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Assessment of the Denver Regional Transportation District's Automatic Vehicle Location System

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Office of Mobility Innovation
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13. ABSTRACT (Maximum 200 words)

This report documents the implementation and early operation of an automatic vehicle location (AVL) system by the Regional Transportation District (RTD) in Denver, Colorado. AVL system installation began in 1993 but, due to a number of hardware and software difficulties, was not accepted until 1996.

The AVL system has helped RTD provide better quality service, especially in the improvement in on-time performance. The system has received a wide level of acceptance from operators, dispatchers and field personnel. Operators felt that the system has provided them, as well as their passengers, with a greater sense of safety and security. Dispatchers felt they had more control over on-street operations. Street supervisors liked the ability to locate buses and communicate directly with the operators.

At the end of the evaluation period in 1997, RTD was not making use of AVL data to develop more efficient route schedules. Consequently, the AVL system appeared to have had little impact on the economics of operations. However, RTD is now using AVL data to review their schedules, but the extent of changes that have been made and the effects on operating costs have not been assessed.

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PROLOGUE

Since the draft of this final report was prepared, the Regional Transportation District (RTD) has received upgraded software that has allowed them to improve the performance of their Automatic Vehicle Location system and provide functionality that was previously unattainable. Specifically, the schedule adherence function is now fully operational and the bus operators are shown their schedule adherence condition on the Transit Control Head. In addition, the signboards in the two downtown mall stations provide real-time bus departure information, and the system no longer crashes. Also, RTD has installed kiosks in four locations to provide information to customers. Unfortunately, the limitation on funding for APTS evaluation activities prevents an update of the evaluation to reflect these improvements. However, these advancements should be borne in mind when reading this report.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

In 1993, the Regional Transit District (RTD) in Denver, Colorado installed an automatic vehicle location (AVL) system which was developed by Westinghouse Wireless Solutions. The system received conditional acceptance from RTD in March of 1996. This evaluation assesses the costs and benefits of the AVL system for the 2,400 square mile, 1,335 vehicle-fleet system.

RTD identified the following three objectives as primary reasons for installing the AVL system:

Objective #1 - develop more efficient schedules

Objective #2 - improve ability of dispatchers to adjust on-street operations

Objective #3 - increase safety through better emergency management

The evaluation is based on data received from RTD that covers the years from 1992 (the year before implementation) through 1997, encompassing one complete year after RTD's conditional acceptance.

Financial Impacts

The fixed costs associated with the AVL system implementation totaled $10,400,000. Of this, $72,451 was withheld by RTD because the Public Information Display System (PIDS), which will display real-time bus-arrival and departure information, has not functioned to specifications. The ongoing maintenance and operations costs for the AVL system were $1,897,627 for 1997, which is approximately 1.5% of the total RTD operations budget. The year 1997 was the first year the system was not under warranty, and RTD incurred all costs with the systems operation and maintenance. The system costs are discussed in more detail in Chapter 3.

AVL Functional Characteristics

In evaluation and system acceptance testing, 96% of all vehicle location reports were within the accepted threshold. However, in review of the acceptance testing by the Volpe National Transportation Systems Center, it was suggested that the thresholds were not clearly defined by RTD, and the 96% accuracy may not fully represent the ability of the system to report accurate information. This is discussed in more detail in Section 4.3.

The system achieves the second RTD objective by giving the dispatchers more control over incoming requests because the system now prioritizes calls and allows dispatchers to choose which operators to speak to. The text-based messages allow for many operator and dispatcher calls to be made without requiring voice communications. The ability to see the location of transit, maintenance and supervisor vehicles, as well as accurately know their position relative to their schedules and other vehicles, made coordination easier for dispatchers.

All messages from operators to dispatchers were received and acknowledged by the central processor in less than one second, which was well below the three second threshold established as acceptable for emergency calls. The reliability of message transmission reduced operator stress because they developed confidence that their messages were received and were being addressed.

The system has improved the quality, timeliness and availability of customer information because dispatchers can locate vehicles and report their locations to the customer service center. However, this activity is not common. Eventually, the customer service center will have its own AVL displays and representatives and will easily be able to track buses that customers inquire about. The AVL system also has a playback function, which allows RTD to "rerun" routes to determine if customer complaints, such as a bus skipping a stop or a bus arriving late, are valid.

The AVL system helped achieve the third objective, improved safety, for both operators and passengers. Operators reported that they felt safer now than prior to AVL implementation. Passenger assaults per 100,000 passengers decreased by 33% between 1992 and 1997. There were also many reports of criminal acts thwarted because police responded quickly with accurate information from the AVL system. Section 4.6 details the system's impacts on emergency situations, while Section 7.6 discusses safety and security.

The first objective, developing more efficient schedules, was not achieved through this project. This is due to RTD's inability to integrate the data produced by the AVL system with their existing scheduling software and internal processes. The AVL system, which can document the schedule adherence of all AVL equipped buses at each stop, was not used because there are no means in place to analyze it or include it in the scheduling process.

Acceptance and Perceptions

Overall, the AVL system has received a wide level of acceptance from operators, dispatchers and field personnel. Operators felt that the system provided them and customers with more safety and security, while dispatchers felt that the additional knowledge they had of vehicle locations helped RTD maintenance, supervisors and emergency response teams to quickly reach incident locations. Additionally, dispatchers believed service improved because of the greater control they have over in-service vehicles. They are able to alert drivers that are ahead of or behind schedule, as well as those that are off-route.

The operators had more satisfaction in their jobs, and dispatchers experienced less frustration in monitoring and controlling fleet movement. Dispatchers particularly appreciated the amount of control they now have over vehicle to dispatch communications, and their ability to immediately locate a vehicle. Street supervisors also have the ability to locate buses and communicate directly with coach operators, and they stated they believed this made their roles and responsibilities less stressful and more productive. Customers were pleased with the service that RTD provided. Over 90% rated it as "good" or better in a survey of over 800 riders and non-riders. They felt that RTD is safe, on-time, clean and convenient. Employee and customer perceptions and attitudes are detailed in Chapter 5.

Transit System Efficiency

The first RTD objective for the AVL system was to use its data-collection capability to develop more efficient route schedules. Because of conflicts in scheduling procedures and difficulties in coordinating existing and new software applications, RTD has not been able to fully utilize the system to achieve its first objective. There is no evidence of increased ridership, or more economic efficiency in the RTD transit network as a result of the AVL system.

The cost per operating hour and the cost for delivering each revenue mile did not increase beyond inflation, and since 1994, costs have declined per revenue mile and for per hour for RTD bus operations. There are several factors that impacted the operating costs, including increased labor fees, expanded service, and the addition of light rail. While it cannot be definitively stated that the AVL system was responsible for the decrease in these costs, the cost savings do coincide with its implementation.

Transit System Effectiveness

Since the AVL system was implemented, the transit system has provided the customers with higher quality service. RTD decreased the number of vehicles that arrived at stops early by 12% between 1992 and 1997. The number of vehicles that arrived at stops late decreased by 21%. These improvements are to a system that was already performing well, and outstanding considering the impact that inclement weather can have on on-time performance during the winter. From 1992 to 1997, customer complaints decreased by 26% per 100,000 boardings. This is probably in part due to improved schedule adherence by RTD.

Because of the expansion of RTD service to meet the needs of new communities and the new Denver airport, the productivity did not significantly change. The number of passengers per vehicle mile in 1997 was similar to that in 1992, and the number of passengers per revenue mile decreased.

The number of passenger trips per year increased from 58 million in 1992 to 71 million in 1997. The 1997 total includes 4.4 million light rail passengers. However, the number of passengers per hub mile of service decreased by 2.5%. During the evaluation period, light rail trains and express bus service to the airport began and they attracted a new demographic to RTD services. There is no evidence that the AVL system helped to increase the number of passengers, or passengers per hub mile.

Revenue per hub mile has increased, but this is primarily due to increased fares and the higher fares charged for the new services, such as the SkyRide airport buses. SkyRide trips usually cost passengers four to eight times more than local bus service.

Conclusions

RTD now provides better quality and safer service to its customers than it did before AVL implementation. Additionally, operators, dispatchers and on-street personnel all believed that the AVL system makes them more productive and gives them better tools with which to handle their roles and responsibilities.

Overall, the AVL system has helped RTD successfully achieve two of its three objectives. Dispatchers and supervisors have more control over on-street operations. RTD has improved the fleet's on-time performance and can improve that even more with more effective use of the schedule adherence function. Safety and security experienced significant improvements. Operators believed that their vehicles were safer because of the AVL system. When the scheduling issues are resolved, the AVL system will have the potential to provide more accurate and complete operational information to the scheduling process than RTD ever had before.

The benefits of the AVL system on ridership and operating costs are less clear. Although ridership on RTD buses increased substantially between 1992 and 1994, the number of passengers carried per vehicle revenue mile declined due to the expansion of service and the increase in long-haul service which carries each passenger for more miles per trip. Similarly, although operating costs per vehicle hour and per passenger declined between 1992 and 1997, the decrease cannot be directly attributed to the AVL system. It does, however, coincide with its implementation.

1. INTRODUCTION

1.1 Background

The Federal Transit Administration (FTA), through the Volpe National Transportation System Center (Volpe Center), conducted the evaluation of the Denver Regional Transportation District's (RTD) Automatic Vehicle Location (AVL) system as part of its evaluations of selected Advanced Public Transportation Systems (APTS) operational tests. The evaluations are intended to measure the degree to which both FTA's national APTS objectives and the local RTD's APTS objectives are achieved. The purpose of this evaluation is to assess the RTD AVL's performance in order to determine its applicability and potential effectiveness in other cities.

Battelle and its subcontractor, Castle Rock Consultants (CRC), were retained by the Volpe Center to conduct this evaluation. Westinghouse Wireless Systems was the initial supplier of RTD's AVL system. Westinghouse subsequently divested itself of its transit management business, and the resulting Transportation Management Solutions (TMS) oversaw the final acceptance and maintenance stages of the AVL development.

The AVL system utilizes a global positioning system (GPS)-based vehicle location system. It is installed on all of the buses, field supervisors' vehicles and light rail trains in the RTD fleet. AVL dispatch stations are installed in Boulder, and two locations in Denver, one for light rail, and the other for bus operations. The AVL system installation began in 1993, and RTD gave TMS conditional acceptance in March, 1996.

1.2 RTD Overview

The RTD transit system consists of about 1,335 vehicles, including buses, supervisor and maintenance vehicles, and light rail cars. Of this, the number of bus and light rail vehicles that are dedicated to fixed-route service is 980. They are broken down by type in Table 1.1. RTD serves a six county area covering over 2,400 square miles with a mix of local, express, regional and airport service. In 1997, they served more than 71 million passengers, including free local shuttle services.

RTD's objectives in implementing the AVL system were to develop more efficient schedules, improve the ability of dispatchers to adjust on-street operations, and increase safety through better emergency management. In conjunction with the new AVL system, Westinghouse replaced RTD's entire dispatcher-to-field communications system. The new communications system is significantly more advanced and provides more capacity than the old system. However, this evaluation is intended to document the impacts that the AVL system has made, and will attempt to separate those from impacts made exclusively by the improved communications system.

Vehicle Type	Quantity
Fixed route service buses (large and small)	936
16th Street Mall buses	27
Light rail	17
ADA, Access-a-Ride vehicles	175
Maintenance and supervisor	180
TOTAL	**1,335**

Table 1.1 RTD fleet composition in 1997

1.3 RTD Executive Support

The procurement and implementation of the AVL system received full support from the Board of Directors. Since its implementation, the Board has been replaced; however, the new Board is also supportive of the AVL system.

In 1992, the Board of Directors approved the RTD's request for procurement of the system. The system was most heavily promoted by the Director of Operations. His objectives in deploying the AVL system were to:

- improve transit operation efficiency;
- improve passenger and operator safety;
- improve the transit system's user friendliness (through better real-time information dissemination); and
- to replace an antiquated radio system with a state of the art system.

This last element, improving the radio system, was most important to the operations department. The AVL system required a better radio system, and was included in the AVL system. The new radio system was, in part, funded with Federal funds as a component of the AVL system.

1.4 Evaluation Approach

The Volpe Center's report, Advanced Public Transportation Systems: Evaluation Guidelines, established the generic evaluation process that has been followed throughout this APTS evaluation.
This process was broken down into six parts:

1. evaluation frame of reference;
2. evaluation framework;
3. evaluation plan;
4. evaluation implementation;
5. data reduction and analysis; and
6. evaluation report.

The evaluation frame of reference for Denver was completed in April, 1993. It established and documented the base conditions in Denver. It described the RTD coverage area and site characteristics, the AVL system, the operational test and the objectives. It also identified external influences which might affect the evaluation, design, implementation and results.

The evaluation framework laid out the scope of the evaluation in terms of the measures that are included. In the Denver case, the draft report, Evaluation Plan for AVL Implementations, prepared by the Volpe Center, was the evaluation framework.

The Denver evaluation plan discussed in detail the evaluation methodology, measures, data and analytic techniques to be employed. Specifically, the evaluation plan outlined all of the measures of effectiveness (MOE) and discussed the data necessary to develop such measures. This discussion included data collection approaches, sample size, timing and stratification where appropriate. The evaluation plan outlined the responsibilities of the different parties involved in the evaluation process. It also established a schedule and staffing plan. The plan discussed the data reduction and analysis techniques to be employed in the evaluation. In summary, the purpose of the evaluation plan was to establish the steps for conducting the evaluation, and to provide the framework for the final evaluation report.

An early version of the evaluation plan was developed in October, 1993. That version was based on the pre-implementation information provided by RTD. However, the implementation and acceptance of the AVL system took longer than originally anticipated. Additionally, the functions of the AVL system were not implemented simultaneously, but over the course of four years. Because of the delay and the staged implementation, several of the evaluation methods documented in the original evaluation plan were no longer applicable. They were amended with new evaluation plans that took the delays into consideration. The amended evaluation plan was updated in June of 1996, shortly after RTD's conditional acceptance of the AVL system.

The amended evaluation plan focused on the same goals and objectives as the initial evaluation plan. It implemented the evaluation and collected and analyzed the data in a modified way because of the three year delay in the system acceptance. This final report is based on the amended evaluation plan.

1.5 National Objectives

It was the intention of FTA to evaluate RTD's AVL system within the context of the national APTS program objectives. In 1994, four principal objectives of the APTS program were defined by FTA:

Objective #1 - Enhance quality of on-street service to customers

- improve the quality, timeliness and availability of customer information
- increase the convenience of fare payments within and between modes
- improve safety and security
- increase service reliability
- minimize passenger travel time
- enhance opportunities for customer feedback;

Objective #2 - Improve system productivity and job satisfaction

- improve schedule adherence and incident response
- improve the timeliness and accuracy of operating data for service planning and scheduling
- improve the response to vehicle and facility failures
- provide integrated information management systems and develop improved management practices
- reduce worker stress and increase job satisfaction;

Objective #3 - Enhance the contribution of public transportation systems to overall community goals

- facilitate the ability to provide discounted fares to special user groups (e.g., disabled or employees eligible for tax-free employer subsidies)
- improve communication with users having disabilities (e.g., visual or hearing impairments)
- improve the mobility of users with ambulatory disabilities
- increase the extent, scope and effectiveness of Transportation Demand Management programs
- increase the utilization of high occupancy vehicles; and

Objective #4 - expand the knowledge base of professionals concerned with APTS innovations

- conduct thorough evaluations of operational tests
- develop an effective information dissemination process
- showcase successful APTS innovations in model operational tests
- assist system design and integration.

The RTD AVL system operational test was to address the first two of the National APTS objectives.

1.6 Local Objectives

RTD had three specific objectives to achieve through the AVL deployment. They were:

Objective #1 - develop more efficient schedules
Objective #2 - improve ability of dispatchers to adjust on-street operations
Objective #3 - increase safety through better emergency management

1.7 APTS Objectives and the Evaluation

By examining the local and National APTS objectives, a correlation can be developed as shown in Table 1.2. Each of the national and local objectives is shown along with the measures to be used to evaluate the AVL system's effectiveness in achieving the objective. The table also indicates in which chapter the evaluation of each measure can be found.

APTS Objectives	Objective #1 - Enhance the quality of on-street service				Objective #2 - Improve system productivity and job satisfaction					
Project Objectives	**Improve the quality, timeliness and availability of customer information**	**Improve safety and security**	**Increase service reliability**	**Reduce passenger travel times**	**Reduce transit system costs**	**Improve schedule adherence and incident management**	**Improve the timeliness and accuracy of operating data for service planning and scheduling**	**Improve the response to vehicle and facility failures**	**Provide integrated information management systems and develop improved management practices**	**Reduce worker stress and increase job satisfaction**
Research efficiency of scheduling	Ch. 4 Functional Characteristics • Vehicle position determination Ch. 6 Transit System Efficiency • Pre-trip passenger information		Ch. 6 Transit System Efficiency • transit vehicle performance Ch. 7 Transit System Effectiveness • Travel time • Schedule adherence	Ch. 6 Transit System Efficiency • transit vehicle performance Ch. 6 Transit System Efficiency • Travel time	Ch. 6 Transit System Efficiency • transit system costs Ch. 7 Transit System Effectiveness • Revenue generation • Change in productivity	Ch. 4 Functional Characteristics • AVL equipment reliability • Data transmission reliability Ch. 6 Transit System Efficiency • transit vehicle performance Ch. 7 Transit System Effectiveness • Schedule adherence	Ch. 4 Functional Characteristics • Vehicle position determination Ch. 5 Acceptance and Perception • Employee perception of report generation functions		Ch. 5 Acceptance and Perception • Employee perception of report generation functions	Ch. 5 Acceptance and Perception • Employee acceptance of system
Research dispatchers ability to adjust on-street operations	Ch. 4 Functional Characteristics • Vehicle position determination		Ch. 4 Functional Characteristics • Vehicle position determination Ch. 5 Acceptance and Perception • employee perception of service Additional Impacts • Driver/dispatcher interaction • Control room interfaces	Ch. 4 Functional Characteristics • Impacts on emergencies		Ch. 4 Functional Characteristics • Vehicle position determination • Impacts on emergencies		Ch. 4 Functional Characteristics • Impacts on emergencies Ch. 5 Acceptance and Perception • Employee acceptance of system		Ch. 4 Functional Characteristics • Utility of AVL system Additional Impacts • Roles of employees
Research emergency management and emergency response	Ch. 4 Functional Characteristics • Vehicle position determination	Ch. 4 Functional Characteristics • Impacts on emergencies Ch. 5 Acceptance and Perception • employee perception of safety Ch. 7 Transit System Effectiveness • Safety and security Ch. 7 Transit System Effectiveness • Number of emergencies • frequency of incidents				Ch. 4 Functional Characteristics • Impacts on emergencies		Ch. 4 Functional Characteristics • Impacts on emergencies		Ch. 5 Acceptance and Perception • Employee perception of safety
Additional Measures		Ch. 7 Transit System Effectiveness • losses due to theft • Injury distribution due to crime or crashes	Additional Impacts • Roles of maintenance personnel		Ch. 7 Transit System Effectiveness • Change in number of passengers • Revenue per UPT, passenger mile and vehicle trip Additional Impacts • Training Costs					Additional Impacts • System interfaces • Amount and type of training by employee group

Table 1.2 APTS objectives and evaluation

2. AVL SYSTEM OVERVIEW

2.1 Introduction

There are four elements to the RTD AVL system (Figure 2.1). These elements include the following:

- the communications system;
- the GPS satellites;
- the in-vehicle equipment; and
- the dispatch center.

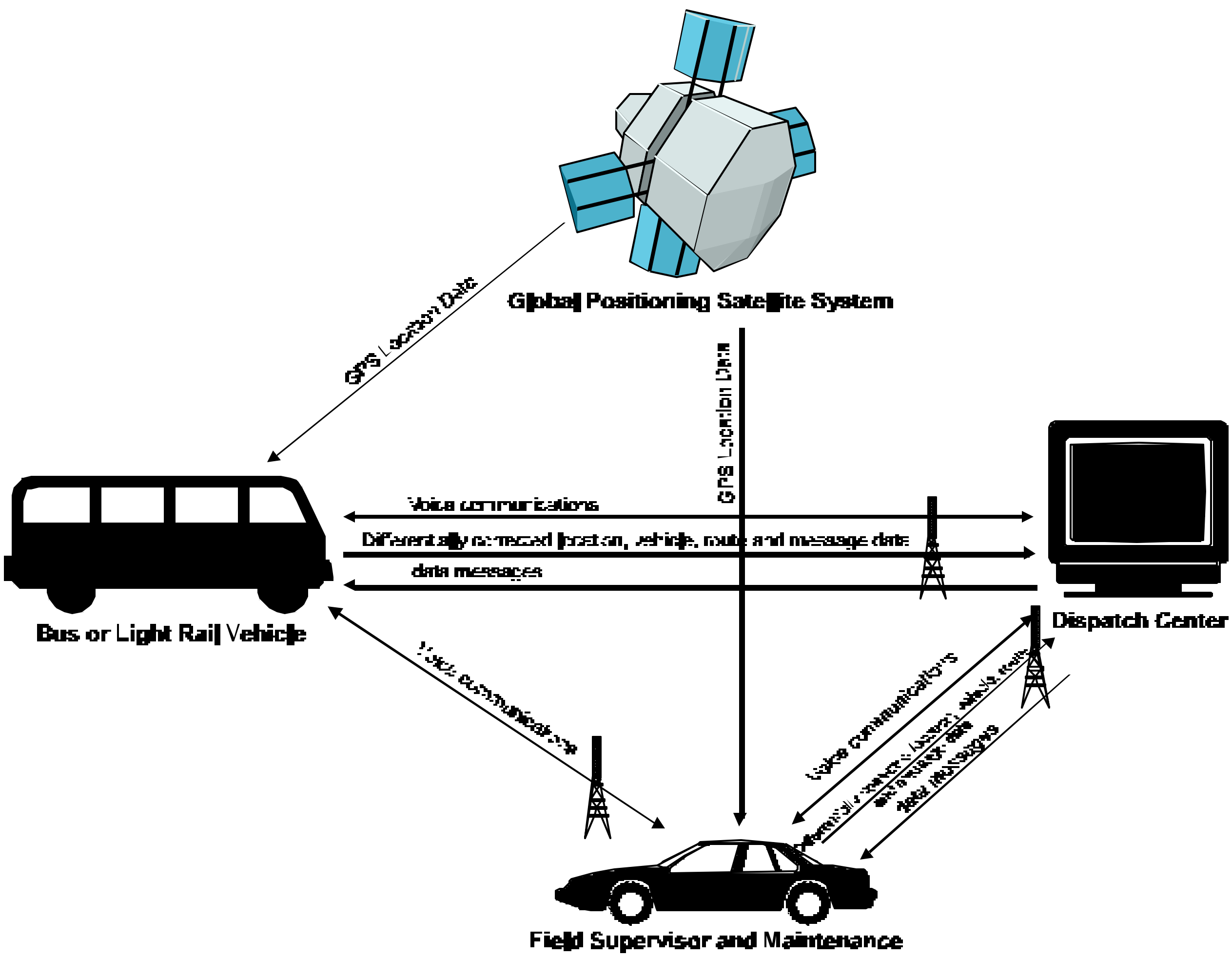

Figure 2.1 Conceptual drawing of AVL system

2.2 Communications

The communications portion of the RTD AVL system consists of nine microwave channels in the 450 MHZ range. Seven channels are used for fixed-end voice dispatch communications and two are for data transmission. There are three fixed-end repeater stations in the Denver Metropolitan area. RTD owns the microwave channels and all of the equipment used for transmission over them.

At the time of the AVL system installation, a new radio system was also installed. To understand the impact of this change requires a brief review of the previous radio system. Before the AVL system was installed, two voice channels and no data channels were used by RTD. During busier times, one dispatcher was dedicated to each channel, and the vehicle fleet was split evenly between them. Each channel worked similar to a party line where any vehicle operator could pick up a handset and listen, join ongoing discussions, or state his or her need at any moment. If operators had to contact dispatch, they picked up their handsets and listened to see if anyone was already talking. If nobody was, operators announced their names, routes, and locations, and then stated the issues they needed to discuss.

In cases of emergencies or high priorities, an operator could break into ongoing conversations and announce the emergency. A dispatcher then assessed the priority of the emergency and either addressed it immediately or told the operator to wait. Each of the two dispatchers had to prioritize all incoming requests, a task that could be daunting during peak-hours of especially heavy times, such as snow days or during road closures.

Since AVL implementation, five channels are dynamically assigned to dispatcher-operator pairings, two channels are for data communications, and two channels are dedicated to maintenance and supervisor communications. Operators no longer pick up the handset and announce their situations. Instead, they press a button on their Transit Control Heads (TCH) to indicate they would like to speak with a dispatcher. The button pressed shows the urgency of the call, and the dispatchers respond in order of urgency and time of request. Dispatchers now control when the operators will speak with them. Any conversation can be carried by any of the five voice channels, and the system automatically assigns the first that is open, eliminating potential overloading for a single channel or dispatcher. The operators still state their names, routes and locations when they speak to dispatchers, but this information has already appeared on the dispatchers' screens, and the restating of it serves as verification.

With five channels and dynamic channel assignment, RTD has been able to increase the number of dispatchers on duty from two to five during the busiest times. Previously, operators would often have to wait up to 45 minutes before the dispatchers would be able to respond to them. Since AVL implementation, the longest operators will wait is usually around 15 minutes.

The old system had a silent alarm which triangulated a vehicle's position in relation to the microwave radio channels. This system was inaccurate and unreliable and was rarely used by RTD. The AVL system also has a silent alarm. An operator can discreetly trigger the alarm and dispatchers can open a hidden microphone that captures any sounds from the bus and transmits them back to the dispatch center. Silent alarms have the highest priority in the dispatch center and override any other incoming calls to any particular station.

Street supervisors are able to speak directly to the dispatchers and operators through their in-vehicle equipment. They may directly contact operators, and dispatchers may put them in contact with operators. They also are able to send and receive location and vehicle data through their Mobile Data Terminals (MDT).

2.3 Vehicle Location using GPS Satellites

GPS receivers use satellite triangulation to determine their position within a reasonable amount of error. To triangulate position, a GPS receiver measures its distance from at a minimum three geosynchronous orbiting satellites. This is done by using the travel time of a radio signal broadcast from the satellites. However, there are inaccuracies in the signal partially due to signals being reflected by the atmosphere and partially intentional on behalf of the Department of Defense. To correct for this error, an additional differential signal is used to provide a correction. As a result of the combination, many GPS receivers are accurate to within a few meters.

Each vehicle in the RTD fleet is equipped with an Intelligent Vehicle Logic Unit (IVLU) which is manufactured by Trimble Navigation. Each vehicle has an antenna mounted on it for receiving GPS signals and the differential correction signals. Based on the satellite signals received, an onboard computer determines the location of the antenna (and vehicle).

Urban canyons or other obstructions prevent the antenna from "seeing" enough satellites to accurately calculate a location. The AVL system then "dead-reckons" the vehicle locations. During dead-reckoning, the system recalls the last known GPS location, then uses compass direction and odometer readings to determine the vehicle's current location.

In addition to the GPS and dead-reckoning, the AVL system can "snap" a vehicle to its known route. The server in the dispatch center has a record of the route of each bus. GPS and dead-reckoning location estimates do not always fall directly on the route. When the GPS-determined location is not on route, and the vehicle is within an acceptable buffer distance from its actual route, the system recalculates the vehicle coordinates to coincide with the route.

2.4 In-vehicle Equipment

The in-vehicle equipment has two interactive components used by the vehicle operators. The TCH and silent alarm are connected to the In-Vehicle Logic Unit (IVLU) which controls communications and vehicle location determination from the vehicle. Besides the interactive pieces, there are the radio and GPS antennas, and the IVLU power source.

2.4.1 Transit Control Head

The TCH (Figure 2.2) is mounted beside the vehicle operator. It is a small black box with a Liquid Crystal Display (LCD) screen and a series of buttons that the operator uses to send data communications to the dispatch center. All data communication between the operator and dispatch is sent through the TCH to the IVLU.

Figure 2.2 Transit Control Head

The LCD screen can display the following information:

- the time of day;
- the amount of time that the vehicle is ahead or behind schedule;
- acknowledgment that requests or messages to dispatch were received; and
- text messages from the dispatch center.

Text messages from dispatch can be specific to a single bus as selected by a dispatcher, or they can be messages sent to the entire fleet or subset of buses.

The options that the operator has for requesting communication or sending information to the dispatch center through the TCH are:

- RTT - Request to Talk is used by operators when they have a reason for wanting to speak to a dispatcher that is not urgent. This may include asking for road condition information, inquiring about a fare dispute, to let dispatch know that a personal possession has been accidentally left on the vehicle, or other issues of similar urgency. RTT is not used for issues that should be addressed immediately.

- PRTT - Priority Request to Talk is used by operators for urgent matters, such as a fight on the bus, a sick passenger, if the bus is in an accident or any other matter that should be addressed immediately. The operators are instructed to use this only during emergencies and not just to have their requests receive higher priority from dispatchers.

- MECH IN - A vehicle has a mechanical problem, but the vehicle is operational and can continue to service passengers. A MECH IN type problem may be a poorly working windshield wiper, a loose engine flap or anything else that currently does not warrant stopping service, but may if it worsens.

- MECH OUT - A vehicle has a mechanical problem that prohibits it from continuing service. This may be a flat tire, a stalled engine or anything else that debilitates the vehicle.

- STUC - The operator uses this to indicate that the vehicle is immovable. This may be because of snow, or that it is boxed between other vehicles.

- FR DISP - The vehicle operator can request a call to dispatch and indicate that it is due to a fare dispute with a passenger by using this button. Fare disputes usually rise when in-service vehicles charge different fees based on trip length, or because prices change throughout the day.

- LIFT OUT - The lift used to raise wheelchairs onto the bus is not working. This does not necessarily prevent a vehicle from serving customers, but may if the operator or dispatcher know a handicapped customer will likely be using that service in the near future.

- NO RLF - The vehicle operator can use this preset message to inform the dispatchers that the person who is supposed to relieve him or her has not arrived. Dispatchers can use this information to track down the relief individual, or determine what action to take to insure that the vehicle remains on route and schedule.

With each of the preceding messages, the dispatchers receive the message and the vehicle's location. The dispatcher can determine the priority of the request by seeing the request type. Occasionally, the dispatcher can dispatch the appropriate response to the location without having to speak to the operator.

2.4.2 Mobile Data Terminal

The MDT is a modified Intel 486 processor laptop computer and allows for a larger number of data communications functions than the TCH. Later models of the MDT can use the latest available laptop technology, including Intel Pentium or equivalent processors. It is only used by street supervisors. Using it, a supervisor can query a vehicle's location and schedule adherence information by accessing the central processor at the dispatch center. The MDT can receive and transmit data to the dispatch center. It displays information sent by dispatch, such as incidents or issues to be addressed, text descriptions of vehicle locations, and text messages.

The MDT is used for many tasks that the street supervisors previously had to do manually, including, but not limited to, accident reports, traffic reports, and operator violation reports. The paper report forms are automated and the street supervisor can enter information directly into the computer. These can later be downloaded into the AVL system databases.

2.5 Dispatch Center

Three dispatch centers have a total of seven dispatch consoles. There are five at the RTD operations center in Denver, one in Boulder, and one dedicated to light rail vehicles. Each dispatch console has three monitors that the dispatcher must watch. One is for tracking vehicles and AVL system related information, one is for computer-aided dispatch (CAD) radio functions, and the third displays information from the schedule databases. The third monitor is held over from the previous scheduling system (Figure 2.3) , and is redundant of an AVL function. However, some dispatchers prefer to use the old display because they perceive it to be easier to use than the similar feature provided by the AVL.

Figure 2.3 SATURN, the previous scheduling database, still used by some dispatchers

The AVL equipment is primarily based at the RTD operations center in Denver. It includes the dispatch workstations, a host computer, back-up host, the CAD workstations and other components needed for communications and vehicle tracking. The equipment is connected through a Local Area Network (LAN). The host, which is a Hewlett-Packard 9000 series server, controls the system and handles communications and vehicle monitoring.

Previously, the dispatchers had two text-only screens. The one that displayed schedule databases is still used. The other was for computer-aided dispatch and entering report records. The dispatchers could not select the order in which they responded to calls, and they had to prioritize calls based on what the operators told them. A vehicle's location was only known once the operator described it. The dispatchers could not observe any vehicle's schedule adherence or its whereabouts without communicating with the operator. Reports of each request were written on paper and the times of the initial call and the resolution were documented by the dispatcher. The report records were transferred to a database by dispatchers when they had time to do so.

On the current CAD display screen, the dispatcher has control over several windows of information. These include a list of the pending operator requests to talk. The order that these appear on each dispatcher's screen can be prioritized by the lead dispatcher. The dispatcher can then select which to respond to, which does not necessarily correspond to the order in which they are received or prioritized.

On the vehicle tracking screen (Figure 2.4), the dispatchers can observe the location of any vehicle at any time by selecting its route. The screen shows the vehicle location and the names of the surrounding streets. Color- and icon-coding indicate whether the bus is ahead or behind schedule and whether it is off-route. The reports that were previously recorded by hand and later entered into the database can now be automatically recorded by the AVL system.

Figure 2.4 Vehicle tracking screen for AVL

Dispatchers can simultaneously send a text message to operators on all routes, a selected set of routes, or a single route. These can come from a set of "canned" or routine messages, or can contain information entered in by the dispatcher. Additionally, dispatchers can initiate voice conversations with any operator.

With the AVL, the role of dispatchers has expanded. They are now more responsible for insuring that vehicles run on-time, that vehicles meet at transfer points, that mechanical problems with vehicles in service are resolved more quickly, and the safety of operators and passengers.

2.6 AVL Functions

The AVL system has been added at RTD to provide additional functions to the District's operations and maintenance as well as to enhance the existing functions. The objectives of the system for RTD are to improve customer service, reduce costs through better central control of vehicles, and improve safety and emergency response. This section describes the primary functions of the system and how they are used by RTD.

2.6.1 Vehicle Tracking

In addition to alerting dispatchers of off-schedule vehicles, the AVL system can identify when vehicles are on- and off-route. By checking the GPS determined location of vehicles relative to the path of their route, the system can alert dispatchers to off-route vehicles. A threshold can be set that determines how far off course a vehicle may go before dispatchers are notified. This function may be used for such activities as alerting new operators they have made a mistake, or monitoring operators taking shortcuts to make up time.

2.6.2 Automated Recording and Archiving

The AVL system has automated many old paper-based functions. Previously, dispatchers and street supervisors had to document each call on paper and later enter it into a computer. The new system allows the dispatcher to generate incident records in real-time. Also, street supervisors are able to file their reports electronically. All records that are entered into the AVL system are archived for future reference.

The databases that store documented incidents are much more efficient than the previous paper-based archives. Searches for particular incidents or individual records for drivers or vehicles can be done much more thoroughly and quickly than before.

2.6.3 Messaging

Dispatchers can send text messages to a single vehicle, a selected set of vehicles, or the entire fleet. These messages can be an efficient way to provide information to operators or alerting them to conditions that affect their service. Operators can now specify the priority of the message or question they have by selecting the preset buttons on the TCHs. Operators with high priority issues can now receive quicker responses because dispatchers respond in order of the priority indicated by the operators (Silent Alarm, PRTT, RTT, etc.).

2.6.4 Playback

The AVL system records the location and time information for each on-road vehicle every thirty seconds. The "playback" function gives dispatchers the ability to retrieve the records for any particular vehicle and track its progress to see if it went off-route, was significantly ahead of or behind schedule, or stopped in any location for a long period. RTD has been able to use this system to investigate complaints by customers, identify schedules that cause unnecessarily long layovers for operators, and schedules that provide either too much or too little time between stops.

2.6.5 Reporting

The AVL system can produce reports on a specific vehicle, operator, route, area, route type, or system wide data that has been collected. This report information includes, but is not limited to, the following:

- schedule adherence performance;
- operator performance;
- summaries of operators' requests;
- resolution of operators' requests;
- travel distances; and
- vehicle and operator time in operation.

These reports can be printed out or written to files.

2.6.6 Schedule Adherence

Each vehicle reports its GPS determined location to the AVL system every thirty seconds. This information is related to a database at the dispatch center which indicates where each vehicle should be at that moment. Based on the position of the vehicle in comparison with where it is scheduled to be, the AVL system calculates the amount of time each vehicle is ahead of or behind schedule.

During the evaluation period, the schedule adherence function was not fully employed by RTD. If the schedule adherence function were working properly, the time ahead of or behind schedule in minutes would be displayed on each vehicle's TCH. Additionally, the dispatch center would be able to set thresholds on their displays, and dispatchers would be alerted to any vehicles ahead of or behind schedule by an amount greater than the threshold.

TRAPEZE, a dispatch software package, is used by the RTD scheduling department to generate route schedules. The AVL system does not directly feed route information to the TRAPEZE software. Instead of using AVL data, the scheduling department sends "riders" out to ride each of the routes several times each year. These riders record the time it takes the buses to reach their stops. This information is used by the TRAPEZE scheduling system. Because this process collects only a limited amount of time data for each route, the resulting schedules often do not match running times for all time periods.

The AVL system continuously collects route-time information. It collects a much wider and more complete sample for use in setting route schedules than "riders" do. Ideally, the AVL system will report times and compare them to the fixed route schedule to determine how far ahead of or behind schedule a vehicle is. However, the routes defined in TRAPEZE are not identical to those in the AVL system. The TRAPEZE routes are coded by the scheduling department, which often uses shortcuts in coding that directly go from route stop to route stop without regard to the street network. When the AVL time data is compared with the schedules, the differences in the two route systems causes inaccurate and unreliable schedule adherence reports. Because there is not enough staffing to keep up with route and schedule changes, the scheduling department is not actively trying to keep their TRAPEZE routes consistent with the AVL system.

Unfortunately, many aspects of the evaluation are dependent on the schedule adherence function being fully operational.

2.6.7 Silent Alarm

The AVL system added the silent alarm to vehicles. This device can be triggered discreetly by the operator. It alerts the dispatch center of a potentially life-threatening situation on-board the signaling vehicle. A silent alarm takes precedence over all other calls at the dispatch center and the requesting vehicle's location is automatically displayed on a dispatcher's screen. A hidden microphone can be turned on by dispatchers so they can hear any activity on the bus without detection.

2.6.8 Public Information Display Systems (PIDS)

The two main transit centers in the RTD coverage area are the Market Street and Civic Center Stations. The AVL system should interface with signboards in both locations in order to display real-time vehicle arrival and departure times. This display would be similar to the arrival and departure signs commonly found in airports. This is a highly beneficial feature, particularly during times of inclement weather when buses can run late or are canceled.

There have been integration problems that have prevented the PIDS from being deployed. RTD has withheld part of the initial system budget in order to contract with another firm to make the signboards operational.

2.6.9 Mall Operations

The 16th Street Mall in the Central Business District is home to retail shopping, apartments and professional offices. RTD provides a free shuttle on the mall which is funded by a Merchant Tax. The mall is not open to other motor vehicles. Because of the frequent loading and unloading and the high frequency of the shuttles on this short route, vehicles become bunched. Before AVL implementation, manual starters were stationed at each end of the mall, signaling vehicles when to leave the stations. Now, the manual starters have been replaced by AVL monitors, and a single supervisor at one end of the mall performs the function of the two starters.

3. SYSTEM COSTS

3.1 Introduction

This section documents the various costs of the Denver AVL system. It includes all quantifiable costs directly related to the deployment of the AVL, and the ongoing costs associated with its continuing operation. Fixed costs related to system implementation include equipment, software, training, documentation and any other miscellaneous one-time costs. Ongoing costs include those related to ongoing operation and maintenance in terms of both dollars and RTD resources.

Unit costs for components are calculated as the average cost per unit based on the total price for all units. It does not reflect the actual current price per unit.

3.2 Summary of Findings

The fixed costs associated with AVL system implementation totaled $10,400,000 as summarized in Table 3.1. The $10,400,000 represents the total amount paid to the contractor through the completion of the contract in 1998. This included all radio and computer hardware, software, initial support, training materials and documentation.

Fixed Cost Element	Cost
System Software	$1,394,635
Dispatch Center Hardware	$1,247,866
In-vehicle Hardware	$5,231,814
Field Communication Hardware	$1,451,940
Initial Training	$148,622
Planning and Implementation	$852,672
Other Costs	$72,451
TOTAL	**$10,400,000**

Table 3.1 Total fixed costs

The ongoing costs were not determined until 1996, because RTD did not make final acceptance and assume the maintenance and operation costs until March of that year. Ongoing costs for operation and maintenance of the AVL system found in Table 3.2 are listed for 1997. Operations costs include the salaries of dispatchers at all three dispatch locations (Metro, Boulder, Light rail), as well as maintaining the equipment and the workplace for the dispatchers.

Ongoing Cost Element	**Cost** (for 1997)
Maintenance	$174,223
Operations	$1,723,404
TOTAL	**$1,897,627**

Table 3.2 Ongoing costs for 1997

Maintenance costs include the salary of the AVL system manager and contracts with Hewlett- Packard and TMS for the maintenance of the hardware which serves both the bus and light rail systems.

The maintenance and operation total of $1,897,627 represent approximately 1.5% of the total 1997 RTD operations budget of $129,411,000.

3.3 Fixed Costs

The fixed cost of the AVL system includes all items that were directly related to the implementation of the AVL system. It does not include expansion of the system to include more hardware and software that was not part of the initial installation. Those items are included in the ongoing costs.

A breakdown of the seven elements to the fixed costs are shown in the following sections.

3.3.1 System Software Cost

The software development required for the AVL system included the base console operation software, data interface software, and the modifications required to meet the needs of RTD. The software costs, in development and installation costs are shown in Table 3.3.

Software Description	**Quantity**	**Unit Cost**	**Extended Cost**	**Install Cost**	**Total Cost**
Application Software	1	$179,214	$179,214	$0	$179,214
PRIME Interface	1	$47,268	$47,268	$24,842	$72,109
Test/Acceptance/Engineer	Lump Sum	$11,481	$11,481	$1,131,830	$1,143,311
TOTAL			**$237,963**	**$1,156,672**	**$1,394,635**

Table 3.3 System software cost

3.3.2 Dispatch Center Hardware

The dispatch center hardware at all three centers for the Denver AVL system includes radio communications hardware, radio/data computers and the AVL consoles at which the dispatchers can track the field vehicles. Table 3.4 details the components and costs.

Hardware Description	Quantity	Unit Cost	Extended Cost	Install Cost	Total Cost
Console electronics	1	$29,670	$29,670	$7,958	$37,628
Supervisor Position	1	$69,185	$69,185	$7,785	$76,970
Console Position	6	$71,278	$427,666	$40,953	$468,619
Radio/Data Computer	1	$339,484	$339,484	$94,645	$434,129
CAD Terminals	10	$2,732	$27,318	$66,154	$93,472
Logging Recorder	1	$77,757	$77,757	$0	$77,757
Electrical Backup (UPS)	2	$29,646	$59,291	$0	$59,291
TOTAL			**$1,030,371**	**$217,495**	**$1,247,866**

Table 3.4 Dispatch hardware cost

3.3.3 In-Vehicle Hardware

In-vehicle hardware includes everything on the inside and outside of the equipped vehicle that is required for it to send and receive data and voice communications. In short, it is all components that keep the vehicle active within the AVL system. This includes the IVLU, TCH, odometer readers and antennas. It also includes the AVL equipment used by field supervisors and maintenance, such as MDTs. Table 3.5 details the components and costs of the in-vehicle hardware.

3.3.4 Field Communication Hardware

Field communication hardware includes all devices that are neither vehicle or dispatch center based, but which are necessary for vehicle to dispatch and field service communications. This includes microwave radio transmitters and antennas. Table 3.6 lists the field communication hardware components and their prices.

3.3.5 Planning and implementation cost

Planning and implementation includes any charges to the preparation or actual deployment of the AVL system. They include the cost of overseeing the implementation and any costs incurred during the planning stage. There were no direct costs from RTD as all labor came from existing staffing. Table 3.7 indicates all cash outlays in planning and implementation.

Hardware Description	Quantity	Unit Cost	Extended Cost	Install Cost	Total Cost
Supervisor radio and mobile power source	98	$1,878	$184,050	$41,816	$225,866
Supervisor MDTs	30	$3,653	$109,585	$0	$109,585
Bus mobile radio and power source	832	$1,545	$1,285,174	$476,292	$1,761,466
GPS/IVLU/TCH	865	$3,517	$3,042,276	$0	$3,042,276
Portable radio	80	$851	$68,101	$66,154	$93,472
Single unit charger	50	$81	$4,032	$0	$4,032
Six unit charger	16	$478	$7,652	$0	$7,652
Electrical Backup (UPS)	2	$29,646	$59,291	$0	$59,291
Mobile port charger	30	$168	$5,040	$0	$5,040
Spare battery	30	$68	$2,050	$0	$2,050
Speaker/Mike Assembly	30	$57	$1,714	$0	$1,714
TOTAL			**$4,709,674**	**$522,140**	**$5,231,814**

Table 3.5 In-vehicle hardware cost

3.3.6 Other Costs

During implementation, the AVL system was integrated with the electronic display boards in the downtown Denver stations. Through these signs, the integrated system should be able report the actual departure time of routes. The cost of the integration of this sign is shown in Table 3.8.

It should be noted that the Station Signboard Interface has not functioned properly and the fee assigned to it is being withheld by RTD. They intend to use the funds to contract with another contractor to get the signboards operational.

3.3.7 Additional Information Technology Hardware

In addition to the hardware directly related to the implementation of the AVL system, the Information Technology (IT) department of RTD was required to upgrade their computer system. Before the AVL system, they used a VAX mainframe for storing and retrieving data. As part of the AVL implementation, they upgraded to a Digital Alpha workstation system. This interfaces directly with the UNIX-based Hewlett-Packard workstations used for the AVL dispatching and management.

Hardware Description	Quantity	Unit Cost	Extended Cost	Install Cost	Total Cost
UHF repeater	27	$6,877	$185,674	$109,698	$295,372
200' 7/8" Tx line	26	$6,493	$168,822	$66,840	$235,662
Voting comparator	6	$5,399	$32,394	$0	$32,394
Multicoupler/combiner	6	$0	$0	$184,815	$184,815
Microwave terminal	8	$49,060	$392,480	$36,403	$428,883
Microwave antenna	8	$5,673	$45,387	$17,053	$62,440
Battery/charger	6	$7,039	$42,236	$5,376	$47,613
Digital mux	6	$1,886	$11,313	$4,536	$15,849
Digital channel bank	12	$5,192	$62,304	$0	$62,304
Microwave service channel	6	$2,128	$12,769	$0	$12,769
Microwave alarm master	1	$14,561	$14,561	$0	$14,561
Microwave alarm remote	6	$1,993	$11,957	$3,024	$14,981
7.5 dB antenna with line	4	$3,941	$23,765	$3,560	$27,325
Desktop base station	4	$4,243	$16,972	$0	$16,972
TOTAL			**$1,020,634**	**$431,305**	**$1,451,940**

Table 3.6 Field communications hardware

Planning and Implementation Description	Quantity	Unit Cost	Extended Cost	Install Cost	Total Cost
Program Management	Lump Sum		$11,985	$840,687	$852,672
TOTAL			**$11,985**	**$840,687**	**$852,672**

Table 3.7 Planning and implementation costs

Other Costs	Quantity	Unit Cost	Extended Cost	Install Cost	Total Cost
Station signboard interface	Lump Sum	$0	$0	$72,451	$72,451
TOTAL			**$0**	**$72,451**	**$72,451**

Table 3.8 Other costs

Additionally, the IT department upgraded its data retrieval and reporting software. This allowed them to create reports and analyze the AVL data. The cost of these upgrades were in addition to the AVL costs, but were not provided by RTD.

3.4 Ongoing Costs

The ongoing costs of the AVL system include all maintenance and operating costs, both in equipment and salaries. Until 1996, the costs of maintaining the AVL system were absorbed by Westinghouse/TMS because the equipment had not yet been accepted by RTD. Upon conditional acceptance in 1996, a one year warranty period went into affect. The costs detailed here are broken into operating and maintenance, with a description of what each involves.

3.4.1 Maintenance Costs

Maintenance costs of the AVL system do not include the maintenance of the IVLUs or TCHs. RTD includes these costs in their radio equipment maintenance, and does not specifically track costs for AVL system components. However, it is estimated that maintenance of the in-vehicle radios and equipment requires the full time equivalent of approximately one person. The costs are included in the total radio maintenance costs, with no specific data for the IVLU costs.

The costs shown are for 1997, which was the first full year after system acceptance (Table 3.9). They reflect realistic expectations because the system was stable and operating at the level RTD expected. Maintenance costs include the cost of maintaining all AVL equipment **not** in the vehicle, including, but not limited to, the following:

- AVL manager salary and costs;
- central processor maintenance (hardware maintenance contracted through Hewlett-Packard);
- six dispatch stations maintenance (hardware maintenance contracted through Hewlett-Packard);
- wireline communications and microwave towers maintenance;
- AVL manager station maintenance;
- software maintenance (contracted through TMS); and
- peripherals (back-up equipment, hard drives, printers, etc.) maintenance.

AVL Element	Cost
Staffing and general maintenance	$116,459
Hardware maintenance (monitors, processors, peripherals, etc.)	$22,764

Software maintenance	$35,000
Total	**$174,223**

Table 3.9 AVL maintenance costs for 1997

The hardware maintenance is a contract with Hewlett-Packard to maintain the workstations originally built by them. The software maintenance is a contract with TMS to maintain and upgrade software, and to resolve any software problems. Both contracts are on-site, on-call agreements that cover one-year.

3.4.2 Operation Costs

The operation of the AVL system does not add cost to on-the-road operations. There are no additional requirements or costs for the vehicle operators because the system has been rolled into their existing duties and are performed in the same time. Additionally, the TCH does not does not permanently store data or require any special servicing outside of maintenance. The AVL operation costs shown in Table 3.10 reflect the costs of the following components:

- communication system, including microwave towers;
- power use by AVL system and communication towers;
- supplies such as paper, floppy disks, etc.; and
- salary and benefits for 25 to 30 full- and part-time dispatchers.

AVL Element	Cost
Operations (1997)	$1,723,404
Total	**$1,723,404**

Table 3.10 Operations costs for 1997

RTD was unable to provide the costs for dispatcher operations prior to AVL implementation. Because of this, no comparison can be made between the costs of dispatch operations before and after the AVL system was implemented. However, RTD currently employs between 25 and 30 full and part-time dispatchers. Prior to AVL implementation, there were between ten and 15.

It should be noted that the AVL system resulted in some reorganization in the maintenance department. Prior to the AVL system, the maintenance department had a Supervisor position who oversaw the electronic repair shop. The supervisor reported to the District Shops Manager, who reported to the General Superintendent of Maintenance. That maintenance Supervisor position was upgraded to a Manager position. This Manager now has the responsibility of overseeing the AVL system and the electronic repair shop. The position reports directly to the General Superintendent of Maintenance.

4. AVL FUNCTIONAL CHARACTERISTICS

4.1 Introduction

RTD's AVL system was designed to enable the continuous monitoring and control of vehicle fleets. This would improve schedule adherence, vehicle spacing and vehicle usage efficiency. The AVL system identifies the location of each AVL-equipped vehicle and can show its location on the dispatch screens. In Denver, a silent alarm function was added to help improve responsiveness to emergencies.

4.2 Summary of Findings

Accurate vehicle location is essential for improving safety and security as well as incident response times because supervisors, dispatchers and emergency response teams can quickly find the vehicle and operator requesting assistance. It also improves service reliability and schedule adherence by allowing the dispatch center to accurately track vehicles and alert operators to their status in relation to the route schedule. Finally, through better schedule adherence, traveler passenger times can be reduced by ensuring that transfer connections are made. The AVL system proved to be highly accurate at determining positions. In 304 tests of the system by RTD, the system was within the acceptable threshold 292 times. The thresholds ranged from 100 to 300 feet, depending on the location of the test. These results are detailed in Table 4.1. This is a success rate of more than 96%.

AVL equipment reliability has improved significantly since the system's implementation. Between 1995 and 1998, the number of needed radio repairs decreased more than 15%, with the number of repairs in 1996 and 1997 almost 40% below the 1995 levels. Repairs were often needed as a result of environmental factors, such as rain or lightning damage to AVL equipment. Other areas requiring frequent repairs were the AVL's in-vehicle electrical systems, and the equipment used to measure vehicle odometer readings.

During the same period, RTD experienced a 39% decrease in repeat radio repairs and a 23% decrease in lost service hours due, in part due to improved radio reliability. Preventive maintenance on all fleet-vehicle AVL equipment is conducted semi-annually and requires almost one Full Time Employee to complete. This is included in RTD's radio maintenance budget. The decrease in service delays that resulted from higher system reliability meant improved service to customers because more vehicles were available for service. The primary effect of a more reliable system, however, was that it was available to perform its functions and improve on-street service, productivity and job satisfaction.

The data transmission reliability of the AVL system was documented by the Sandia National Laboratory. They noted that the system almost always transmitted messages from vehicle to dispatch center within one second. The specification for suitable transmission times was less than three seconds.

Sandia Labs noticed a pair of anomalies in the data transmission. One was that the messages were logged as having been received at the dispatch center prior to the time they were sent from the vehicle. The other was that messages were received at the CAD, but not documented as being sent by the IVLU. This was because IVLU acknowledgment is a low priority for the on-board processor and is often not performed when the processor is undertaking other tasks. In general, the results of the Sandia tests confirmed the suitability of GPS for determining vehicle locations in a large urban fleet. Their tests also confirmed that the dead-reckoning feature of the RTD AVL system was necessary for the times when GPS data could not be collected.

The AVL system's impact on emergency response was measured qualitatively and in terms of how the silent alarm function is used. There are several instances on record of criminal activity on buses being thwarted because of quick response time. Additionally, as is documented in Chapter 7, the number of passenger and operator assaults decreased significantly from 1992 to 1997.

Misuse of the silent alarm is a continuing problem. Additional training is constantly performed by RTD, and the operations department indicated that the number of silent alarm misuses has decreased as a result. However, operators cited that the on-board location of the emergency button makes it easy to accidentally bump.

4.3 Vehicle Position Determination

The Sandia National Laboratory was responsible for testing the technical performance of the AVL system, and for documenting the position location accuracy of the system. The results were documented in Performance Assessment of the RTD Automatic Vehicle Location (AVL) System, and are summarized here. Tests were conducted during August, 1995 and June, 1996. Twenty-two points in the Denver metro area were surveyed by licensed land surveyors Merrick and Co. The survey included measuring the locations of the 22 points from known benchmarks.

During the AVL system testing, position data was logged at each surveyed test point for at least eight minutes so that a minimum of three standard position reports could be recorded. Position accuracy results were obtained by comparing the position reported from an RTD supervisor's test vehicle to coordinates obtained from the professional surveyor. The test vehicle was parked over the surveyed test point so that the GPS antenna was aligned directly above the survey mark. This alignment was done visually, but care was taken during the process so that the alignment procedure could not be expected to introduce uncertainties of more than one or two feet. The supervisor's vehicle logged navigation data and communications at one second intervals.

RTD specified acceptable thresholds for positions errors under four geographical conditions. The acceptable errors were:

- within 100 feet of the actual location along the 16th Street Shuttle route;
- within 200 feet in the downtown and dense suburban areas;
- within 200 feet for all supervisor vehicles at all times; and
- within 300 feet in the suburban and rural areas.

For each accuracy level, a series of tests were performed and the results are shown in Table 4.1.

Area	Point Number	Accuracy Required	Maximum Error	Average Error
16th St.	101	100 ft	188.0 ft	78.7 ft
Downtown	102	200 ft	84.9 ft	84.9 ft
16th St.	103	100 ft	227.3 ft	158.9 ft
Downtown	104	200 ft	398.1 ft	89.8 ft
	105	200 ft	99.5 ft	75.7 ft
	106	200 ft	200.1 ft	117.8 ft
16th St.	107	100 ft	46.8 ft	28.5 ft
	108	100 ft	44.9 ft	30.3 ft
	109	100 ft	243.0 ft	177.5 ft
Downtown	110	200 ft	251.4 ft	171.0 ft
Suburbs	111	330 ft *	48.2 ft	47.8 ft
	112	330 ft *	297.8 ft	160.0 ft
Golden	113	330 ft *	50.4 ft	30.1 ft
	114	330 ft *	159.0 ft	82.4 ft
	115	330 ft *	544.0 ft	162.4 ft
Suburbs	116	330 ft *	229.8 ft	33.5 ft
Boulder	117	230 ft *	60.1 ft	44.8 ft
	118	230 ft *	84.5 ft	70.7 ft
	119 **	300 ft	145.8 ft	22.9 ft
	120	330 ft *	53.8 ft	49.1 ft
Suburbs	121 **	300 ft	23.7 ft	16.7 ft

	122 **	300 ft	224.3 ft	214.6 ft

* Position requirements are increased by 30 ft. because of failure to offset survey location to route center line
**Results are reported from GPS solution only due to problems with route definition

Table 4.1 Location accuracy by test point

In some cases, the surveyed point was to the centerline of the road, and not to the bus stop. In these cases, an additional thirty feet was added to the allowable threshold to compensate for the difference between the reported bus location and the surveyed centerline.

There is no difference in the way the AVL system position determination works in the different areas. However, the conditions in the varying locations are different, and that is the reason for the differing thresholds. For example, urban canyons along the 16th Street Mall and the dense central business district limit satellite sight lines. Vehicles in these areas may have to rely more heavily on the dead reckoning function to determine their locations. In the suburban and rural areas there are fewer overhead obstructions. In the foothills, there are groves of trees and small canyons that may block satellite sight lines.

The test distinction among 100-, 200- and 300-foot accuracy was made to meet the varying needs of the system in different areas. For tests on the 16th Street shuttle in the densely urban downtown area, the need was for accuracy within 100 feet. Larger errors could result in vehicles being reported on the wrong street or intersection. Other urban and suburban areas surrounding Denver, where streets aren't as close to each other, the accuracy needs were to be within 200 feet of the actual position. And in the regional and rural areas, where there are few landmarks and roads, the need was for accuracy to within 300 feet.

The location as determined is not necessarily the vehicle location shown on the dispatcher's screen. When a message is received by the dispatch center, the vehicle, route and driver it is coming from is identified. The AVL system then uses the vehicle position that is calculated by GPS to determine the vehicle's location. The GPS position is compared to the spatial location of the vehicle's planned route. If it is within an allowable distance of the route, the location is "snapped" to the route. This means that the vehicle is identified along the route at the point that is closest to its determined position. If the determined position is outside the allowable distance, it is snapped to the nearest street. When the vehicle is not on its planned route, the dispatcher can be alerted and speak with the operator to verify this.

In the central business district, the system has more potential interference. The taller buildings of downtown may obscure the satellites from the roof-mounted sensor's sight. Additionally, exhaust fumes, trees, and wires may also block a clear sensor to satellite view. In the more rural areas, topographic features such as canyons and trees also have the potential to block the satellite view. Another factor in the Denver area is the weather. During winter months, snow may accumulate on the roof of vehicles, which prevents the GPS sensor from receiving any signals from satellites. In situations where the location cannot be determined by GPS, the AVL system uses the last determined location, the vehicle route and the time since the last location report to “dead-reckon” a location for the vehicle. Dispatchers felt that the dead-reckoning function was generally accurate.

The GPS based vehicle location function rated very well with dispatchers. In the surveys and interviews with dispatchers, none found it unreliable and the majority felt it was either “very reliable” or “reliable.” In interviews and observations of the dispatchers, it was noted that they are comfortable with the displayed vehicle location and understand the limitations of the GPS system. One dispatcher stated that the AVL system is a “plus in tracking bus locations,” and another stated that it gives the dispatchers “visual control over road calls.” Road calls are messages sent from service vehicles.

The Sandia team also assessed the quality of the AVL’s “snapping” function. This is part of the AVL’s location algorithm. The algorithm determines where along the route the vehicle will be snapped to. According to the Sandia tests, the snapped locations are generally NOT located on the GIS map trace of the route. However, Sandia was not able to identify the source of this error and cannot tell if the problem is in the algorithm or elsewhere. Trimble, the GPS hardware manufacturer, reports that their results using the same software and hardware combination produced accurate and reliable “snapping” results. Additional tests have not been undertaken to compare the two sets of results.

The results of the Sandia tests are summarized as: “A total of 485 position reports were analyzed for this evaluation. Out of the total sample set, 21.6% of the reports failed to meet system accuracy specifications. The majority of these out-of-spec reports were located in the Denver Central Business District for points 101-110. Only 16.5% of the GPS position reports failed to meet the accuracy specifications.”[1] This means that, with the “snapping” feature on, the system was less accurate (21.6% in error) than when only the GPS data was used (16.5%).

4.4 Equipment Reliability

Equipment reliability was assessed through a series of criteria. Equipment failures documented the number of times that components of the AVL system did not operate as specified. Equipment downtime is the amount of time that AVL equipment was out of service for repairs or parts replacement. Preventive maintenance is the amount of effort that RTD must exert on a regular basis to insure that the AVL system components are fully operational.

4.4.1 Equipment Failures

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[1]Volpe National Transportation Systems Center, Performance Assessment of the RTD Automatic Vehicle Location (AVL) System, November 1996

The AVL and communications equipment are documented by R T D maintenance as the radio system. R T D maintenance keeps a monthly record of repairs by category. Figure 4.1 shows the number of radio repairs for the month of February for each of the last four years. Previous data was no longer stored by RTD. RTD did not specify what number of these are specific to the AVL portion of the radio system.

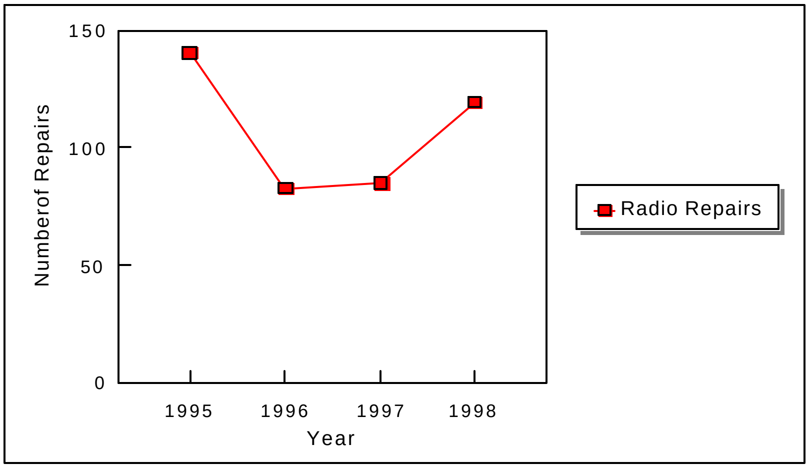

Figure 4.1 Radio repairs for February (1995-1998)

While the RTD records do not indicate the reason that a repair was needed, RTD stated that most radio repairs are due to the following reasons:

- lightning strikes, which can short-out a vehicle system;
- power surges in a vehicle's electrical system;
- water damage, where a vehicle has leaks that short out the radio or AVL;
- operator damage, where the vehicle operator abuses the equipment; and
- voltage regulator problems on vehicles, which can cause a short.

According to Westinghouse, the system developer, the number of repair calls from the road due to radio problems decreased by 53% from before the AVL system was installed to 1996. However, as the above chart, shows, however, 1996 and 1997 had a very low number of radio repair requests compared to 1995 and the most recent year, 1998. Other reliability results of the AVL system cited by Westinghouse are:

- a 39% decrease in repeat maintenance to radio equipment; and
- a 23% reduction in service delay hours.[2]

Although RTD does not have any similar documentation of radio reliability, their maintenance staff stated that those results were accurate.

4.4.2 Equipment Downtime

When in-vehicle radio equipment fails and goes out of service, the equipment is repaired when it returns to its service bay. These repairs are almost always done overnight with the vehicle going back into service the next day. For the equipment at the dispatch or at the communication stations, the equipment is repaired during "hot standby." Most system elements are redundant, and the backup system operates while the primary system is being repaired. There is no down-time during "hot standby" repairs. Consequently, there have been no AVL system failures at the dispatch center.

4.4.3 Equipment Preventive Maintenance

Radio equipment is maintained semi-annually. Maintenance includes inspecting all key parts of each vehicle's equipment. Failed or aging equipment is removed and replaced with new components, while other pieces may be repaired while still in-vehicle. Most components of the vehicle AVL and radio equipment are modular and can be easily and quickly switched. The semi-annual maintenance takes approximately one hour per vehicle twice a year, or 2700 hours to service all 1335 equipped vehicles on an annual basis. This is more than one full time employee.

4.5 Data Transmission Reliability

Sandia Labs conducted the tests of reliability and associated time delays of the Time Division Multiple Access (TDMA) data/voice communication system. Before installation of the AVL system, RTD relied exclusively on voice communications. Operators monitored voice traffic on the radio and waited for a break in the conversation when they needed to speak to a dispatcher. The new communication system allows many standard messages to be sent digitally. This more efficient communications system allows an increase in information flow while operating within the limited bandwidth allocated for RTD operations.

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[2]Transportation Management Solutions, "Early Results from the Denver AVL Operational Test," 1997

Since it is not always apparent to the operators that digital messages are being transmitted immediately, Sandia Labs was asked to measure the communication delays for standard digital messages. During the position result tests they simultaneously logged communication traffic on both the IVLU and CAD ends of the communication link. The IVLU's and CAD are all synchronized to a time tick broadcast over the radio system.

Message transmissions were logged with a system time stamp at the IVLU and all messages received at the CAD from the test vehicle were logged at the same time. A similar data extraction program to the one used for position result processing was used to match messages broadcast from the test vehicle with messages received at the CAD. This program used the CAD data file as the master and searched the IVLU log attempting to match each received message with a corresponding transmitted message on the vehicle end.

Several points were noticed when examining the processed results. In general, all times at the dispatch center were documented as being between zero and one second earlier than when the message was sent if a matching message was found. This infers that there is a synchronization error between the CAD and IVLU, since it would be impossible for messages to be received at the CAD before they are sent by the IVLU. After noticing the synchronization problem. Sandia Labs sent digital messages while simultaneously verifying the actions over the voice channel. This procedure verified the digital messages are indeed received at the CAD within 1 second of their transmission by the IVLU which is well within even the 3-second limit for emergency messages.

Occasionally, the message "Time Frame Exceeded" is output from the data processing program. This message indicates that a message was received at the CAD but no corresponding message was logged as being sent by the IVLU. This anomaly is attributed to the IVLU diagnostic program being used for data collection not having time to log the message transmission event. Data logging is given a low priority in the diagnostic program task definitions so messages only get logged if the computer has time available.

There are a few dead spots within the RTD service area where no communications are possible. However, Sandia Labs reports that these are limited in scope and are expected for a radio communication system designed to cover such a wide area. It is certainly feasible to cover these areas with additional repeaters if required, but RTD seems to be managing with the current coverage.

Sandia Labs concludes their assessment of the AVL system by noting that the ability to transmit digital messages has reduced the amount of unnecessary conversation on the voice channels. Operators and dispatchers are able to communicate more quickly and efficiently. Additionally, the system is performing within specifications, with no significant number of messages being lost, or being delayed in transmission. The data transmission reliability and timeliness helps enhance the quality of on-street performance by improving the quality, timeliness and availability of information for dispatch and, subsequently, customers. It improves system productivity and job satisfaction by improving the ability of dispatch to more quickly respond to vehicle and facility failures.

4.6 Impacts on Emergencies

The AVL system gives RTD two distinct functions that are beneficial in responding to on-board emergencies. Both provide more information more quickly than the RTD's previous system. The first function is the vehicle tracking capability. The second is the silent alarm.

Prior to the installation of the AVL system, RTD had a method for tracking vehicles based on triangulation from three microwave towers. Dispatchers indicated that this system was unreliable and only moderately successful at determining the position of a vehicle. Their level of reliance on it was low. The primary problem with the old system is that it could not track a moving vehicle because of the amount of time it required to collect data and calculate the location.

The new AVL system has a high level of reliability and is trusted by the dispatchers. They can easily track a vehicle as it moves. The system normally relays a vehicle's location every thirty seconds, but falls into a more frequent location reporting mode when the silent alarm has been triggered. In cases of emergencies where the operator can speak to the dispatch center without jeopardizing the operator's or passengers' lives, the dispatcher may make a priority request to talk. The operator can talk with a dispatcher while the dispatcher tracks the vehicle on the dispatch station screen and has the operator verbally verify the AVL determined location. If the AVL- determined location does not match the operator's description of the location, the dispatcher can work with the operator to determine the actual location. In moments of emergency, operators can sometimes be confused, and this verification is a valuable function. In the old system, the operator had to announce the emergency over the shared communication channel. This often required the dispatcher to drop other requests already made by operators, or to determine the importance of more than one simultaneous emergency request.

The silent alarm function is not new to RTD. Their previous system also had a silent alarm. However, its use resulted in radio channel lock-up and RTD decided to disable it on all vehicles. Because of this decision, the operators had no silent alarm to use. As part of the new AVL system, a silent alarm was developed with a fail-safe system mechanism to prevent channel lock-up. The silent alarm, in practice, does not lock-up the system.

The silent alarm is triggered by the operator when there is an incident on or near a vehicle that prevents the operator from picking up the handset to speak. Once triggered, dispatch can listen to activity on the vehicle through a covert microphone. Examples of silent alarm emergencies that have been experienced by RTD drivers are agitated passengers, passengers with weapons that threaten the operators or other travelers, or situations where the operator wants dispatch to be able to hear an incident without the passengers knowing. It takes the AVL system approximately one to two seconds from the time the silent alarm is triggered by an operator until the audio alarm is sounded in the dispatch center. Once the silent alarm is acknowledged in the dispatch center, the vehicle location and status are displayed, along with the closest supervisory vehicles. The dispatcher can activate the covert microphone previously described and then determine the appropriate response and closest supervisor to respond to the emergency. The vehicle location is updated every few seconds until the situation is resolved, and dispatch can relay the potentially changing vehicle location to the police, fire or paramedics as needed.

Three examples of the benefit of the silent alarm are:

- In 1993, a passenger assaulted a female operator with a knife. The dispatchers used the covert microphone to listen in on the incident and send the correct response. Police and RTD supervisors were on the scene within four minutes and the assailant fled. With the previous radio system the operator would have had no opportunity to report the incident without risk.

- In 1995, a suspect in an armed robbery jumped onto an RTD bus to escape the police. By using the covert microphone, GPS tracking and data messages, dispatchers were able to ascertain the situation and determine the vehicle location. The dispatchers called the police and provided this information to them. Through the dispatch center, the dispatcher's call to the police was connected through the new CAD system so that the police could listen to the hidden microphone on the bus. The suspect was apprehended at the bus's terminal.

- In 1997, a female operator was receiving verbal assaults from a passenger on a daily basis. She used the silent alarm's covert microphone to document this abuse. Dispatchers heard the exchange and sent police and a supervisor to remove the abusive passenger from the bus.

The appropriate use of the silent alarm should be when a situation exists where harm could result either to the operator or passengers if the operator were to pick up the handset and attempt to speak. Once the silent alarm is triggered and the covert microphone is on, the operator should describe the situation whenever possible to help the dispatchers determine the appropriate type of response needed. The major disadvantage of the silent alarm function, as indicated by the dispatchers, is the misuse of it by operators and the high frequency of false alarms. Many operators have had to be retrained in the proper use of the silent alarm. Because they know it gets the highest priority by dispatchers, some operators use it to get the attention of dispatchers during busy times when normal request response times are longer. Additionally, some operators trigger it, assuming that it generates an immediate mobile response. In actuality, the dispatchers must listen in to the covert microphone in order to determine which type of response is appropriate. RTD has reprimanded and retrained operators that misuse the silent alarm, and misuse has declined.

The silent alarm is tested during the operator log-in sequence that is performed at the beginning of each shift. If the procedure is not done in the correct order, when the silent alarm is tested it appears as an actual silent alarm at the dispatch center. Also, the position of the silent alarm trigger on buses is such that it can be accidentally bumped and activated. These occurrences, where there was no incident that prompted the use of the silent alarm, are considered false alarms.

For this evaluation, silent alarms were monitored during a 20- month period. During that time 77 silent alarms were triggered that were not false alarms. The 77 silent alarms average out to less than one per week during the data collection period, and that includes incidents where the operator used the silent alarm where another type of request would have served better. There is no record of the number of false alarms because follow-up reports are not filled out for them. However, dispatchers estimate that 90% of all silent alarms are false alarms.

Table 4.2 illustrates the silent alarms by type, and the number of them that were misuses of the silent alarm function.

	Medical Emergency / Accident	**Operator Threatened**	**Passenger Threatened**	**Total**
Correct Use	3	27	18	**48** (62.3%)
Incorrect Use	7	5	17	**29** (37.7%)
Total	**10** (13.0%)	**32** (41.6%)	**35** (45.5%)	**77** (100%)

Table 4.2 Silent alarm usage

In most medical emergencies or accidents, the operator should use the PRTT button instead of triggering a silent alarm. The silent alarm only allows one-way communication. While a silent alarm is occurring, a dispatcher is unable to make other contact with the requesting vehicle. Because the silent alarm prevents two-way communication, a PRTT will serve an operator more quickly if he or she needs to discuss a situation. With two-way communication, dispatchers would be able to clarify the incident type and provide instructions to operators until emergency crews arrived. The types of medical emergencies and accidents in which the silent alarm was misused include passengers having seizures and buses bumping into other vehicles.

When the operator is threatened, he or she should always use the silent alarm. Table 4.2 shows five cases of misuse when an operator was threatened. These cases dealt primarily with instances where the incident was over before the operator triggered the silent alarm, or the operator was not directly threatened and could pick up the handset. For example, in one instance a drunk man at a bus stop kicked the bus' door glass in, and the operator used the silent alarm.

Most misuses of the silent alarm in the case of threatened passengers resulted from the operator using the silent alarm to report a brawl or threat that would not have prevented him or her from using the PRTT button and talking on the handset. Many of the operators stated that they believed the silent alarm connected them directly to the police. It does not. Another problem with the silent alarm use is that the operators frequently do not describe the incident, leaving the dispatchers to try to interpret the sounds coming over the covert microphone in order to determine the appropriate response.

5. ACCEPTANCE AND PERCEPTIONS

5.1 Introduction

With the introduction of the AVL system, the RTD employee attitudes were affected by changes in their operating procedures and the information available to them. The RTD staff attitude as well as the users' and non-users' perceptions of the AVL system is an important measure of its success. While the attitudes and perceptions do not result in quantifiable changes in service or system performance, they represent important measures of how well the system is satisfying employees and attracting customers.

The acceptance of the AVL system by the affected community was measured through surveys and interviews. Attitudes of the RTD employees concern the AVL components' impact on the transit system performance. The perceptions of the users and non-users are defined in terms of the transit riders and the general public's (potential riders) opinion of the transit system performance. Perceptions were measured through telephone interviews with RTD customers and potential customers. The following groups of employees were surveyed and/or interviewed to determine their attitudes toward the AVL system:

- operators;
- dispatchers; and
- field supervisors.

5.2 Summary of Findings

Employee surveys were not taken until after the AVL system was mostly functional. Because of hardware and software difficulties, there was no time where the system went quickly from being unavailable to fully available. This happened over a long period of time, and operators, dispatchers and street supervisors experienced the system's growing pains and developmental glitches.

The surveys queried employees that had worked with both the AVL system and the previous system separately from those that had only worked with the AVL system. Employees that had worked with both systems were asked to give comparative answers to questions, citing the differences in performing their jobs before and after implementation.

From RTD employees, the AVL system received a high level of acceptance. More than 80% of the dispatchers found the system "easy" or "very easy" to use, while more than 50% of operators, and street supervisors felt likewise. All groups felt that the system helped RTD respond more quickly to emergencies and that the messaging and vehicle location functions were accurate and reliable. Many operators and dispatchers noted that the system was not always operational. Twenty percent of dispatchers indicated that the system "frequently" had hardware or software problems. RTD has worked with TMS to improve the system performance and believes it has improved. In addition, all groups felt that the system made RTD safer and more secure for passengers and vehicle operators.

Customers and potential customers were interviewed over the telephone by RTD volunteers. The main impact that would be experienced by the public would be better on-time performance and more realistic route schedules. These are two components of the AVL system that were never fully deployed during the evaluation period, and, as a result, the public could not be surveyed to determine if their perception of RTD performance was improving. Instead, the surveys cover the overall impression of and level of satisfaction with RTD service. The majority of users felt that the RTD vehicles were either "always" or "usually" on time. More than 90% said that there was "usually" a seat available on vehicles they rode. And more than 90% of respondents, both RTD riders and non-riders, believed RTD's service was "good" or better.

5.3 Employee Surveys

5.3.1 Survey Development

The purpose of the surveys was not to seek empirical data on the AVL system's reliability and performance. Rather, it was designed to assess the employee's perception and acceptance of it. The employee surveys were developed by CRC, RTD and Volpe. The questions asked were mapped directly to the measures of effectiveness defined in the Evaluation Guidelines for the Advanced Public Transportation Systems Operational Tests, which is discussed in Section 1. The surveys were tailored so that each employee group would answer questions that were directly relevant to their use of the AVL system.

The surveys were drafted by CRC with input from Volpe. Once the preliminary surveys were developed, RTD provided input into the phrasing of questions. The final surveys were developed to minimize the amount of time required to fill them out, and to leave space for additional comments, which were later explored during interviews.

5.3.2 Employee Survey Methodology

Employee attitudes were gathered through surveying and interviewing them on the following issues:

- degree of acceptance of the AVL system;
- perceived reliability of the AVL system;
- in-vehicle unit ease of use and possible impact on operator safety;

- the training performed; and
- perceived quality of the information presented to employees by the AVL system.

Unique surveys were developed for three employee groups. These groups were:

- Dispatchers at the Metro, Boulder and Light Rail dispatch centers;
- Operators, separated into newer operators with no experience with the older communication systems and older operators having experience with both communication systems; and
- Street supervisors monitoring and attending to incidents in the field.

The surveys for each group were designed to evaluate each of the measures for each component with which the employee group interfaced. The AVL components are:

1. Dispatcher/AVL interface

2. Dispatcher/CAD interface

3. Operator/AVL/Radio system interface

4. Database

Figure 5.1 shows the schedule of employee groups and the components that their survey addressed.

Employee Group	Component			
	1.	2.	3.	4.
Dispatchers	X	X		X
Older Operators			X	
Newer Operators			X	
Street Supervisors			X	

Figure 5.1 Components on which each employee group was surveyed

Surveys were distributed to the employee groups by RTD according to the sampling scheme in Figure 5.2. The sample size shown for the operator groups represents the total number of workers that returned the surveys, and not the number that were asked to complete the survey.

At the survey time, there were 25 part-time and full-time dispatchers at RTD. Because they are the group that works most directly with the AVL system, it was important to receive the widest spectrum of perceptions from them. For this reason, the surveys were supplemented by interviews and observations of them operating the system.

Employee Group	Sample Size Compared to Total Employees
Dispatchers	100% (25 respondents)
Older Operators	25% (184 respondents)
Newer Operators	25% (124 respondents)
Street Supervisors	100% (39 respondents)

Figure 5.2 Sample size by employee group

There are over 1,200 operators of RTD vehicles, including contract operators from three outside companies. Surveying all operators would have required significant effort not only in surveying but also in data reduction and analysis. An approximate 25% random sample was collected. It should be noted that this survey was not meant to be statistically accurate, but was meant to reflect the acceptance and general perception employees have toward the AVL system.

Newer operators and older operators were surveyed separately at the recommendation of RTD. RTD hypothesized that older operators and newer operators had a different perception of the system because the older operators were familiar with how dispatcher/operator communications were conducted prior to AVL system implementation. The survey responses revealed this hypothesis to be true.

The survey of street supervisors was meant to assess their perception of how the AVL system affects the way supervisor and operator requests are serviced in the field. All 39 part-time and full-time street supervisors at the survey time were asked to respond. Some part-time street supervisors were also part-time dispatchers and responded to both surveys.

Castle Rock Consultants, Inc. developed the surveys with the assistance of Volpe National Transportation Systems Center and RTD. Once all parties were satisfied with the survey methods, they were distributed to the employee groups by RTD. The responses were collected by RTD and provided to CRC for summary and analysis in this report.

The employee surveys and interviews occurred over a six-month period as the AVL system went through final acceptance. It is important to note that throughout the six month period, all functions that RTD intended for the AVL system to perform were not implemented. Specifically, the schedule adherence functions were not operational.

5.3.3 Degree of Acceptance of the AVL system:

In general, the three groups of RTD employees surveyed - the dispatchers, operators and street supervisors - responded favorably to the system. It can also be said, as a general rule, that older employees were less accepting of the system than newer employees. Some of those that were able to compare it to the previous communications system either had a resistance to change or genuinely believed the previous system better served their purposes. Following is a summary of the acceptance of each employee group.

Dispatchers

Dispatchers found that the system worked well for locating vehicles. In the survey, over 80% of the dispatchers rated the system as "very easy" or "easy" to use for vehicle location. Less than 10% thought it was "difficult," and none of the dispatchers found the system "very difficult" for vehicle location. The dispatchers had a strong understanding of how to call buses up on their display screens and had mastered the tasks required to track several buses.

For contacting operators and field supervisors, however, only slightly more than 50% rated the system as "very easy" or "easy" to use. Additionally, more than half of the dispatchers indicated that the AVL system is "about the same" or "more difficult" than the old system for responding to a single call. One reason for these lower ratings may be because the system often crashed when it was first installed. The system reliability has improved significantly since then and fewer calls have been "lost" recently. However, dispatchers believed that it takes more time from when they request contact with field personnel to the time the contact is actually made. When the system is heavily loaded, the request response times become even longer. Additionally, the graphical interface for responding to a call was cited by dispatchers as not being user-friendly.

As figure 5.3 shows, the dispatchers felt the system was useful to them in performing their functions. Many recognized that the system required them to adjust their roles, and these dispatchers tended to be more satisfied. Those that preferred to continue performing their job as they did before the AVL system was installed were less satisfied with it, and they continued to perform many tasks with the portions of the old system that were intact.

Operators

Overall, operators found the AVL system useful. However, they were not as enthusiastic about it as the dispatchers or street supervisors. One key reason for this is the difference in the functionality of the AVL system for dispatchers and the coach operators. Where the AVL system provides the dispatchers with more information and is a tool that allows them to better monitor the vehicle fleet, many operators perceived it as an intrusion or a way for RTD to control them.

This "Big Brother" perception by operators was particularly noticeable among older operators that had used both the AVL system and the previous radio communications network. Many comments from older operators indicated that they felt they were being watched, and that RTD was using this system as a discipline measure against operators. These operators felt the system did not provide better service to the customer. Newer operators, however, never experienced the old system and were more willing to accept the AVL system.

Question: **Rate the usefulness of the AVL and CAD systems to you in performing your job:**

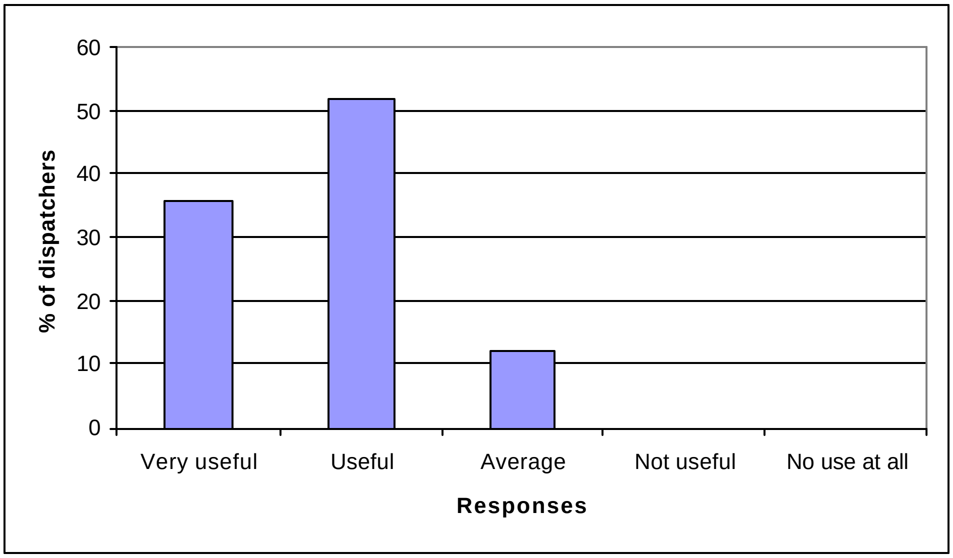


Figure 5.3 Dispatchers' attitudes toward system usefulness

All operators found the TCH to be a useful tool for them. The TCH is used by the operator to alert the dispatch center of their need to communicate. For standard messages, the TCH has preset buttons. It also has a display screen which gives the operator text messages and the time. At the survey time the schedule adherence display, which alerts operators as to how far ahead of or behind schedule they are, was not implemented. Operators are penalized for not adhering to their schedules and have expressed a particular desire to have the schedule adherence function help them to make adjustments throughout their route.

Most operators found the new system to be about as easy to use as the previous system for contacting dispatch. In the old system, the operator would pick up a handset and could immediately start talking. In the new system, the operator pushes a button that indicates the urgency of the request and then waits for dispatch to initiate the communication.

Overall, operators found the AVL system to be useful to them in their jobs, as shown in Figure 5.4. In general, newer operators found it more useful than older operators did, but very few of either group found it without any merit.

Street Supervisors

In their role, the street supervisors are primarily concerned with the AVL system's ability to assist in resolving on-street problems and issues. In their survey responses, the street supervisors indicated a strong acceptance of the AVL system and a firm perception that it improved their job performance.

Question: **Rate the usefulness of the Radio/AVL system to you in performing your job:**

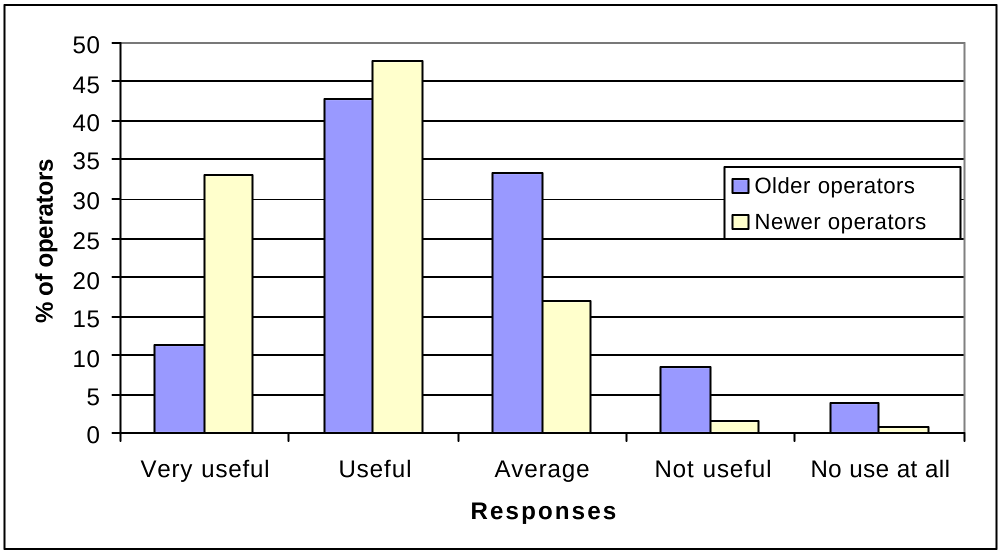


Figure 5.4 Operators' attitudes toward system usefulness

Most street supervisors felt that the AVL system made communication with the dispatch center easier. They indicated that the system's ability to send data messages reduced the amount of unnecessary voice traffic and allowed them to more easily review messages. Additionally, the supervisors overwhelmingly indicated that the new AVL system made it easier for them to communicate with operators. They also receive improved information regarding the vehicles, operators and incident types before talking to the vehicle operators. As a result, 80% said they were able to respond to incidents at least as quickly as before AVL implementation.

The previous system tended to be less crisis-oriented and more "first-come first-served." The supervisors indicated that the AVL system allowed them to better prioritize their workloads than the previous system. As shown in Figure 5.5, most supervisors find the AVL system to be useful.

5.3.4 Perceived Reliability of the AVL System:

As with almost all new technologies, Westinghouse had to perform a series of debugging and system improvements on the AVL system they installed. However, RTD accepted the AVL system and is satisfied that it is functioning properly and to their specifications. Through interviews with RTD employees, it was learned that the reliability of the system has improved compared to the first three years of implementation, when components and software were still being installed and debugged. System crashes reportedly no longer occur.

Question: **Rate the usefulness of the MDT to you in performing your job:**

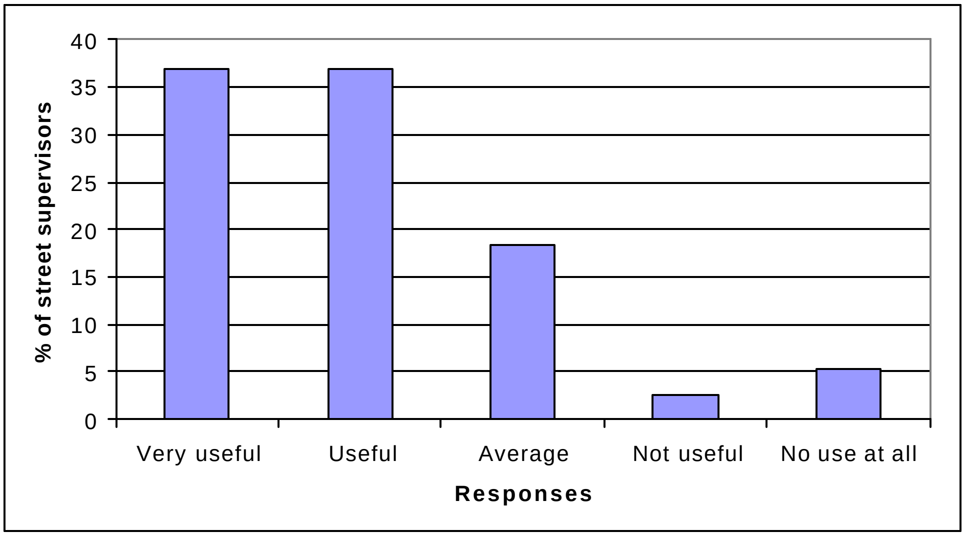
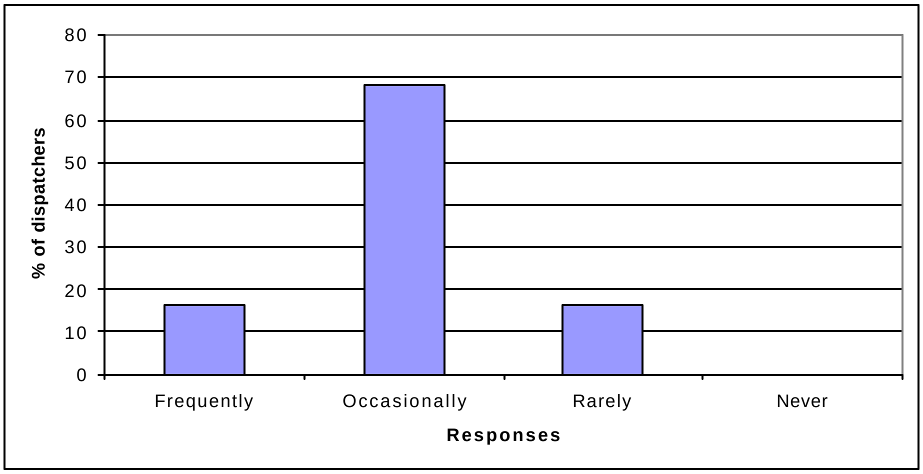


*Figure 5.*5 *Supervisors' attitudes toward system usefulness*

Dispatchers

Dispatchers interface with more components of the AVL system than any other employee group. Among other tasks, their daily routines require them to operate three display screens, radio communications on nine radio channels, log reports, interface with the scheduling system and retrieve and play records from previous days. When surveyed on how often there was a software or hardware problem that prevented them from performing their jobs, almost 20% indicated that it happened "frequently" (Figure 5.6). More than half of the dispatchers said it happened occasionally, and no dispatchers said there were never hardware or software problems. This suggests that the system still has some instability.



When asked how often the system fails to establish a requested radio connection with a particular operator, the majority of dispatchers said that this happens occasionally (Figure 5.7). Other personnel suggested that many of these incidents are due to errors made by the dispatchers and not system failures. If dispatcher error is the cause, dispatchers should be retrained on this function in order to increase both their efficiency and confidence in the system.

Operators

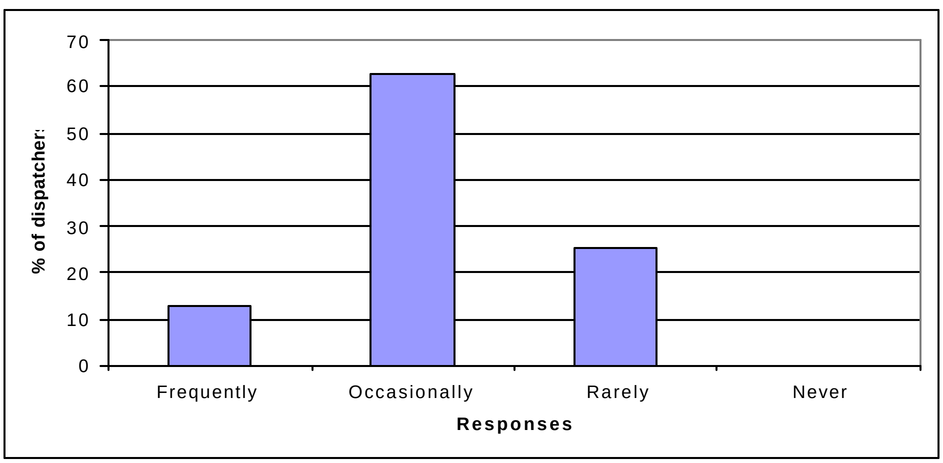
Newer operators have little concept of how dispatch communicated with operators using the previous system, while older operators make inevitable comparisons between the two. The majority of newer operators indicated that the system "occasionally" or "rarely" does not function (Figure 5.8).

Question: **How often are you not able to use a portion of the AVL system due to a hardware or software problem?**

Figure 5.6 Dispatchers' perceptions of system reliability

Question: **How often does the system fail to make a radio connection that you've requested?**

Figure 5.7 Dispatchers' perceptions of radio reliability



Question: **How often does the Radio/AVL system not work?**

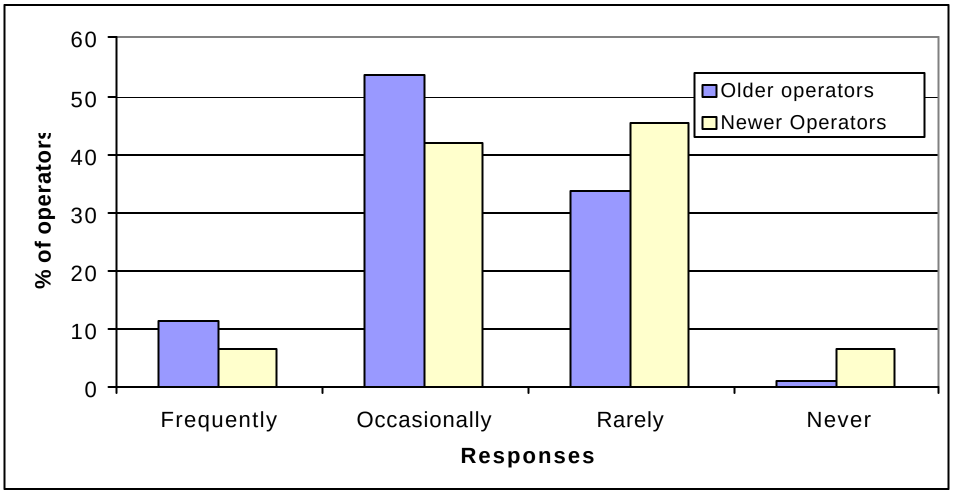


Figure 5.8 Operators' perceptions of AVL reliability

Some said that it "never" broke down. In contrast, the majority of older operators felt that the system "frequently" or "occasionally" did not work.

The perception that the AVL system sometimes does not work may be caused by a lack of feedback provided to the operators, and not by actual system failures. In the previous system, older operators were able to pick up the handset and start communicating. Now, they must press a button and wait for a response. On dispatch's busier days, some minor requests may not be responded to for up to fifteen minutes. Because of this, the operator often thinks that the request has not gone through to dispatch and the operator repeats it, or gives up.

Street Supervisors

Street supervisors indicated a greater reliance on the AVL system and their MDTs in communicating with other service vehicles. Many expressed a perception that the new AVL system is much better at allowing them to contact vehicles and work directly with operators rather than using the dispatcher as an intermediary (Figure 5.9). In general, the street supervisors have a strong perception that the location data and the communication links are very reliable.

5.3.5 <u>In-vehicle Unit Ease of Use and Possible Impact on Operator Safety:</u>

Operators interact with a much different device than the dispatchers and street supervisors. They are provided with less information than the others, while they and their vehicles generate the most information. The ease of use of the TCH is important to the quality of information that operators provide. The operators perception of their safety and the safety of their patrons has been impacted by the AVL system.

Question: **Rate the usefulness of the entire Radio/AVL system to you in performing your job:**

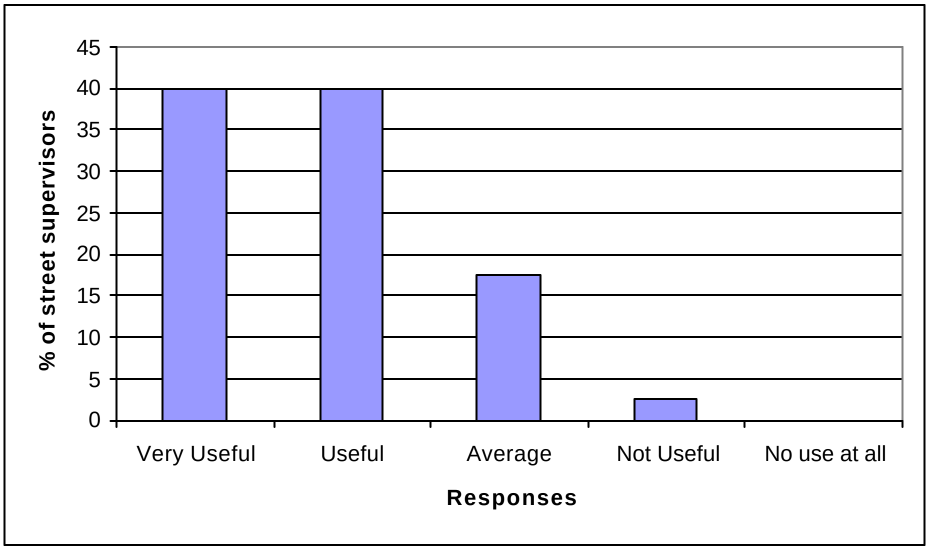


Figure 5.9 Street supervisors' perceptions of AVL system usefulness

Operators

No new operators, and less than 2% of older operators, feel that the TCH is difficult to log into (Figure 5.10). This log-in procedure requires the operators to enter their identification, their route and block number and to test the silent alarm.

Among older operators, half felt that it is about the same or easier to call dispatch with the new system than it was with the previous communications system (Figure 5.11). Between 8% and 12% felt that it was "much easier" or "much more difficult." As previously discussed, some operators expressed a dislike for the lack of instant feedback after placing a request because it made them believe they had not correctly made the request.

The silent alarm is a key component in offering the operator and passengers safety and security. The silent alarm is a hidden button that the operator can trigger when it is not safe to make a request through the TCH. When pressed, it immediately opens a line of communication between the bus and dispatch. Operators are only to use the silent alarm when using the handset would put the operator or passengers at risk. Almost all operators found the silent alarm to be easy to use. However, many felt that its location on the left side of the driver's seat was not ideal. Some said that the button was located where they store their lunch or other belongings, while others said the location made it too easy to accidentally trigger. The possibility that the silent alarm is too easy to accidentally trigger is corroborated by dispatchers who state that they receive ten false alarms for every real emergency.

Question: **Rate the ease or difficulty of logging into the Transit Control Head (TCH)**

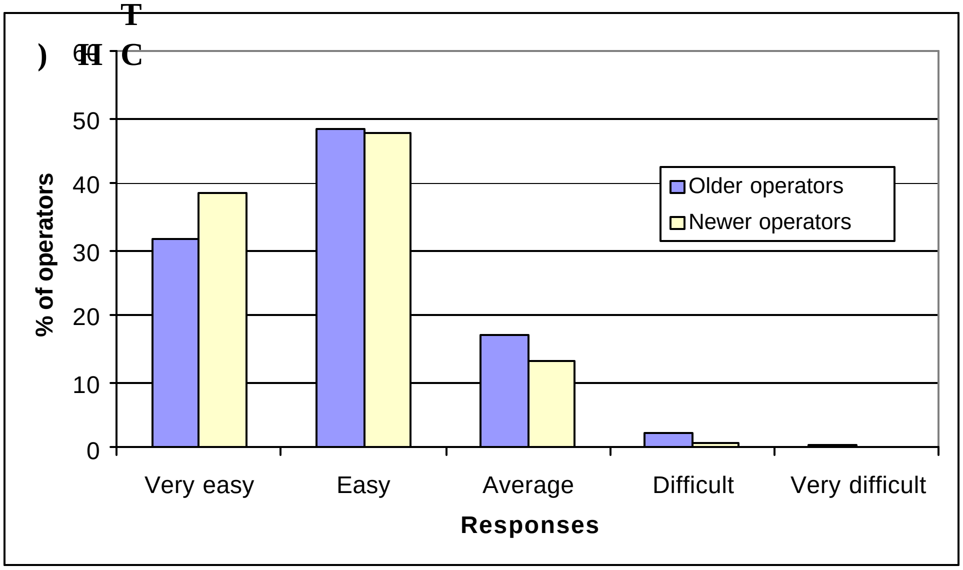
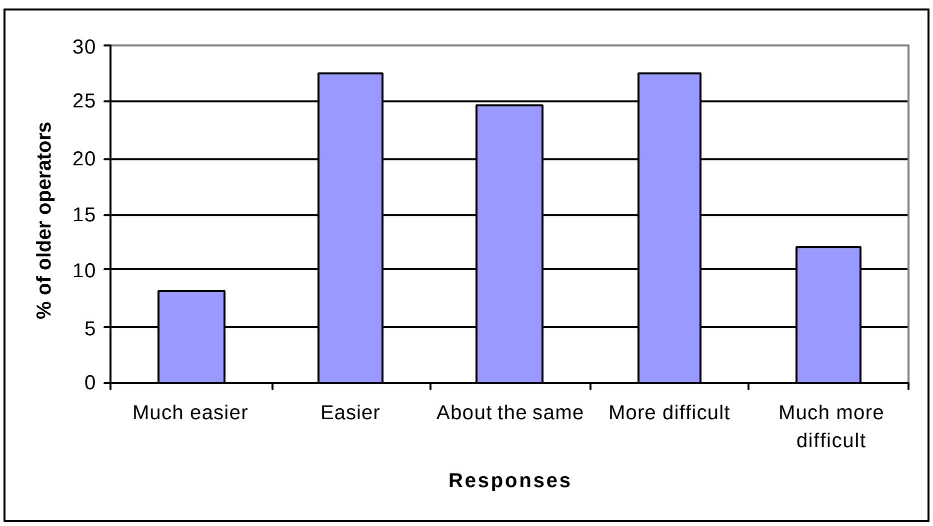


Figure 5.10 Operators' perceptions of TCH log-in ease

Question: **Compared to the old system, rate the ease or difficulty of NOW calling dispatch:**



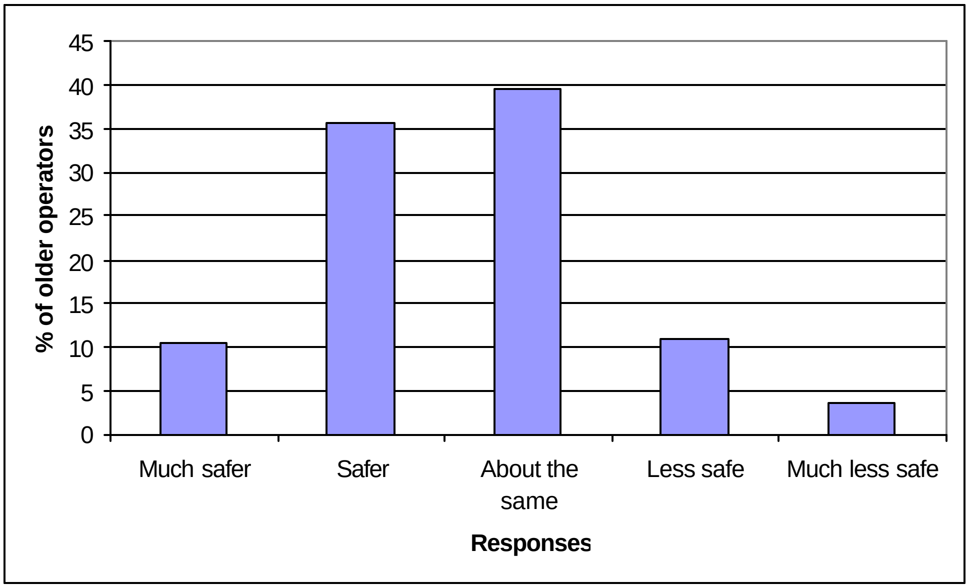


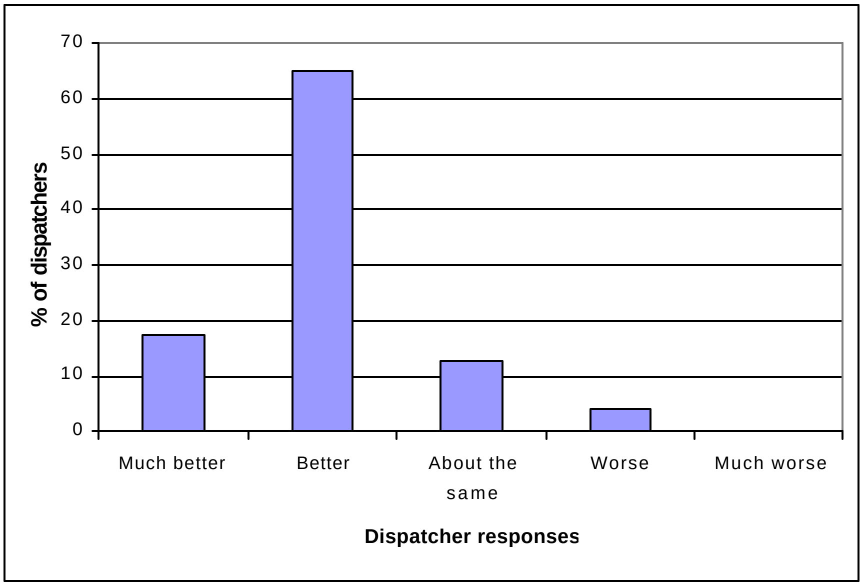
Figure 5.11 Older operators' perceptions of AVL system's calling ease

Overall, about half of the operators feel that the AVL system provides them with more safety than the previous system (Figure 5.12). Some operators felt that, while they feel safer now, they will not know whether they actually are safer until they need to use the silent alarm.

Question: **Compared to the old system, rate how safe you and your passengers are NOW:**

Figure 5.12 Operators' perceptions of safety

Dispatchers



Dispatchers believed that they are better able to handle and respond to emergency situations with the AVL system (Figure 5.13). The dispatchers especially liked having information on the operator, bus and route as well as its location on the screen while they speak with the operators, or listen to the activity on the bus through the hidden microphone. Their trust in the system's accuracy in reporting locations allowed them to direct supervisors and police to a location without the verification of the operator. Because of their better control over situations aboard buses, the dispatchers feel that passengers are now safer than they were under the old system.

Almost all dispatchers stated that the operators do not properly use the silent alarm and that this dilutes its potential value. As previously stated, dispatchers receive ten false silent alarms for every real silent alarm emergency. This may eventually cause dispatchers to discount the importance of a silent alarm when one comes into the dispatch center. RTD has indicated that the silent alarm problem has lessened through further training, but with the current in-vehicle design, they do not expect the false alarm problem to completely disappear.

5.3.5 <u>Identification of the Training Performed:</u>

Each employee group was given formal training by RTD trainers for the operation of components of the AVL system. After training and when the employees are using the system in actual

Question: **Compared to the old system, rate your ability NOW to handle emergency situations:**

Figure 5.13 Dispatchers' perceptions of ability to handle emergencies

operations, their performance is reviewed and additional, less formal training is provided when necessary.

Dispatchers

When the first wave of dispatchers to use the new system was trained, the training took place before the system was operational. Delays in the system implementation then made the length of time between their initial training and their actual use of the system much longer than originally planned. During the delay, the dispatchers resumed using the old system. Because of this, they had a difficult time transitioning once the AVL system was operational, and some were resistant to giving up their existing way of functioning.

Half of the dispatchers indicated that the amount of training they received was the right amount, while one fourth believed it was not enough and another fourth said they received no formal training (Figure 5.14). RTD says that all dispatchers received the same formal training.

When asked how they received most of their training, the majority of dispatchers indicated that their training was through other dispatchers and not through formal classes. This is probably because other dispatchers are available at any moment to answer questions while the formal training only occurs at the beginning of a dispatcher's career and then as-needed. However, the response to this question suggests that training personnel should be available to dispatchers throughout the early stage of their careers.

Question: **When you first started using the CAD and AVL, how much training did you have?**

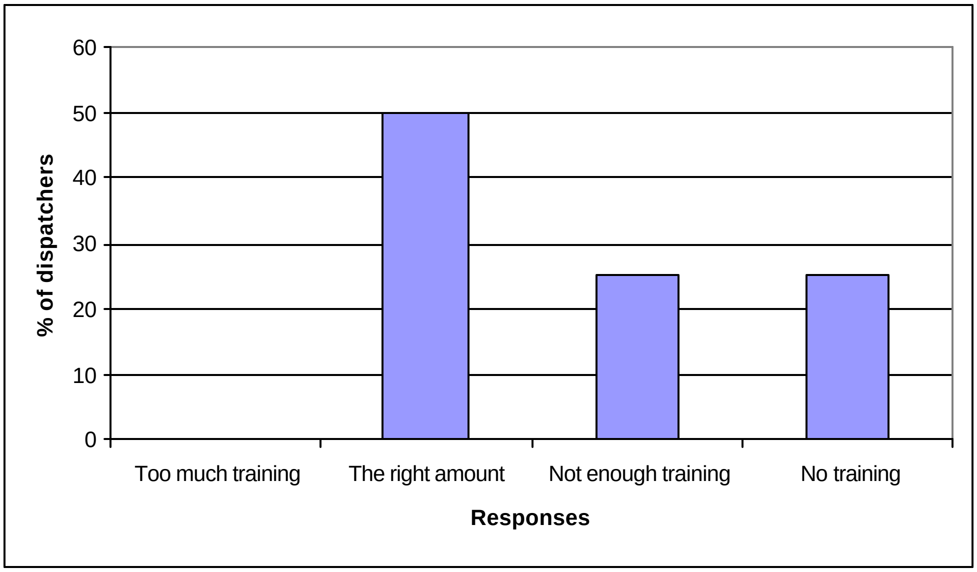


Figure 5.14 Dispatchers' perceptions on training

Operators

Ninety-five percent of all operators said they received the right amount of training, with the response rate for older and newer operators consistent (Figure 5.15). When dispatchers detect that a operator is using the AVL system improperly, such as accidentally triggering the silent alarm or abusing the PRTT function, the dispatchers will conduct review training with that specific operator. In interviews, dispatchers indicated that these reviews work well, and operators have not indicated a dislike for them. Because the events of silent alarms and misuse of the AVL's functions have decreased through this policy, the policy appears to be effective.

In contrast to dispatchers who almost always have coworkers available to assist with questions, operators operate alone on the road. This fact may be one reason why they indicated overwhelmingly that they have received their training through formal training classes and not from other operators.

Street Supervisors

The majority of street supervisors also felt that they received the appropriate amount of training. However, this was not as unanimous a feeling as it was for operators. In fact, many felt that they received either little or no training. Additionally, the training for street supervisors is not as formal as it is for operators and dispatchers, and therefore may not be as in-depth or focused.

Question: **How much training for the Radio/AVL system did you receive?**

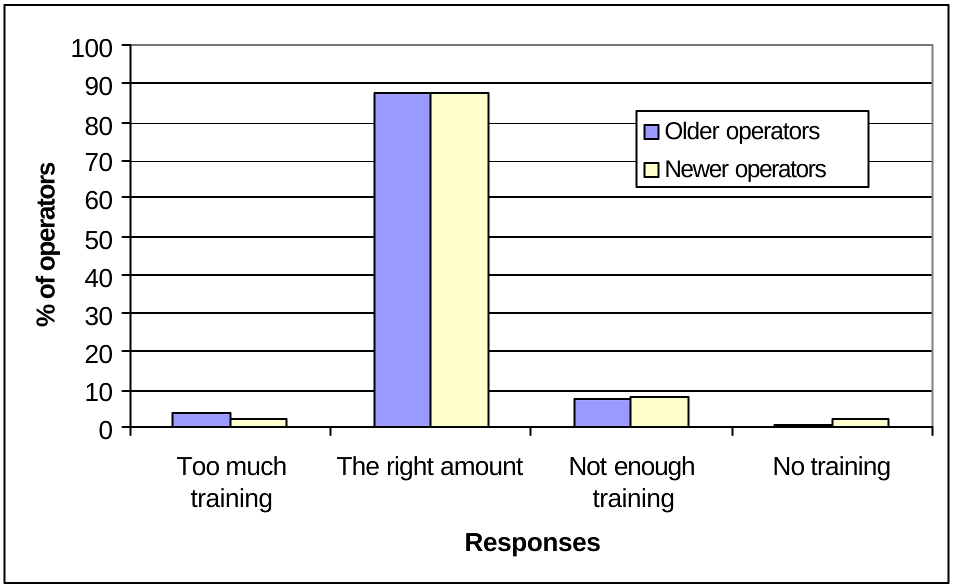


Figure 5.15 Operators' perceptions of training

A further reflection of the less formal nature of the street supervisors' training is that more than half said they learned how to use the system by working with other RTD employees. Only about one third felt they got most of their training through formal training (Figure 5.16). Despite the

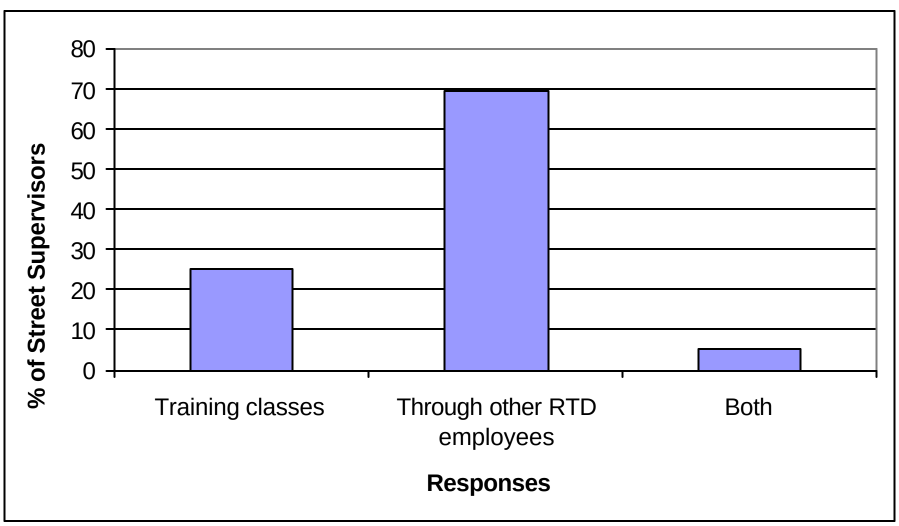
Question: **How did you receive most of your training for the Radio/AVL system?**

Figure 5.16 Street supervisors' perceptions of training

apparent lack of formal training that supervisors received, very few claimed to be uncomfortable with the system, and their approval rating of the AVL system was the highest of any group.

5.3.6 Perceived Quality of the Information Presented

As previously mentioned, each of the employee groups has a different display and receives different types of information through the AVL system. The dispatchers are the only group to have a graphical display which features a map, user interfaces for operating the communications functions of the radio system and pop-up windows that display information concerning personnel, routes and vehicles. Street supervisors have MDTs, which provide limited textual information regarding buses, routes, personnel, and information passed on by the dispatchers.



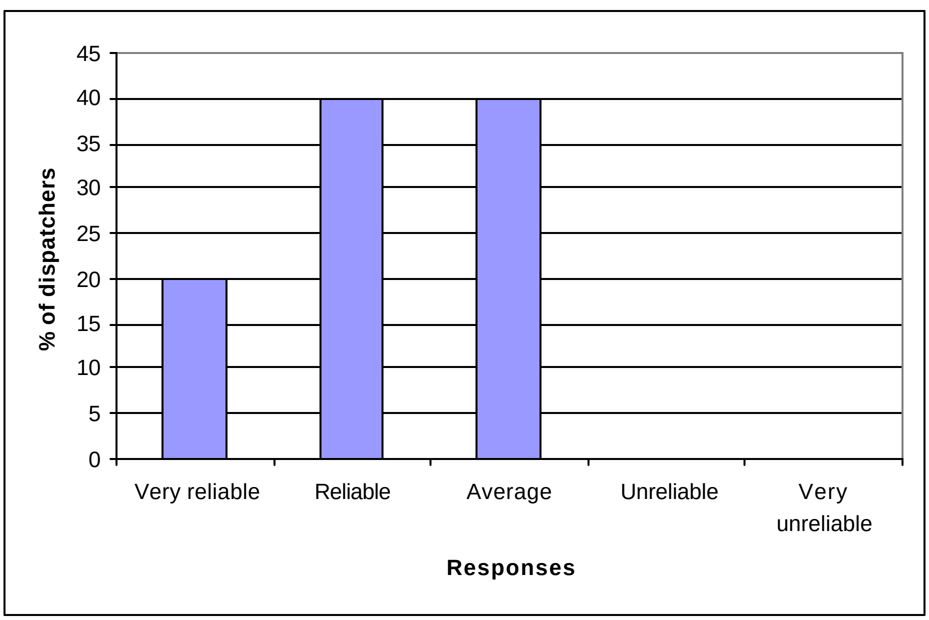
The operators have TCHs which have a small display screen for textual messages from dispatch, the time, and other vehicle and personnel related information.

Dispatchers

The GPS-based vehicle location function rated very well with dispatchers. None of the dispatchers found it to be unreliable and the majority felt it is either "very reliable" or "reliable" (Figure 5.17). In interviews and observations with the dispatchers, it was noted that they are comfortable with the displayed vehicle locations and understand the accuracy limitations of the GPS system. Most dispatchers have used their experience to develop methods for estimating vehicle locations between reports.

Question: **How reliable is the vehicle locating function?**

Figure 5.17 Dispatchers' perceptions of location accuracy



In interviews, dispatchers indicated that the graphical display of vehicle location is easy to use and understand.

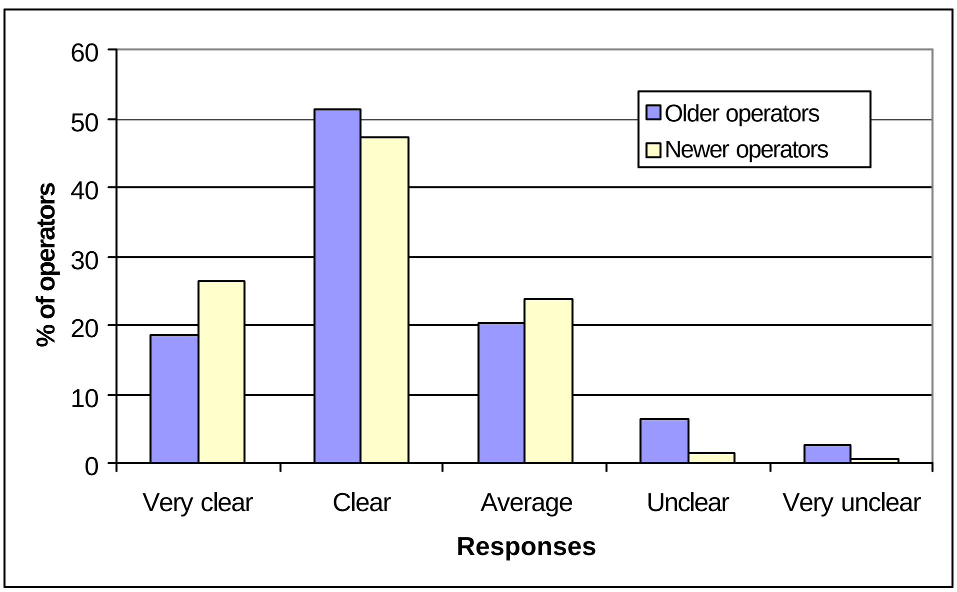
Dispatchers can easily navigate between displays of different transit vehicles, field maintenance and street supervisor vehicles. They can also easily bring up street names and other landmarks for easy identification, and zoom in and out on specific areas.

Dispatchers felt the display of requests and messages sent from buses was less reliable than the location data. More than half of the dispatchers felt that the system either "frequently" or "occasionally" displayed messages that were incorrect. No incidents of false messages were observed by the evaluation team other than those that were actually due to operator error. One dispatcher commented that operator error is the source of most false messages.

Operators

Both older and newer operators felt that the "canned" and other text messages that dispatch sends out to the operators are clear, understandable and useful (Figure 5.18). These messages usually inform operators about recommended detours, responses to their requests, if they are noticeably off schedule or route, and service-wide bulletins that affect several operators. However, while many operators believed the messages are clear, they feel that they were not easy to read. Some said that the TCH screen is difficult to read in sunlight or while wearing sunglasses. Others said that the TCH is too far from them to be easily read, or that they could not read the screen and watch the road at the same time. The complaint that the display is too far away to read may be

Question: **Rate how clear and understandable the data messages from the dispatch center are:**



Figur5.18 Operators' perceptions of dispatch messages

dependent on the operator's vehicle type and not on the TCH itself, as the TCH's are located in different locations on different vehicles.

While dispatchers can send messages to a specific bus, the operators indicated that the broadcasts to groups were often received by operators who were not affected. Some operators requested that the system be able to direct messages to certain groups of buses, such as regional service or local service, since the irrelevant messages are too distracting.

Another common theme among operators was their dislike for the beeping sound emitted whenever a message is displayed. Some felt it was too loud, while others said it was too piercing.

Street Supervisors

In interviews and surveys, street supervisors indicated that the information they received from the AVL system is accurate and easy to understand (Figure 5.19). In particular, street supervisors indicated that they performed their job more efficiently because of the information they received in-vehicle.

Question: **Rate the ease or difficulty of using the MDT:**

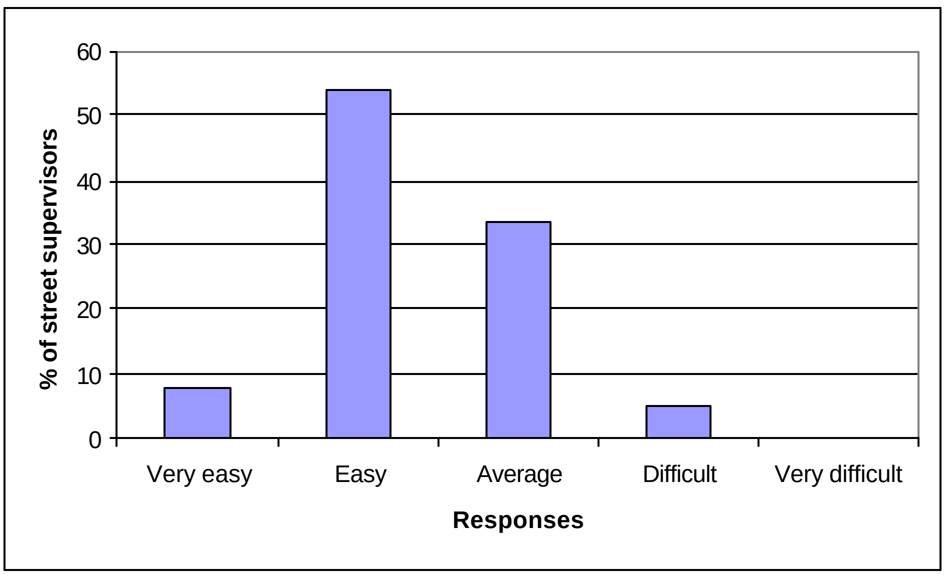


Figure 5.19 Street Supervisors' perception of MDT ease

5.4 Customer Perceptions

5.4.1 Survey Development

As with the employee surveys, the purpose of the customer survey was to assess the customer's perception and acceptance of the AVL system. The survey was designed to ascertain baseline impressions of the transit system's reliability and usefulness. The initial intention was to compare customer baseline perceptions with customer perceptions after the system was fully functional. The schedule adherence and scheduling functions were the two features that would have had the most noticeable effect for customers because they would have helped to ensure more on-time service and more realistic schedules. However, since the schedule adherence and scheduling functions were not implemented during this evaluation, and it was expected that there would be little change in customer perception.

The customer surveys were developed by CRC, RTD and Volpe. The questions asked were mapped directly to the measures of effectiveness defined in the Advanced Public Transportation Systems: Evaluation Guidelines. The length of the customer surveys was constrained to less than five minutes of phone interview because customers completed them on a voluntary basis.

5.4.2 Customer and Potential Customer Survey Methodology

Customer perceptions were gathered through surveying them on the following measures:

- perceived travel time;
- perceived schedule adherence;
- attitudes toward service provided;
- perceived convenience of service; and
- perceived safety and security.

Unique surveys were developed for two groups, RTD customers and people that had never used RTD service. The surveys were conducted by volunteers in the RTD information center. Customers and potential customers who called in requesting information were asked if they would participate in a survey. Those who agreed to take the survey were forwarded to a group of volunteers who conducted the surveys.

The public has little or no knowledge of the AVL system. RTD has no intentions to provide the public with a better awareness of it. Rather, RTD will implement service improvements based on the available functions and information provided by the AVL.

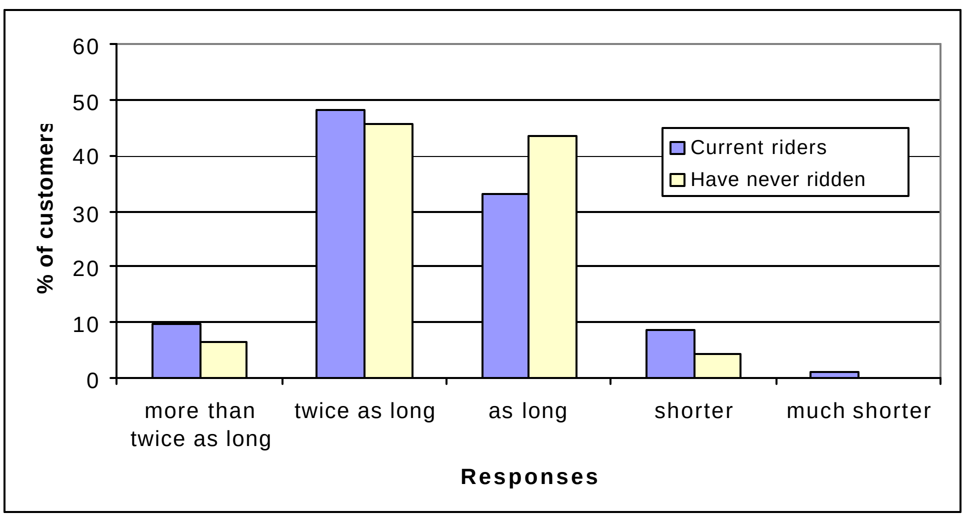
The two functions of the AVL system that would have the most noticeable impacts for the general public would be the schedule adherence and scheduling capabilities. The schedule adherence function is intended to improve the on-time performance of vehicles. The scheduling would allow for data collected by the AVL to be used in the development of route schedules, so that they accurately reflect real-world vehicle travel times.

It was intended that surveys would be taken prior to the implementation of the schedule adherence function and the use of the AVL data to develop schedules. Once these tools were implemented, two additional surveys would have been conducted at six-month intervals to assess any change in customer perceptions of RTD service. The schedule adherence was not fully implemented, however, and the scheduling department is still not using AVL data for developing route schedules. Therefore, no change in customer perceptions were analyzed.

Two surveys were developed for assessing the public's perception of the transit system. These surveys were for transit users and non-users. During the first time period of the panel survey, 673 current riders and 45 people that had never used RTD were surveyed.

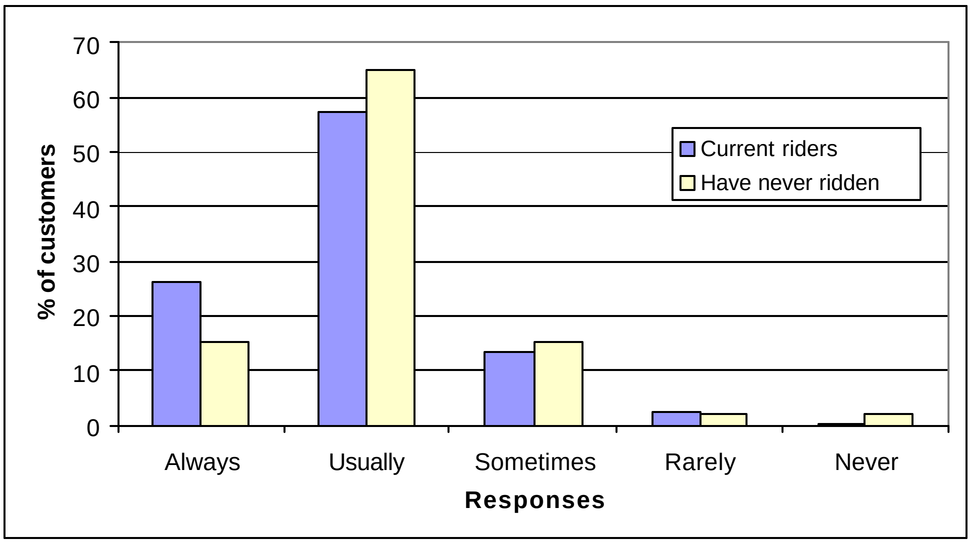
5.4.3 Perceived Travel Time

The majority of current RTD riders felt that the bus took approximately twice as long for their trips as driving themselves would take (Figure 5.20). Approximately 10% of the riders felt that it takes them less time to travel by bus than by car. Of the people that have never used RTD, the perception was slightly more positive. A little less than half the non-users felt the bus would take about the same time or less than traveling by car. A little over half felt it would take twice as long or longer.



Question: **Compared to traveling by car, rate your trip time by transit:**

Figure 5.20 Customers' perceptions of travel time

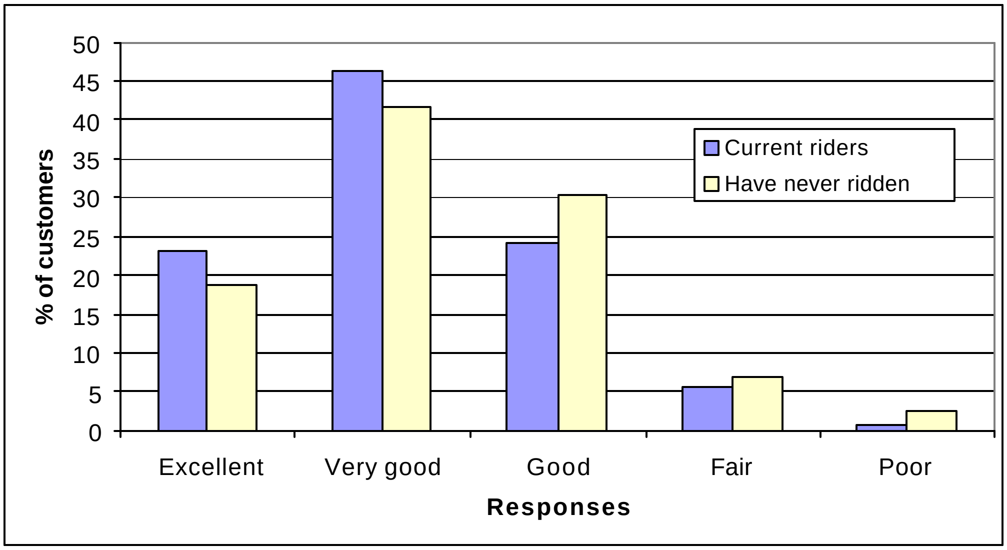


5.4.4 Perceived Schedule Adherence

Without the implementation of the AVL's schedule adherence function, most current RTD users that were surveyed felt that RTD buses were "usually" on time to their stops (Figure 5.21). Almost 30% of current users felt that the buses were "always" on time. Among non-users the perception was similar with the majority of riders feeling that the buses were "usually" on time.

Question: **How often do RTD buses reach their stops on time?**

Figure 5.21 Customers' perceptions of schedule adherence



5.4.5 <u>Perceptions of Service Provided:</u>

Over 90% of the riders surveyed stated that the service of RTD is "good" or better, with almost half of all surveyed saying it was "very good" (Figure 5.22). Less than 1% of all survey respondents felt that service was "poor." Among non-users, the perception of RTD service was almost identical.

5.4.6 <u>Perceived Convenience of Service</u>

As with the general response to the customer perception questions, the response to this question was strongly positive. Ninety-five percent of all respondents believe that RTD transit service is either "convenient" or "very convenient" (Figure 5.23). This level of satisfaction with the service was true for users of all services and for all age groups.

Question: **Rate the overall quality of RTD's service:**

Figure 5.22 Customers' perceptions of service provided

Question: **How convenient is using transit for you:**

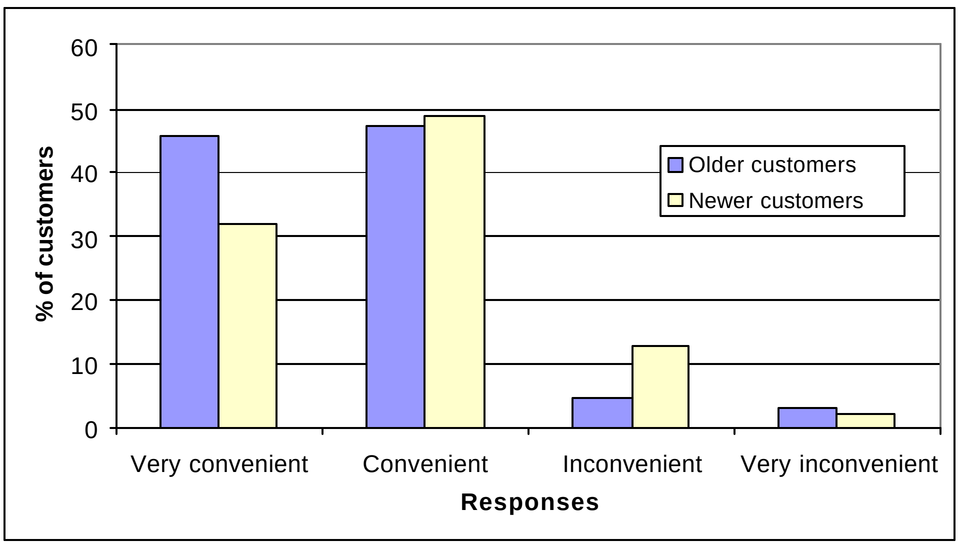


Figure 5.23 Customer and non-customer perceptions of transit convenience

5.4.7 <u>Perceived Safety and Security:</u>

Ninety-five percent of all respondents to this question said that feel either "safe" or "very safe" on RTD buses or light rail (Figure 5.24).

Question: **How safe do you feel on RTD buses and light rail?**

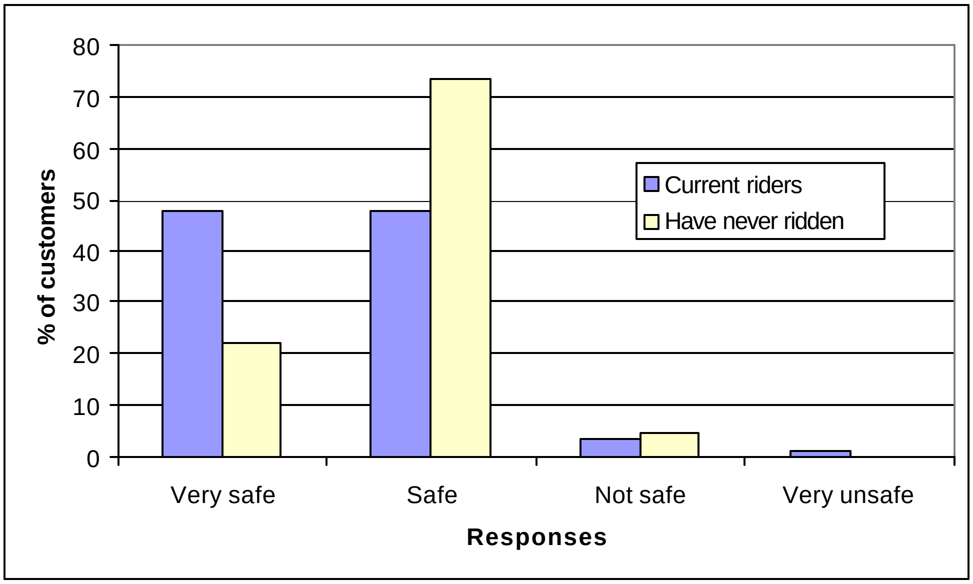


Figure 5.24 Customers' perceptions of RTD safety

6. TRANSIT SYSTEM EFFICIENCY

6.1 Introduction

One measure of the AVL's success in improving RTD's service, safety and efficiency is its cost and benefits. The AVL system has the ability to generate cost savings through more efficient routing and vehicle allocation. It can be a tool to improve customer service, with the potential of retaining more riders and attracting new ones. In this section, the efficiency of the RTD bus network is examined from 1992, the year prior to installation of the AVL system, to 1997, the year after RTD made their conditional acceptance of it.

Two related functions of the AVL which may have impacted the overall efficiency were not operational during the study period. They are the schedule adherence and scheduling functions. The schedule adherence function, as discussed in Chapter 2, allows the AVL system to track the buses on their routes and determine whether they are ahead of or behind schedule. The system can automatically alert operators of their schedule adherence performance so that the operator can adjust. Dispatchers can also manually alert operators. This could help improve efficiency by identifying buses that are consistently behind or ahead of schedule. Buses ahead of schedule will often result in excessive layovers at the end of their routes. Buses behind schedule will often result in hurried operators that accelerate and decelerate more abruptly, resulting in increased fuel consumption and less safe and comfortable conditions for passengers. Additionally, schedulers can identify buses that cannot adhere to their schedules and adjust the schedules to better fit the real world conditions observed through the AVL.

In scheduling, the information provided by the AVL system could be used to develop more realistic route schedules. For efficiency, the data concerning actual route times could help the RTD scheduling department determine appropriate headways and number of buses required for each route. This could have significant impact on the operational costs for the system if it is implemented in the future.

This chapter discusses the efficiency of RTD services and not the AVL system. It is important to note that several factors beyond the control of the AVL system also impact the operating efficiency. They include, but are not limited to:

- labor rates;
- fuel costs;
- the use of newer and more efficient equipment;
- maintenance costs;
- the size and extent of the transportation networks;
- local population fluctuation;
- weather;

- congestion;
- route system expansions and contractions; and
- RTD policy changes.

This discussion of transit system efficiency will be in broad terms because the AVL system is not the only change made to the system over the last six years, and the impacts of the various changes cannot be distinguished. It is unclear what portion of certain impacts are solely due to the AVL system.

6.2 Summary of Findings

In interviews, RTD operations personnel indicated that they do not expect the AVL system to provide noticeable economic impacts. Their reasons for selecting the system were to give them better control over a growing fleet, and to provide better customer service in order to retain customers and attract new ones. It is difficult to separate the economic impacts of the AVL system on transit efficiency from the impacts caused by other direct and indirect factors. However, it is apparent that the addition of the system has not adversely affected operational efficiency.

The efficiency measures indicate that RTD has continued to be as efficient or more efficient throughout the deployment of the AVL system. RTD ridership increased 23% while the number of hub miles increased 26%. The increase is likely the result of expanded service, population growth, and new services, such as airport expresses and light rail. Meanwhile, the cost of the service per passenger has changed only 4% over five years, a rate much lower than inflation. While the AVL system does not appear to offer a large economic incentive, it does not make any noticeable negative impacts on the system costs.

6.3 Revenue Vehicle System Miles per Revenue Vehicle Hour

Revenue vehicle miles per revenue vehicle hour is a measure of how much service is provided to customers. The total number of system-wide vehicle operating hours represents the amount of hours that vehicles are out of the yards and on the road. It does not represent the actual number of hours of revenue-generating service. Revenue miles are the total number of miles of service that are actually available to customers. An increase in the number of revenue miles provided per operating hour indicates an improvement in the delivery of service. This assumes that the service characteristics, congestion, weather and any other factors that may affect service remain relatively constant from year to year.

Revenue vehicle hours are an important indicator of customer service. As a general rule, on a fixed route system, more revenue hours result in more service to customers. There are many factors that determine the number of revenue hours, and they include:

- network size;
- service frequency;
- number of routes;
- time of day in service; and
- transportation network characteristics.

A change in the number of operating hours can be the result of either changes in the service provided, or the efficiency with which the service is provided. From an efficiency perspective, one objective of RTD is to decrease the number of operating hours while maintaining or increasing the number of revenue miles provided to the customers. Table 6.1 shows the revenue vehicle hours for RTD from 1992 to 1997.

	1992	1993	1994	1995	1996	1997
RTD Bus Revenue Hours	1,591	1,613	1,606	1,680	1,743	1,817
Light Rail Revenue Hours	-	-	-	42	47	51
Contract Revenue Hours	371	371	405	464	474	479
Total Revenue Vehicle Hours	1,962	1,984	2,011	2,186	2,264	2,347
Change from Previous Year	-	1.1%	1.4%	8.7%	3.6%	3.7%

Hours are in Thousands

Table 6.1 Revenue vehicle hours

Between 1992 and 1997, the operating hours for Denver increased 19.6%, with 2.6% of that due to the addition of light rail service. Other reasons for the increase include express service to the new Denver International Airport, which opened in 1995, and service dedicated to Rockies baseball games. RTD does not specify the operating hours dedicated to these services. Additionally, the Denver Metropolitan area has expanded throughout the 1990s as suburban cities have annexed rural areas and new developments have grown. RTD service has expanded to serve these areas. This includes Douglas County, south of Denver, which is one of the fastest growing counties in the United States.

Maximizing the number of revenue generating miles is important for two primary reasons. The first is that they account for RTD's farebox recovery. The second is that the higher the number of revenue miles, the greater the service to customers. Table 6.2 shows the change in hub miles provided by RTD. Hub miles include all revenue miles, and are used here instead of revenue miles because RTD only documents revenue miles for buses that it operates and not for contract buses or light rail. The same factors that increased the operating hours also impact hub miles.

	1992	1993	1994	1995	1996	1997
RTD Bus Hub Miles	23,834	24,294	24,502	26,407	27,727	28,287
Light Rail Hub Miles	-	-	-	492	576	705
Contractor Hub Miles	7,548	8,278	8,204	8,995	9,354	9,597
Total Vehicle Hub Miles	31,382	32,572	32,705	35,892	37,657	39,588
Change from Previous Year	-	3.8%	0.4%	9.7%	4.9%	5.1%

Miles are in Thousands

Table 6.2 Total hub miles

Total hub miles increased 26% between 1992 and 1997. The same factors that caused the rise in operating hours are likely responsible for the increase in hub miles. Specifically, the beginning of light rail operations in 1995, the new services to the airport and baseball games, and the continuing expansion of RTD's service area. It should be noted that hub miles increased more quickly than operating hours, suggesting some improved efficiency in service delivery. However, one factor affecting miles per hour is the increase in long-haul service, which tends to cover larger areas more quickly than local service.

One measure of transit system efficiency is the average hub miles per operating hour. This measure reflects the true efficiency of the RTD bus operations because it indicates the amount of service they are able to provide for every operating hour. Table 6.3 shows the average vehicle hub miles per vehicle operating hour for the years 1992 to 1997.

	1992	1993	1994	1995	1996	1997
Vehicle Hub Miles per Vehicle Operating Hour	16.0	16.4	16.3	16.4	16.6	16.9
Change from Previous Year	-	2.5%	-0.6%	0.6%	1.2%	1.8%

Table 6.3 Vehicle hub miles per vehicle operating hour

As previously stated, the new airport service (SkyRide) began in 1995. Most SkyRide buses stop only at park-and-ride lots and at the airport. Because they make few stops, they commonly travel as many as forty hub miles per hour. These buses, which accounted for between 9.0% and 10.9% of revenue between 1995 and 1997, may have a significant impact on the amount of hub miles per hour. Because RTD does not document their hub miles separately, it is unclear how significant their impact is.

6.4 Operating Costs per Revenue Vehicle Mile

This measure reflects the actual cost of delivering a mile of service to customers. It is based on the total operating cost and the number of revenue miles provided. It is a more accurate reflection of cost-efficiency than operating cost because it reflects the total amount of service provided. It also reflects economies of scale for resources shared by the entire vehicle fleet, such as the dispatch centers. Operating costs per revenue mile, however, are impacted by issues beyond the control of the AVL system, such as fuel, labor and maintenance costs. Overall operating costs include all labor, fuel, depreciation and other costs directly associated with the operation of the RTD and contractor buses and light rail cars, management, communications, dispatch services, scheduling and customer relations costs. Two major occurrences in 1994 increased the overall operating costs within RTD. The first was the renegotiation of labor contracts at higher rates, increasing the labor portion of operating costs. The second was the construction of light rail lines.

The costs shown in Table 6.4 include those of two to three subcontractors who provide bus service for RTD.

	1992	1993	1994	1995	1996	1997
RTD Bus Operations Cost	$75,576	$71,481	$85,913	$85,214	$88,118	$86,119
Light Rail Operations Cost	-	-	-	$4,321	$4,741	$4,957
Contractor Operations Cost	$16,476	$17,581	$21,583	$26,325	$27,188	$26,807
Total Operations Cost	$92,052	$89,062	$107,496	$115,859	$120,047	$117,883
Change from Previous Year	-	-3.2%	20.7%	7.8%	3.6%	-1.8%

Dollar values are in Thousands

Table 6.4 Overall operating costs

As previously mentioned, significant increases in cost are due to new service to Denver International Airport and the light rail in 1995. Total operating costs also were impacted by the following circumstances from 1992 to 1997:

- the redevelopment of the downtown area;
- an increase in longer-haul regional service;
- the addition of light rail service;
- the addition of service to Colorado Rockies baseball games; and
- a population increase of more than 15%.

Table 6.5 shows the operating cost to provide each revenue mile to RTD customers. Because revenue miles for contractors and light rail were not available from RTD, they are not included in this measure, which only examines RTD bus service.

On average, RTD bus operating costs per revenue mile decreased significantly between 1994 and 1997. This time frame corresponds with the implementation of the AVL system, and suggests some potential efficiencies that resulted from it. However, 1995 was also the year that RTD increased long-haul services, which would result in decreased operating costs per revenue mile. Long-haul routes increase the average measures of efficiency because they have very few stops and can travel more than 40 revenue miles in an hour.

	1992	1993	1994	1995	1996	1997
Operating Cost per Revenue Mile	$3.23	$3.42	$3.64	$3.26	$3.13	$2.94
Change from Previous Year	-	5.9%	6.4%	-10.4%	-4.0%	-6.0%

Table 6.5 Operating costs per revenue mile

6.5 Operating Costs per Revenue Vehicle Hour

The operating cost per revenue vehicle hour indicates the cost for every hour of bus service that is provided to customers in the Denver area. It includes only the hours that a bus is on its route and serving customers. Total revenue vehicle hours are shown in Table 6.1. Table 6.6 shows the operating cost per vehicle revenue hour for 1992 through 1997.

From 1992 to 1997, the cost of providing an hour of service has increased by 7.1%, which is nominal when compared with inflation over the same period. Excluding the light rail, the operating cost per revenue hour has increased by only 4.8%. In fact, since 1994, the system has shown significant improvements in efficiency. In 1994, costs increased significantly because of the addition of light rail service, and the renegotiation of labor contracts. It cannot be stated that the AVL system is responsible for the improved efficiencies; however, they do coincide with AVL implementation.

6.6 Overall Operating Costs per Passenger

The operating cost per passenger represents the average cost of transporting one passenger on a single route, regardless of the distance. It counts a single customer making one or more transfers as an additional passenger each time he or she transfers. Table 6.7 lists passenger travel, including 16th Street Mall passengers. The 16th Street Mall is a walking mall in the center of downtown. RTD provides free shuttle service along the mall, and the trips are all under one mile.

	1992	1993	1994	1995	1996	1997
RTD Bus Costs per Vehicle Revenue Hour	$47.50	$44.32	$53.50	$50.72	$50.56	$47.40
Light Rail Costs per Vehicle Revenue Hour	-	-	-	$102.88	$100.87	$97.20
Contractor Costs per Vehicle Revenue Hour	$44.41	$47.39	$53.29	$56.73	$57.36	$55.96
Total Operating Costs per Vehicle Revenue Hour	$46.92	$44.89	$53.45	$53.00	$53.02	$50.23
Change from Previous Year	-	-4.3%	19.1%	-0.8%	0.0%	-5.3%

Table 6.6 Operating costs per revenue vehicle hour

	1992	1993	1994	1995	1996	1997
RTD Bus passengers	38,996	40,515	40,276	39,420	41,677	41,882
RTD 16th St. Mall	13,380	13,892	13,955	13,874	13,655	14,893
Light Rail Passengers	-	-	-	4,054	4,075	4,428
Contractor Passengers	5,999	7,038	7,804	10,280	10,776	10,632
Total Passengers	58,374	61,445	62,452	67,550	70,105	71,834
Change from Previous Year	-	5.3%	1.6%	8.2%	3.8%	2.5%

Passengers are in Thousands

Table 6.7 RTD bus passengers

The AVL system could impact the operating cost per passenger, as shown in Table 6.8, by increasing ridership through increased customer satisfaction and on-time performance. Additionally, the system can be used to make schedules and routing more efficient, thus reducing costs. These two factors could decrease the operating cost per passenger. In Denver, however, due to their difficulties integrating the AVL system into their existing scheduling practices, it was not utilized to improve scheduling or routing during the evaluation period.

Since 1994, the cost to serve a passenger by bus has decreased in real and nominal value. As previously discussed, the higher operating costs per passenger in 1994 were due in part to increased labor costs. The cost per passenger since 1992 has increased slightly, but slower on average than the rate of inflation. There is not enough evidence to state that the AVL system reduced the operating cost per passenger. However, its implementation coincides with the cost savings. At the very least, the AVL system appears not to have adversely impacted operating costs per passenger.

	1992	1993	1994	1995	1996	1997
Operating Costs per RTD Bus Passenger	1.44	1.31	1.58	1.60	1.59	1.52
Operating Costs per Light Rail Passenger	-	-	-	1.07	1.16	1.12
Operating Costs per Contractor Passenger	2.75	2.50	2.77	2.56	2.52	2.52
Average Operating Costs per Passenger	$1.58	$1.45	$1.72	$1.72	$1.71	$1.64
Change from Previous Year	-	-8.2%	18.6%	0.0%	-0.6%	-4.1%

Table 6.8 Operating costs per passenger

7. TRANSIT SYSTEM EFFECTIVENESS

7.1 Introduction

A main component of this evaluation is to determine if the deployment of AVL systems is cost effective for RTD. To accomplish this, the effectiveness of various aspects of the service that are affected by the introduction of an AVL system were considered:

- service quality;
- service utilization;
- productivity;
- safety and security;
- revenue generation; and
- customer satisfaction.

When RTD deployed the AVL system, they believed that it would have a major impact on customer service. They planned for it to improve the scheduling and schedule adherence, as well as provide better information to customers. Three main components of the AVL that have a major impact on RTD's objectives proved far more problematic than originally expected. These components were the schedule adherence, scheduling interface and Public Information Display System (PIDS). A description of each of these components and why it was not implemented in Denver during the evaluation period is included in Chapter 2.

The schedule adherence function would have helped to ensure a higher level of on-time performance. Operators would have been notified as to how many minutes ahead or behind schedule they were in relation to the planned schedule. Additionally, once the bus reached certain thresholds for being early or late, they would have been automatically notified. The operators could adjust their progress to match the published schedule more closely. The impact of this on system effectiveness could be significant. Passengers expect buses to arrive at the planned times. Passengers experience discomfort and dissatisfaction in waiting for a bus, especially during winter months. Early buses can result in missed passengers or missed connections, increasing passenger travel time. Late buses result in passengers waiting longer in the elements, reaching their destinations late and missed connections. While the schedule adherence is not officially utilized, the dispatchers often manually use the AVL system to track late or off-route vehicles and inform the operators.

The scheduling interface would have allowed the scheduling department of RTD to collect information on schedule performance of all the routes at any time of the year. It would have allowed them to identify locations where buses were chronically early or late, and adjust the schedules to meet the real-world conditions. Accurate schedules are crucial for customer satisfaction. When the schedules accurately reflect the time that buses will reach their stops, the customers grow to trust the schedule guides and plan their trips accordingly. Late or early buses quickly erode that trust and force potential customers to seek more reliable forms of transportation.

PIDS would have provided real-time route information to customers at the downtown transit stations. It was to be updated by the AVL system to reflect the real arrival and departure time of buses passing through the station. This would have been useful to downtown passengers who could walk into the station, view the time their bus was planning to depart, and then return to activities in the mall or other locations. RTD still intends to resolve the problems with the PIDS system, and have it operational.

During RTD personnel interviews and surveys, the AVL system was strongly supported as a means to improve the effectiveness of the service.

7.2 Summary of Findings

Comparing the transit system effectiveness measures prior to the implementation of the AVL (1992) through 1996, RTD transit operations have become significantly more effective. The on-time performance, even without full-utilization of the schedule adherence capabilities of the system, has shown improvement. Before the AVL implementation, the RTD system had an 87.8% on-time performance record. Since AVL implementation, this has improved to 89.2%, with a reduction in both late and early arrivals.

Passengers per revenue and vehicle mile were unchanged, even with the expansion of the RTD service area to include new communities to the north and south, and the Denver International Airport to the east. However, the safety and security of passengers increased significantly as passenger and operator assaults declined 20% from 1992 to 1997, and the assaults per 100,000 passengers boarded decreased by 33%. During the same period, the number of documented customer complaints per 100,000 boardings decreased by 26%.

7.3 Service Quality

Service quality examines RTD's overall effectiveness at providing transit service to the Denver area. Potential customers choose their transportation modes in a rational manner, weighing the advantages and disadvantages of all their options. Therefore, transit's appeal is based on the overall quality in comparison with the other options. It is assumed that as transit becomes more effective and the quality improves, its attractiveness to travelers will increase.

7.3.1 Pre-trip passenger information

Pre-trip passenger information is a current service provided by RTD to the Denver Metro Area. Dedicated RTD phone lines and customer service representatives provide transit users with specific routing and scheduling information as required. As of 1995, a web site was added that also provides route, schedule and pricing information (http://www.rtd-denver.com/).

The roles of customer service personnel are to:

- provide information on routes, schedules and pricing;
- provide personalized routing from potential customers' origins to destinations;
- take service commendations or complaints; and
- follow-up with customers regarding commendations and complaints.

Eventually, RTD wants to install AVL monitors in the customer service area. Currently, when customers call, customer service representatives provide canned information about route schedules. With the AVL monitor, they will be able to provide real-time information and answer questions about whether a particular bus is on-time or late. This function will be particularly helpful during winter months when buses may be significantly delayed by road/weather conditions. A potential customer would be able to call in and learn at what time the bus will be at the desired stop, and then wait inside until that time.

There are two primary impacts of the AVL on operations in the customer service center. The first is the AVL playback function. When customers call to complain that a bus or light rail car missed their stops, or were not there when scheduled, customer service may contact the dispatch center. Dispatch can use the playback function of the AVL to observe the actual movement of the bus or light rail in question and either verify or invalidate the customer's complaint. This has been helpful in determining whether or not to penalize coach operators based on the complaints received.

Although the AVL system cannot be monitored from the customer service center, customer service personnel occasionally call the dispatch center to determine the actual location of a vehicle. This information can then be relayed to the potential customer. Because of the high number of requests that the customer service center receives, and the heavy workload in the dispatch center, this does not occur very often.

7.3.2 Schedule adherence

Schedule adherence by RTD is quite possibly the most important measure of effectiveness that the public experiences. Schedule adherence relates RTD's ability to provide consistent, reliable and on-time service. Although schedule adherence is not fully functional, it is used in some circumstances to get vehicles back on schedule and on route. Additionally, because the AVL system allows the dispatchers the ability to more closely monitor vehicle progress, operators are more likely to be cited for running ahead of or behind schedule. Because they can be punished for their on-time performance, operators have a significant incentive to adhere more closely to their schedules.

Schedule adherence statistics are currently determined through "quasi-random" time checks at 40 or more locations within the service area. Approximately 11,000 trips are checked each year. Table 7.1 shows the on-time performance of RTD buses from 1992 to 1997.

	1992	1993	1994	1995	1996	1997
Observations	12,602	12,851	12,586	10,077	12,720	11,494
% of observations Early (1 minute or more)	5.2%	5.2%	4.9%	5.1%	4.9%	4.6%
% of observations on time	87.8%	86.5%	87.5%	87.9%	89.3%	89.2%
% of observations Late (5 minutes or more)	7.1%	8.2%	7.0%	6.1%	5.7%	5.6%
% of Regional and Express Service within 5 minutes of schedule	95.1%	93.1%	93.2%	94.7%	94.7%	94.2%

Table 7.1 RTD schedule adherence

Between 1992, the year before the AVL system was deployed, and 1997, the system-wide schedule adherence improved in every category. The improvements over the five years were as follows:

- a 12% (from 5.2% to 4.6%) reduction in buses arriving at stops early;
- a 2% (from 87.8% to 89.2%) improvement in the number of vehicles arriving on time; and
- a 21% (from 7.1% to 5.6%) reduction in the number of vehicles that were late.

Because RTD's service was performing well in 1992, these achievements are even more noticeable. It appears from these statistics that even without a fully operational schedule adherence function, the AVL system made a significant positive impact on on-time performance.

7.4 Service Utilization

Service utilization is one end result of the efficiency improvements, marketing strategies, and promotions intended to increase market share. The measures of effectiveness for service utilization are the number of people using the service, and the way in which the service is used. Improvements in the service provided to customers can increase utilization in several ways. As service improves, more customers may be retained by the system, or those that use the system irregularly may use it more frequently. Additionally, new customers may be attracted through word of mouth or observation of service improvements. If they are satisfied with the service, existing passengers may find additional reasons to use RTD.

7.4.1 Passenger Trips per Year

The number of passengers carried by RTD is a strong indication of the effectiveness of the transit organization. Table 7.2 shows the change in ridership between 1992 and 1997.

	1992	1993	1994	1995	1996	1997
RTD Bus passengers	38,996	40,515	40,276	39,420	41,677	41,882
RTD 16th St. Mall	13,380	13,892	13,955	13,874	13,655	14,893
Light Rail Passengers	-	-	-	4,054	4,075	4,428
Contractor Passengers	5,999	7,038	7,804	10,280	10,776	10,632
Total Passengers	58,374	61,445	62,452	67,550	70,105	71,834
Change from Previous Year	-	5.3%	1.6%	8.2%	3.8%	2.5%

Passengers are in thousands

Table 7.2 Passengers per year

As previously discussed, the Denver International Airport opened and light rail began service in 1995. They are main factors responsible for the increase in ridership during that and later years. In 1995, SkyRide service accounted for 915,000 passenger trips (1.4% of all trips). That increased to 1,292,000 in 1996 (1.8%) and 1,534,000 in 1997 (2.1%). The other known contributing factors that impacted the ridership were increased service and population growth. A better indicator of service utilization than total number of passengers is the number of trips per member of the population.

7.4.2 Trips per member of Population per Year

The Denver Metropolitan Area has grown significantly during the 1990s, both in population and in area. New communities have expanded into unincorporated areas to the north and south of the city. Table 7.3 shows the change in population in the Denver Metropolitan Area from 1992 to 1997.

Table 7.4 shows the number of trips per member of the Population from 1992 to 1997.

	1992	1993	1994	1995	1996	1997
Denver Metro Population	2,088	2,147	2,190	2,233	2,277	2,329
Change from Previous Year	-	2.8%	2.0%	2.0%	2.0%	2.3%

Source: U.S. Census Bureau, Population is in thousands

Table 7.3 Denver metropolitan area population

	1992	1993	1994	1995	1996	1997
Passengers per Member of the Population	28.0	28.6	28.5	30.3	30.8	30.9
Change from Previous Year	-	2.1%	-0.3%	6.3%	1.7%	0.3%

Table 7.4 Passenger trips per member of the population

During each year, except for the estimated number for 1994, the number of passenger trips per member of the population has increased. Since 1992, the year prior to AVL implementation, the total number of trips per member of the population has grown by more than 10.3%. However, new light rail service, which began in 1995, accounts for all but 3.2% of that increase, while SkyRide accounts for approximately 2.4%. The AVL system does not appear to have made a significant impact on passenger trips per member of the population.

7.5 Productivity

One measure of transit system effectiveness involves the overall productivity which RTD experiences. Productivity includes measures needed to evaluate the major performance categories of financial impacts, transit system efficiency and effectiveness as well as overall operating and maintenance costs. Productivity is assessed through the following measures:

- number of passenger trips per vehicle mile;
- number of passenger trips per revenue mile;
- number of passenger hours per vehicle hour;
- number of passenger hours per revenue hour; and
- overall operating costs per UPT.

7.5.1 <u>Passenger Trips per Vehicle Hub Mile</u>

The AVL system may affect a change in passengers per hub mile by allowing planners and schedulers to identify the times of day and routes that receive the heaviest ridership and would benefit from additional service. Additionally, any improvements in service may help to retain customers and add new passengers.

Table 7.5 shows the number of passengers per vehicle hub mile. This more accurately reflects the increase in ridership as a function of the amount of service provided. Changes can result from population and demographic changes, but the passengers per operating mile may also be impacted by the type of service provided, its quality, and the extension or contraction of service in areas.

	1992	1993	1994	1995	1996	1997
Passengers per RTD Bus Hub Mile	2.20	2.24	2.21	2.02	2.00	2.01
Passengers per Light Rail Hub Mile	-	-	-	8.24	7.07	6.28
Passengers per Contractor Hub Mile	0.79	0.85	0.95	1.14	1.15	1.11
Total Passengers per Hub Mile	1.86	1.89	1.91	1.88	1.86	1.81
Change from Previous Year	-	1.6%	1.1%	-1.5%	-1.1%	-2.7%

Table 7.5 Passengers per vehicle hub mile

From 1992 to 1997, the number of passengers carried per vehicle hub mile decreased by 2.7%. This indicates that the transit system has not become significantly more effective at carrying passengers due to the AVL.

7.5.2 Passengers per Vehicle Revenue Hour

The AVL system may also affect a change in passengers per vehicle revenue hour. The efficiency with which RTD delivers each hour of service, in addition to how many miles the buses travel per hour, is reflected in this value. In general, the more miles that are traveled, the more passengers that can be served. Table 7.6 illustrates the passenger trips per vehicle hours for 1992 to 1997.

The change in passengers per hour is only 2.7% between 1992 and 1997, with a slight decrease since 1994. This is in part due to the increase in long-haul service, which carried each passenger for more miles per trip. It appears that there is no significant improvement in passengers per vehicle hour as a result of AVL system.

	1992	1993	1994	1995	1996	1997
Passengers per RTD Bus Revenue Hour	32.9	33.7	33.8	31.7	31.7	31.2
Passengers per Light Rail Revenue Hour	-	-	-	96.5	86.7	86.8
Passengers per Contractor Revenue Hour	16.2	19.0	19.3	22.2	22.7	22.2
Average Passengers per Vehicle Hour	29.8	31.0	31.1	30.9	31.0	30.6
Change from Previous Year	-	4.0%	0.3%	-0.6%	0.3%	-1.3%

Table 7.6 Passengers per revenue hour

7.6 Safety and Security

The safety and security of a transit operation and, more importantly, perceptions of safety and security, have a significant effect on ridership and driver morale. The AVL system allows police, fire and ambulance services to locate a vehicle with an emergency much more quickly than through the previous system. This helps reduce the potential danger that prolonged situations can create.

The AVL system also provides the driver with increased support from dispatch, especially during emergencies. Improved morale is discussed in Chapter Five, where dispatchers, operators and street supervisors indicated a high level of faith in the system during emergency situations.

The safety and security of the system, pre- and post-implementation of the AVL system, are assessed through the number of operator and passenger assaults. In Denver, when passenger or operator assaults occur and a police report is written, there is often an article in the newspapers. Although the instigation of these incidents are usually out of the control of the RTD, the publicity is detrimental to RTD's intention of promoting its buses as a safe transportation mode. The AVL may shorten the duration of incidents by providing police with information regarding vehicle location more quickly than with the previous radio system. It may also prevent assaults by providing information quickly so that police can respond before potential incidents conflagrate. Finally, the system can deter repeat offenders by allowing police to arrest them before they can flee the scene of an assault. Table 7.7 quantifies the number of passenger and operator assaults in total, and per 100,000 boardings.

	1992	1993	1994	1995	1996	1997
Passenger and Operator Assaults	105	102	101	88	122	84
Change from Previous Year	-	-2.9%	-1.0%	-12.9%	38.6%	-30.3
Passenger and Operator Assaults per 100,000 Boardings	0.18	0.17	0.16	0.13	0.17	0.12
Change from Previous Year	-	-5.6%	-5.9%	-18.8%	30.8%	-35.3%

Table 7.7 Passenger and operator assaults

Between 1992 and 1995, the number of assaults decreased each year. The assaults increased significantly in 1996, but declined again in 1997. In total, the number of assaults between 1992 and 1997 decreased by 33% per 100,000 boardings. This decrease is a major achievement and a credit to RTD. One potential contributing factor has been the addition of surveillance cameras in buses along the most troublesome routes, beginning in 1996. No statistics were available for assault reduction on those routes, but RTD indicated during interviews that they have helped in reducing incidents. Overall, the improved safety and security correlates with the implementation of the AVL system. Its safety features, including the silent alarm, appear to have a positive impact on the service provided to customers.

7.7 Revenue Generation

With funding shortfalls at many agencies and a dearth of public funding for transit, it is important that transit agencies generate as much revenue as possible through the farebox. An increase in service utilization should produce a corresponding increase in farebox revenue. The measures of revenue generation effectiveness are:

- transit fares collected;
- ratio of operating cost recovered through farebox; and
- revenue collected per revenue mile.

7.7.1 <u>Transit Fares Collected</u>

Transit fares collected are directly dependent on both the number of passengers and the types of service RTD provides to them. Passenger volumes from 1992 to 1997 are discussed in Section 7.3.1. RTD relies on its customers to provide a large portion of its annual operating revenue. Additionally, the larger the revenue the District generates, the less reliant it is on tax revenue. Additionally, with higher revenue collection, RTD can provide improved service.

Table 7.8 shows the fares collected from 1992 to 1997.

	1992	1993	1994	1995	1996	1997
Transit Fares Collected	$27,381	$27,169	$29,127	$32,551	$34,443	$38,480
Change from Previous Year	-	-0.8%	7.2%	11.8%	5.8%	11.7%

Dollars are in thousands

Table 7.8 Transit fares collected

The increase in revenue in 1995 is mostly due to the addition of the SkyRide service to Denver International Airport, which accounted for approximately 1.9% of paying passengers, but increased revenue through prices that were routinely four to eight times higher than other routes. SkyRide fares are anywhere from $4.00 to $8.00 per trip, where local routes normally cost passengers $0.75 to $1.25 per trip. SkyRide revenue likely accounted for, at a minimum, six percent of the revenue in 1995 and beyond. In 1997, RTD raised rates approximately 25% on all routes except SkyRide service. It is unclear whether the AVL system has had any impact of farebox recovery.

7.7.2 Ratio of Operating Cost Recovered Through Farebox

The ratio of operating cost recovered through the farebox is an accurate indicator of the overall effectiveness of the transit system at supporting itself and providing a necessary service. Lower farebox return ratios can indicate that the system is not as efficient as it should be, or that it is supplying a service without sufficient demand. In Chapter 6, the efficiency of RTD was examined and the system was found to be efficient. Therefore, the farebox return ratio as discussed here indicates the ability of the service to provide a service that is desired. This service includes not only routes in the appropriate geographic areas, but also timeliness, cleanliness and safety. Table 7.9 illustrates the change in farebox recovery ratio from 1992 to 1997.

	1992	1993	1994	1995	1996	1997
Farebox Recovery Ratio	29.7%	30.5%	27.1%	28.1%	28.7%	32.6%
Change from Previous Year	-	2.7%	-11.1%	3.7%	2.1%	13.5%

Table 7.9 Ratio of operating costs recovered through farebox

RTD system increased fares in 1995 and 1998. Additionally, RTD added the SkyRide service in 1995, with fares ranging from $4.00 to $8.00 per trip. These are likely responsible for a large portion of the increase in farebox recovery. The trend suggests that RTD has maintained its farebox recovery ratio, despite the increases in operating cost that resulted from expanding the network. Because of other factors, including increased fares, and expanded service, it is difficult to estimate the impact of the AVL system on the ratio of operating costs recovered through the farebox.

7.7.3 Revenue per Hub Mile

Revenue per hub mile reveals the actual effectiveness of each mile RTD vehicles travel. This measure indicates the usefulness of the service to customers. Similar to the farebox recovery ratio, the AVL system can improve revenue per hub mile by improving service timeliness and safety. Table 7.10 illustrates the change in revenue per mile between 1992 and 1997. The revenue per vehicle mile stayed relatively flat except in years where there were fare increases. It is unclear how the AVL system impacted revenue per hub mile.

	1992	1993	1994	1995	1996	1997
Revenue per Vehicle Mile	$0.87	$0.83	$0.89	$0.91	$0.91	$0.97
Change from Previous Year	-	-4.6%	7.2%	2.2%	0.0%	6.6%

Table 7.10 Revenue per vehicle mile

7.8 Customer Satisfaction

One of the most important measures of the AVL system in Denver is the level of customer and employee satisfaction. When customers are satisfied with the service they receive, they are less likely to seek other modes of transportation. Additionally, a high level of current customer satisfaction will result in new service users.

RTD has stated that their primary reason for incorporating the AVL system into their management and operation system was to have better control over their vehicles and provide better customer service. They did not believe that the system would make a significant impact on the efficiency with which they could deliver each mile of passenger service. However, through improved control of their fleets, and the resulting improvement in service, they anticipated more satisfied customers and employees and higher ridership levels. As Section 7.4 shows, RTD has enjoyed increased ridership, both in total and per member of the metropolitan population. Through surveys of customers and potential customers that are documented in Chapter 5, it can be seen that customers are generally satisfied with the service currently provided.

In this Section, the trend of satisfaction is examined from prior to the implementation of the AVL system to the most recent completed year, to determine if customer satisfaction regarding service has changed. The measure of effectiveness is the number of customer complaints and commendations registered by RTD in each year.

7.8.1 Complaints and Commendations

Complaints and commendations are made to RTD through their customer service center and through the mail. They may include comments about specific operators, schedule adherence, vehicle cleanliness, safety, security and fare disputes. While the AVL system cannot directly address all of these issues, it is intended to help improve service and customer satisfaction. Table 7.11 shows the number of complaints and commendations that have been received each year by RTD, in total and per 100,000 boardings.

	1992	1993	1994	1995	1996	1997
Complaints	12,783	13,866	13,547	10,670	9,773	11,606
Complaints per 100,000 Boardings	21.90	22.59	21.69	15.80	13.94	16.16
Change from Previous Year (per 100,000 boardings)	-	3.5%	-4.0%	-27.1%	-21.2%	15.9%
Commendations	2,095	2,117	1,995	1,647	1,479	N/A
Commendations per 100,000 Boardings	3.59	3.45	3.19	2.44	2.11	N/A
Change from Previous Year (per 100,000 boardings)	-	-3.9%	-7.5%	-23.5%	-13.5%	N/A

Table 7.11 Customer complaints and commendations

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

The purpose of this evaluation was to determine how well the RTD AVL system achieved its major objectives of improving scheduling efficiency, improving the ability of dispatchers to adjust on-street operations, and increasing safety through better emergency management. The evaluation is intended to help the FTA and other transit agencies determine whether an AVL system will benefit transit employees and customers in other locations.

The results of the AVL system have been, in general, successful at achieving RTD's objectives. However, it should be noted that there were several factors discussed in this document that prevented it from being more successful during the period of the evaluation. As stated in the Prologue, however, most of the problems have been resolved and the system is now performing very close to its intended operational level.

8.2 Functional Characteristics

The AVL system deployed in Denver was problematic during its first two years. RTD and TMS spent considerable time "debugging" the system and resolving issues regarding false alarms and computers that crashed. However, TMS and RTD's efforts have resulted in a stable system, with these issues resolved.

The accuracy of the system has proven to be very good. The vehicle location determination tests performed by Sandia National Laboratories showed that vehicle locations were within the acceptable thresholds for urban, suburban and mountainous testing.

It should be noted, however, that the system suffers from the same shortcomings as other GPS-based systems. In urban canyons, where buildings are tall, the GPS satellites are not always visible and this can necessitate position estimation be accomplished by a secondary means. Additionally, glass buildings can serve as reflectors that distort the satellite signals, resulting in errors. In mountainous areas, deep canyons and heavy woods can obscure the satellite-receiver line of sight. If any of these conditions exist in a transit agency's service area, a second method of position determination, such as dead-reckoning, is recommended as a default when the GPS signal is not available.

Since the AVL system has stabilized, the equipment has proven to be reliable. The RTD staff that use the radios and TCH units believes they seldom fail to transmit a call or reliably locate a vehicle.

Nevertheless, the in-vehicle logic units are subject to considerable abuse and this results in some damaged units.

8.3 Acceptance and Perceptions

In general, the employees believe that the AVL system is a useful tool. Supervisors and dispatchers have the highest level of acceptance, primarily because it gives them more control over the fleets. Operators largely have grown to accept and rely on the system. However, they have concerns that dispatchers have too much control, or are monitoring their performance too closely. These concerns were expected because AVL appears to be more intrusive on the operators' independence. In order to remove the "Big Brother" impression, RTD may take steps to insure that disciplinary actions are not directly related to the use of the AVL system. In future AVL implementations, transit agencies should emphasize the benefits of the AVL systems to the operators. They should also define the information that will be collected by it, and, more importantly, what information will not be collected. This will help operators understand that the AVL system has not been installed to monitor them, but to improve customer service.

When first deployed, the AVL system had many software bugs that caused the system to crash with regularity. Consequently, dispatchers and operators perceived it as unreliable. However, since the software bugs have been corrected, the perception of system reliability has improved.

Customers are uniformly pleased with the schedule adherence and reliability of the RTD transit service. Because the schedule adherence and scheduling functions were not in operation during the evaluation period, customer's perceptions of any service improvements due to these functions could not be determined. It is suggested that RTD conduct a customer survey two years after these elements are operational to determine if they have changed customer perceptions.

8.4 Transit System Efficiency

RTD's scheduling department does not take advantage of the vast amount of AVL route information available to it because of the difference in data formats. In its efforts to develop realistic schedules for every route, RTD manually collects data at about 11,000 time points per month. Additionally, routes are driven in supervisor vehicles to determine the proper amount of time it will take a bus to go from one stop to the next. Using this information, scheduling department personnel create the most realistic and feasible schedules they can. In actuality, however, the schedule can be too tight or too loose because of factors not seen in the limited data that is collected.

Based on results of this evaluation, it seems unlikely that RTD can reduce total vehicle miles and hours, or increase revenue miles and hours without the use of AVL data and the scheduling analysis function. RTD is currently developing algorithms for using AVL data in its scheduling process. This is crucial to improving the scheduling efficiency and should be done as quickly as possible. It is recommended that once this function is operational, and new schedules are developed using the data generated by the AVL, that RTD examine whether these schedules are more efficient than the pre-AVL schedules.

Appropriate use of AVL data has the potential to impact the economic efficiency of the transit system through increased ridership as a result of higher customer satisfaction, more efficient scheduling, and improved safety. However, improving the economic efficiency of the transit system was not an objective of RTD in installing the AVL system and there were no quantifiable performance goals established for economic impact during this evaluation or by RTD. It was examined in this evaluation, however. The cost per operating hour and the cost for delivering each revenue mile did not increase beyond inflation, and since 1994, costs have declined per revenue mile and per hour for RTD bus operations. There are several factors that could have increased operating costs, including increased labor fees, expanded service, and the addition of light rail. While it cannot be definitively stated that the AVL system was responsible for the decrease in operating costs, the cost savings do coincide with its implementation.

8.5 Transit System Effectiveness

RTD experienced improved performance in schedule adherence compared to their performance prior to AVL implementation. In general, the service already performed well, with 87.8% of the vehicles in their sample reaching their stops on time in 1992. By 1997, this improved to 89.2%, a slight but valuable improvement. This was achieved despite the schedule adherence function of the AVL system being technically, but not fully, operational.

A fully operational schedule adherence function could further improve on-time performance by providing the operators with the on-time performance of their vehicles at any point along their routes. The system also would alert dispatchers to any vehicles that are significantly ahead of or behind schedule. Resolving this issue should be a priority for RTD. Improved schedule adherence impacts RTD's performance in many ways. Primarily, it improves customer satisfaction, which will help retain and attract customers.

One reason why the schedule adherence function is not fully operational is because the scheduling department has coded many routes differently than they are routed in the AVL system. The differences are slight, but the discrepancies prevent the AVL system from making accurate comparisons. RTD has not been successful in getting the two systems to route vehicles the same, and the result is that the schedule adherence function is unstable. Because of its heavy workload, the scheduling department has not been able to work on the development of a suitable information exchange format.

The AVL system has been deemed a success in helping RTD achieve its objective of improving the ability of dispatchers to adjust on-street operations. Dispatchers can now see the geographic location of a single vehicle or several vehicles. They can identify which street supervisor or maintenance vehicle is closest to a bus or light rail car. However, there is no quantifiable measure of the dispatchers' improved ability to control on-street operations. The primary means for gauging it are through the dispatchers' satisfaction and belief that they have more control. In general, the dispatchers prefer the AVL system over the previous system. They are better able to serve the operators and prioritize calls using the AVL system. The dispatchers ability to control on-street operations will improve even more when the AVL system can automatically notify them of vehicles significantly ahead of or behind schedule.

The area of emergency management has seen significant improvement. The AVL system is not designed to prevent incidents, but to help the dispatchers respond more quickly and appropriately. In this respect, it has achieved its objective. Specifically, the silent alarm and covert microphone has allowed dispatchers to monitor on-board situations and evaluate them without having to call or speak with the operator. Dispatchers are able to track a vehicle that has called in with an emergency. While they track the vehicle, the dispatchers can call the police or other appropriate emergency response agency, such as police, fire or paramedics, and direct them to the exact location of the bus. The hidden microphone on the vehicles and the vehicle tracking capabilities have given operators, dispatchers and street supervisors a higher sense of security. There have been numerous cases of crimes thwarted, or fights stopped, due to the quick response to silent alarms. Because passengers are not aware of the AVL system, it is unclear whether they feel a heightened sense of security.

The main flaws of the silent alarm function are the number of false alarms accidentally triggered by operators, and the times when operators have used the silent alarm when it would have been more appropriate to use the PRTT button on the TCH. These problems are minor in comparison to the positive benefits, however. Strong training and a better placed silent alarm button in the operators' seating areas should resolve most of the false or incorrect alarms.

RTD did not have the stated objective of increasing ridership using the AVL system. However, improving scheduling efficiency and safety are expected to improve the transit experience for the customer. Nevertheless, RTD does not actively advertise the facts that their buses are on time more often, that the schedules and transfers are more efficient, and that the buses are safer. Consequently, the general public in Denver is not aware of the AVL system and the potential benefits it provides to them. If these benefits are made known, this should help retain customers and attract new riders. During this evaluation, RTD saw marginal improvements in ridership per member of the population, but experienced little change in ridership per revenue mile traveled. Therefore, the impact of the AVL system on ridership appeared to be insignificant. In order to increase ridership, a transit agency may have to publicly promote the system improvements.

The AVL system can collect information on schedule adherence from each route for each run of every day. This information could be used to optimize schedules by time of day or season of the year. The result would be more accurate schedules for operators to adhere to, more accurate information for schedulers to plan the entire network and key connections with, and more accurate schedules for customers to plan their trips by. Transit agency personnel should work to identify ways in which the AVL system can help them maximize the system's efficiency through collection and use of AVL data. During AVL system planning and implementation, efforts should be made to involve all staff and have them identify the types of information that will be useful to them. The AVL system should actively be promoted as both a fleet control and a data collection tool, so that it can be utilized to its fullest potential.

For future AVL deployments, agencies should consider their existing data systems and specify that the AVL system interact seamlessly with them. It should be imperative that the vendor understand the transit agencies legacy systems and minimize the amount that must change to serve the AVL system. This will minimize the resistance of the employees conditioned to work with the legacy systems, as well as allow for better information exchange.

9. ACRONYMS USED IN THIS DOCUMENT

APTS	Advanced Public Transportation Systems
AVL	Automatic Vehicle Location
LCD	Liquid Crystal Display
CAD	Computer-Aided Dispatch
CRC	Castle Rock Consultants
FTE	Full-Time Employee
GPS	Global Positioning System
IT	Information Technology
IVLU	In-Vehicle Logic Unit
LCD	Liquid Crystal Display
MDT	Mobile Data Terminal
MECH IN	Mechanical Bus Failure that allows bus to continue service (button on TCH)
MECH OUT	Mechanical Bus Failure that requires bus to go out of service (button on TCH)
MOE	Measure of Effectiveness
NO RLF	Operator has not been relieved in his duties as is scheduled (button on TCH)
PIDS	Public Information Display System
PRTT	Priority Request to Talk (button on TCH)
RTD	Regional Transportation District
RTT	Request to Talk (button on TCH)
STUC	Bus is stuck and cannot move (button on TCH)
TCH	Transit Control Head
TDMA	Time Division Multiple Access
TMS	Transportation Management Solutions

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