had become obsolete. Since the radio RFP was going to procure new radio equipment for rail vehicles, requirements for CAD/AVL also were included. However, TransitMaster does not include functions that are typically required for the management of rail operations, so GCRTA still uses separate tools for

SCADA and signal control. TransitMaster is used only for operator logons and canned data message exchange. The announcement system installed on rail vehicles is not reliable since the system cannot determine the current location of vehicles when they do not have GPS coverage.

- **Project Staffing and Management at GCRTA** – There have been several changes in management at GCRTA since the project was commissioned. Original staff have either retired or left the organization, thus causing a loss of institutional knowledge. Also, the level of staffing dedicated to the project and interdepartmental communication has been limited. Typically, several FTEs are required to ensure a successful deployment and utilization of the product after the deployment. However, based on the discussions with GCRTA staff, it was determined that the staffing levels were not adequate.
- **Training and System Adoption** – The level of training provided by the vendor was very limited. Also, documentation was not developed specific to GCRTA. Further, due to initial issues with the system, users developed a low confidence in the system; thus, the adoption of the system was not as expected.

In summary, delayed acceptance and the current functional state of the system is a result of a combination of issues related to system planning, contract management, staffing levels, deployment processes, and system functions. If GCRTA were to deploy a new system today, several of these factors should be taken into account very early in the planning process to ensure a successful implementation.

GLOSSARY

ADA	Americans with Disability Act
APC	Automated Passenger Counters
ATP	Acceptance Test Procedures
AVA	Automated Vehicle Announcements
AVL	Automatic Vehicle Location
BIB	Bus-in-a-Box
BRT	Bus Rapid Transit
CAD	Computer-Aided Dispatch
DGPS	Differential Global Positioning Satellite
DMS	Dynamic Message Signs
EDACS	Enhanced Digital Access Communications System
FTP	File Transfer Protocol
GCRTA	Greater Cleveland Regional Transit Authority
GPS	Global Positioning Satellite
ICC	Integrated Communication Center
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ITS	Intelligent Transportation System
IVLU	Integrated Vehicle Logic Unit
MARCS	Multi-Agency Radio Communication System
MDT	Mobile Data Terminal
MOE	Measures of Effectiveness
NTD	National Transit Database
OTA	Over the Air
PA	Public Address
PRTT	Priority Request to Talk
RF	Radio Frequency
RNC	Radio Network Controller
RTIS	Real-Time Information System
RTOS	Real-Time Operating System
RTT	Request to Talk
TM	Transit Master

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