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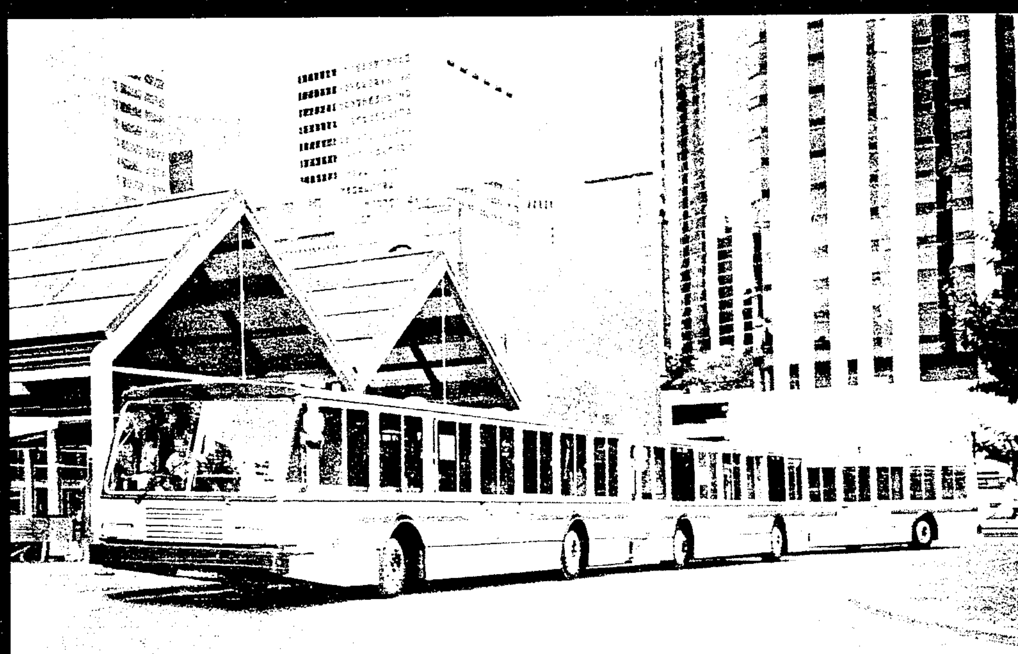
Federal Transit Administration

# Denver RTD's Computer Aided Dispatch/Automatic Vehicle Location System: The Human Factors Consequences



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13. ABSTRACT (Maximum 200 words)
This report documents what happened to employees' work procedures when their employer installed Computer Aided Dispatch/Automatic Vehicle Locator (CAD/AVL) technology to provide real-time surveillance of vehicles and to upgrade radio communication. Denver's Regional Transportation District (RTD) acquired a CAD/AVL system and installed it system-wide. The Operator Performance and Safety Analysis Division, DTS-79, at the U. S. Department of Transportation's Volpe National Transportation Systems Center (Volpe Center), performed this research with the support of the Federal Transit Administration's (FTA) Advanced Public Transportation Systems (APTS) Program.
The analyses examined the usability of the CAD/AVL features and how CAD/AVL affected the employees' work tasks. Employees' responsibilities remained the same but they received additional information. Dispatchers transmit and receive more calls. Street supervisors' duties have expanded but their staffing level is unchanged. Bus operators use new communication procedures but, initially, expressed discomfort with the surveillance capability. RTD can better manage their transit operations because the CAD/AVL system reduces the time they need to respond to incidents in the field.

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Computer Aided Dispatch/Automatic Vehicle Location (CAD/AVL), Denver Regional Transportation District (RTD), Advanced Public Transportation System (APTS), dispatchers, bus operators, street supervisors, transit, bus, usability, human factors

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# METRIC/ENGLISH CONVERSION FACTORS

## ENGLISH TO METRIC

### LENGTH (APPROXIMATE)

| | | |
|---|---|---|
| 1 inch (in) | = | 2.5 centimeters (cm) |
| 1 foot (ft) | = | 30 centimeters (cm) |
| 1 yard (yd) | = | 0.9 meter (m) |
| 1 mile (mi) | = | 1.6 kilometers (km) |

### AREA (APPROXIMATE)

| | | |
|---|---|---|
| 1 square inch (sq in, $in^2$) | = | 6.5 square centimeters ($cm^2$) |
| 1 square foot (sq ft, $ft^2$) | = | 0.09 square meter ($m^2$) |
| 1 square yard (sq yd, $yd^2$) | = | 0.8 square meter ($m^2$) |
| 1 square mile (sq mi, $mi^2$) | = | 2.6 square kilometers ($km^2$) |
| 1 acre = 0.4 hectare (he) | = | 4,000 square meters ($m^2$) |

### MASS - WEIGHT (APPROXIMATE)

| | | |
|---|---|---|
| 1 ounce (oz) | = | 28 grams (gm) |
| 1 pound (lb) | = | 0.45 kilogram (kg) |
| 1 short ton = 2,000 pounds (lb) | = | 0.9 tonne (t) |

### VOLUME (APPROXIMATE)

| | | |
|---|---|---|
| 1 teaspoon (tsp) | = | 5 milliliters (ml) |
| 1 tablespoon (tbsp) | = | 15 milliliters (ml) |
| 1 fluid ounce (fl oz) | = | 30 milliliters (ml) |
| 1 cup (c) | = | 0.24 liter (l) |
| 1 pint (pt) | = | 0.47 liter (l) |
| 1 quart (qt) | = | 0.96 liter (l) |
| 1 gallon (gal) | = | 3.8 liters (l) |
| 1 cubic foot (cu ft, $ft^3$) | = | 0.03 cubic meter ($m^3$) |
| 1 cubic yard (cu yd, $yd^3$) | = | 0.76 cubic meter ($m^3$) |

### TEMPERATURE (EXACT)

$[(x-32)(5/9)]$ °F = y °C

## METRIC TO ENGLISH

### LENGTH (APPROXIMATE)

| | | |
|---|---|---|
| 1 millimeter (mm) | = | 0.04 inch (in) |
| 1 centimeter (cm) | = | 0.4 inch (in) |
| 1 meter (m) | = | 3.3 feet (ft) |
| 1 meter (m) | = | 1.1 yards (yd) |
| 1 kilometer (km) | = | 0.6 mile (mi) |

### AREA (APPROXIMATE)

| | | |
|---|---|---|
| 1 square centimeter ($cm^2$) | = | 0.16 square inch (sq in, $in^2$) |
| 1 square meter ($m^2$) | = | 1.2 square yards (sq yd, $yd^2$) |
| 1 square kilometer ($km^2$) | = | 0.4 square mile (sq mi, $mi^2$) |
| 10,000 square meters ($m^2$) | = | 1 hectare (ha) = 2.5 acres |

### MASS - WEIGHT (APPROXIMATE)

| | | |
|---|---|---|
| 1 gram (gm) | = | 0.036 ounce (oz) |
| 1 kilogram (kg) | = | 2.2 pounds (lb) |
| 1 tonne (t) | = | 1,000 kilograms (kg) |
| | = | 1.1 short tons |

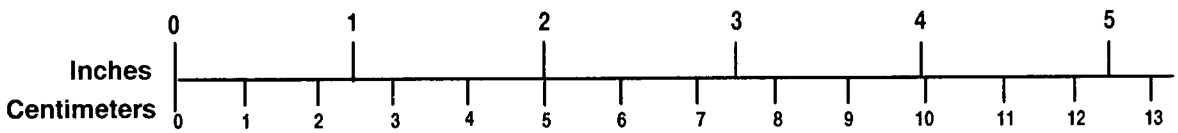
### VOLUME (APPROXIMATE)

| | | |
|---|---|---|
| 1 milliliter (ml) | = | 0.03 fluid ounce (fl oz) |
| 1 liter (l) | = | 2.1 pints (pt) |
| 1 liter (l) | = | 1.06 quarts (qt) |
| 1 liter (l) | = | 0.26 gallon (gal) |
| 1 cubic meter ($m^3$) | = | 36 cubic feet (cu ft, $ft^3$) |
| 1 cubic meter ($m^3$) | = | 1.3 cubic yards (cu yd, $yd^3$) |

### TEMPERATURE (EXACT)

$[(9/5)\ y + 32]$ °C = x °F

## QUICK INCH - CENTIMETER LENGTH CONVERSION




## QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

| °F | -40° | -22° | -4° | 14° | 32° | 50° | 68° | 86° | 104° | 122° | 140° | 158° | 176° | 194° | 212° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | -40° | -30° | -20° | -10° | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° | 100° |

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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# EXECUTIVE SUMMARY

## The Study

This report documents what happened to employees and to their work procedures when their employer, a transit operator, installed a new technology to provide real-time surveillance of vehicles and to upgrade radio communication. Denver's Regional Transportation District (RTD) acquired a Computer Aided Dispatch/Automatic Vehicle Locator (CAD/AVL) system and installed it system-wide on its entire vehicle fleet. This new CAD/AVL system was intended to support a high quality of service and to cover an extensive geographic area.

RTD's dispatchers, street supervisors, and bus operators had to learn to use this new technology. This research documents how these employees adjusted to using the CAD/AVL technology to perform their tasks. This research examined employees' work practices at the Denver Regional Transit District before, and after, the new technology was installed.

The Operator Performance and Safety Analysis Division, DTS-79, at the U. S. Department of Transportation's Volpe National Transportation Systems Center (Volpe), performed this research. The Volpe team collaborated with Professor Bruce Hutton, Dean, College of Business Administration, University of Denver, to conduct focus groups with the bus operators. The research was supported by the Federal Transit Administration's (FTA) Advanced Public Transportation Systems (APTS) Program.

This study collected data at several points in time to monitor how the employees' work was affected by the incorporation of CAD/AVL into daily operations and to identify human factors issues. This report compares data collected in 1996 and 1997, when RTD had completed system acceptance and CAD/AVL was used in revenue service use, with data collected prior to installation, in 1992. The data includes frequency of communications, number of personnel per unit of service, procedures and communication, and the attitudes of the dispatchers, street supervisors and bus operators. Analyses were performed to document their work activities and perceptions of CAD/AVL, to see if CAD/AVL affected the employees' ability to deliver service, and to evaluate the usability of the CAD/AVL features.

## The Results

The results show that the responsibility of work units, i.e., dispatch, street supervision, and bus operation remain the same but that they receive additional information from the CAD/AVL. Dispatchers now have immediate access to real-time location information for all the vehicles in the fleet, except paratransit. Supervisors can access real-time information and are less dependent on the dispatchers. Operators have more accountability to maintain schedules and routes.

Dispatchers receive more information firsthand and make fewer requests to others for information. Dispatchers have found that this real-time information, and their consequent ability to make decisions using real-time information, useful. Dispatchers now act with more authority to improve transit service and to respond better to anomalous service demands due to weather or special events.

The dispatchers' workload has increased because they receive, and transmit, more calls. Their previous radio had a limit on the number of calls that it retained. CAD/AVL retains all calls until they are answered. This increase in communication was one of the factors that led to a 46% increase in dispatch hours per weekday.

The capabilities in the CAD/AVL software have enhanced dispatch operations. The ability to store and replay data gives the RTD better oversight of past, as well as, current system operation. Because the RTD's operations log is linked to the CAD/AVL, dispatchers have less need to make notes on paper. Dispatchers can "park" open calls and revisit closed calls to update information. The lead dispatcher uses software options to reassign work.

There was an initial expectation that the need for street supervisors would decline because of the CAD/AVL system. Street supervisors' duties have expanded but their staffing level has not changed. Street supervisors have acquired more varied duties and no longer have to do field traffic checks. The supervisors have more radio channels in their vehicles and can retrieve real-time information about buses from their laptops. Street supervisors contact more operators, check Light Rail fare collection and patrol larger geographic areas.

Street supervisors report that the CAD/AVL system has enhanced their ability to perform their tasks. They are better equipped to regulate system operations. They find the street location information useful and they particularly like the CAD/AVL system's surveillance capabilities.

Bus operators like many of the CAD/AVL features but expressed some discomfort with the surveillance features. They like receiving text messages because text is an efficient and convenient method to receive and store instructions. This is a particularly important feature when they operate in heavy traffic. They view any official representation of RTD, i.e., the digital clock on the Transit Control Head (TCH) as backing them up to the public.

Bus operators were unsettled by the variation in the length of time it takes for dispatch to respond to their call. This variability occurred due to the priority ranking that dispatch uses to prioritize calls.

Implementing a Silent Alarm (SA) in an operating transportation system is challenging. Bus operators were unclear as to how the SA operated and tended to forget that the SA's covert microphone precluded an immediate response from any other part of the transit system. Bus operators disliked the location of the SA switch because they tend to bump it inadvertently. Bus operators expressed concern about the adequacy of their training on the use of the SA.

**Recommendations**

There are many ways to improve the human factors aspects of future CAD/AVL installations. It is important to consult representatives of all the users at the operating property and to keep them "in the loop" in designing a CAD/AVL system and selecting equipment. Because a CAD/AVL system makes it possible to consider a new range of possibilities for system improvement, any new CAD/AVL system should be upgradable and expandable to add user-required features.

It is important to ensure that the employees clearly understand how any critical new feature operates before it is put into service. Any feature that does not work properly should be disabled until it does to maintain credibility.

Because the CAD/AVL system is computer based, it generates copious amounts of data that might be useful to other parts of the organization and, potentially, to the community. The system designer should anticipate how the data will flow and who will want to use it.

In introducing a CAD/AVL system to transit employees, it is important to provide training so that employees understand how it works, what causes delayed responses, and, under what conditions, a verbal confirmation of a request to a dispatcher may not be possible.

Although a CAD/AVL system enhances communication, there are additional ways to improve communication. Bus operators would like to have the capability to communicate directly with other bus operators, principally to arrange for meetings so passengers can transfer between routes. They also would like to use standard communication protocols, understood by all parties, because they would reduce transmission time.

The SA should make the bus operator feel more secure and it should alert dispatchers and law enforcement in an unobtrusive way. Bus drivers need more training with the SA to attain the former advantage.

New systems should consider features that were not technologically feasible at Denver RTD. Desirable features include the following:

- Integrate the CAD/AVL system controls and displays with other bus controls and displays into a multi-functional unit.
- Display the CAD/AVL information for the passengers' use.
- Add an overlay on the AVL screen to show the dispatchers where the street supervisors' districts are located.
- Give the street supervisors use of the dispatchers' AVL screen.
- Provide more detailed street information on cross-streets and directions, i.e., east and west on the grid system.
- Use complete street databases.
- Add "non-traffic" information, i.e., vehicle operating condition, for dispatchers and street supervisors.
- Use real-time bus information as probes for the ITS traffic control functions.

Because a CAD/AVL system requires advanced software and hardware, it is important to engage a computer system administrator as soon as possible, preferably during the system development phase. To make economical corrections in system operation, it is important to use commercial-off-the-shelf (COTS) hardware and software (where possible). If custom software is developed, the system operator should try to acquire the source code.

The introduction of computer systems means that it is necessary to anticipate the need to train non-computer literate employees. The experience of bus operators, street supervisors and dispatchers suggests that employees need continuing training, support, and assistance during the transition to a CAD/AVL system.

## Conclusion

RTD is able to better manage transit operations because the CAD/AVL system has reduced the time required by dispatchers, street supervisors and bus operators to react to problems. The CAD/AVL system provides real-time, informed support to field operations because it locates buses in real-time and makes it possible for the dispatchers to direct assistance to them, referencing their actual location. There also remains significant potential for further advances in improving field operations using CAD/AVL technology.

# LIST OF ACRONYMS

ACK Acknowledge
APTS Advanced Public Transportation System
AVL Automatic Vehicle Location
CAD Computer Aided Dispatch
CAD/AVL Computer Aided Dispatch/Automatic Vehicle Location
CDOT Colorado Department of Transportation
CEB Central Electronics Bank
COTS Commercial-Off-the-Shelf
DCC Data Channel Controllers
DES Data Entry System
DIA Denver International Airport
FTA Federal Transit Administration
GPS Global Positioning Satellite
HOV High Occupancy Vehicle
ITS Intelligent Transportation System
IVLU In-Vehicle Logic Unit
LCD Liquid Crystal Display
LED Light Emitting Diode
LTB London Transport Buses
MAC Metropolitan Area Connector
MDT Mobile Data Terminal
MIS Management Information System
MOE's Measures of Effectiveness and Efficiency
MSG Message
PRTT Priority Request To Talk
RCVD Received
RDBMS Relational Database Management System
RSA Route Schedule Adherence
RTD Regional Transportation District
RTT Request To Talk
SA Silent Alarm
TCH Transit Control Head
UTC Universal Time Coordinates
VAX Line of minicomputers formerly manufactured by Digital Equipment Corporation
VMS Vehicle Management System

# 1. OVERVIEW

## 1.1 PURPOSE

This report describes what happened to employees and their work procedures when their employer, a transit operator, installed a new technology intended to improve communication and provide real-time surveillance of vehicles. The research was conducted to document whether the installation of a CAD/AVL system resulted in shifts in work responsibilities, affected the dispatchers, street supervisors and bus operators' attitudes and to make recommendations to facilitate subsequent CAD/AVL installations.

The goals of the CAD/AVL system were to develop more efficient schedules, improve the ability of the dispatchers to adjust on-street operations and to increase safety through better emergency management (Castle Rock Consultants, 1999). These goals address two of FTA's four principal objectives for Advanced Public Transportation Systems (APTS), i.e., to enhance the quality of on-street service and to improve system productivity and job satisfaction. "The RTD installed the system primarily for more efficient fleet management. However, safety and security benefits come as automatic bonuses as soon as the dispatcher and the operator are communicating electronically via the operator's mobile data terminal and the dispatcher's console." (Vineis, 1997)

Given the FTA's objective to improve system productivity and job satisfaction, this research identified the human factors consequences for the employees using the CAD/AVL system. To address these issues, this study examined the work of the dispatchers, street supervisors, and bus operators before and after, CAD/AVL system implementation. The research examined whether, and how, procedures changed following CAD/AVL system implementation and user response to the interfaces with these technologies.

The CAD/AVL technology provides instantaneous real-time information on transit system operation and vehicle location and employs pre-coded categories to expedite bus operators' requests. Using the CAD/AVL technology across the vehicle fleet enhanced the amount and quality of real-time information. However, the provision of real-time information and more direct communication altered some employees' work practices.

This report identifies the issues, opportunities and consequences that transit operators can anticipate when they adopt a CAD/AVL technology. This research describes how the dispatchers, street supervisors, and bus operators responded and adapted to, and were affected by, using a new technology. The results also show how the implementation and use of the CAD/AVL system affected service effectiveness.

The research team collected data during 1992 and, in 1996 and 1997. The data collected in 1992 measures RTD's operations <u>before</u> the CAD/AVL system installation. The data collected in 1996 and 1997 captures RTD's operations using CAD/AVL, or <u>after</u> its installation. The data measures communication frequency, number of personnel per unit of service, communication procedure, and attitudes and opinions.

## 1.2 APPROACH

This study focused on the employees who were directly affected by the introduction of an enhanced information and communication equipment, i.e., dispatchers, street (safety) supervisors, and bus operators. The data was collected at several points in time to permit a comparison between the baseline data and data obtained when the CAD/AVL system was used in revenue service. Data analyses examine how tasks and communication were reallocated; the job performance consequences of enhanced information; the usability of the CAD/AVL equipment; and the type of the training provided to employees on CAD/AVL use.

The researchers extracted information from RTD's records to measure the frequency of communication among dispatchers, street supervisors, and bus operators. Dispatchers enter information daily into a computer log. RTD packages and distributes this data in the "Dispatchers' Daily Activity Record," which lists all incidents that have been assigned a RTD problem code. RTD issues this Record daily and RTD departments use it; for example, the maintenance department uses it to generate maintenance reports on the operational problems. Transit system data was collected from RTD's records: i.e., maintenance logs, dispatch logs, customer complaint records, as well as the FTA's National Transit Database.

This research classified communication data by time of day, type of call, duration and intensity, parties involved, and type of problem. Dispatchers handle multiple incidents simultaneously. Intensity measures quantify the number of actions required to resolve an incident. Duration is the time required to close incidents.[1]

The researchers inquired about the dispatchers, street supervisors, and bus operators' attitudes towards their work. Dispatchers and street supervisors were asked about their understanding of the CAD/AVL system. The research team observed them to assess the usability of the CAD/AVL equipment. Bus operators participated in two focus groups in January 1997.

Volpe made site visits to RTD to collect data. Weather during the site visits was clear and dry and temperature was seasonal. To establish that the activity observed was typical, Volpe compared the daily frequency of contacts with dispatch with the mean daily frequencies for the calendar year. RTD activity during site visit days represented normal operations.

During the site visits, Volpe sampled the calls to dispatch and recorded how long it took to respond to the calls. Due to the noise level in the dispatch center, one dispatcher was observed for a specified interval. The researchers rode with street supervisors for a work shift and transcribed information about their activities from their paper logs. Volpe talked with bus operators and, as a matter of policy, always traveled on RTD buses during site visits.

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[1] In the baseline data collected in 1992, duration was the difference between when an entry was logged in the pencil log and when it was closed out on the computer log. CAD/AVL eliminated the paper log because incidents are recorded on the computer immediately.

Volpe sought the opinions of the supervisors of dispatch, supervision, and bus operations to classify the tasks of dispatchers, street supervisors, and bus operators as regular, occasional, or emergency. Volpe identified tasks where responsibilities have been eliminated, added or altered, as a result of the introduction of the CAD/AVL system.

# 2. BACKGROUND

## 2.1 TRANSIT SERVICE IN DENVER

Denver is one of the fastest growing areas in the United States. In 1997, the Denver metropolitan area had a population of 2.3 million and was the 22nd largest metropolitan area in the United States. RTD provides public transportation for forty-four municipalities covering 2,400 square miles. The area served encompasses Adams, Arapaho, Denver, Boulder, Douglas, Jefferson counties, parts of other counties, and the cities of Golden and Longmont.

The Colorado State Legislature established RTD in 1969 and RTD began to provide transportation services in 1973. Prior to 1973, Denver Tramways, a private firm, provided public transportation in Denver.[2] In 1973, RTD also acquired several smaller suburban carriers.

Since 1982, RTD has been governed by a directly elected, 15-member, Board of Directors. The Board sets District policy, the agency's annual budget, and establishes short- and long-range transit goals and plans in concert with local, state, and federal agencies.

RTD operates the 12th largest transit bus fleet in the United States and has 825 vehicles.[3] RTD also operates a 5.2 mile-long, 17-vehicle, light-rail line, known as MAC (Metropolitan Area Connector) which opened October 1994 and is currently constructing an 8.3 mile southern extension of the light rail line. RTD is considering additional corridors for future light-rail expansion.

The State of Colorado mandates that private contractors provide at least 20% of the bus operations. In 1989, RTD began to contract out the operation of some of its routes to private operators. RTD has contracts with three private operators, ATC/Vancom, Laidlaw, and Mayflower (a subsidiary of Laidlaw) to provide one-quarter of its service.

Contract operators use their own, as well as leased RTD, equipment. Contractors must maintain the leased RTD equipment but RTD provides warranty service on the leased equipment. In 1996, contract operators operated 171 contractor-owned buses and leased 21 RTD buses. Since 1992, the contract operators have increased the number of integral transit buses that they operate and eliminated their use of "school bus style" equipment.

RTD operates three bus garages: East Metro in Aurora, Platte located adjacent to the Operations Centers, and the Boulder garage in Boulder. East Metro and Platte are in the Metro division. Boulder is operated as a self-contained division with separate dispatchers and supervisory staff. The heavy maintenance facility ("District Shops") shares a building with the Operations Center. Each contract operator has a maintenance facility.

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[2] Denver Tramways discontinued electric street railway service in 1950.

[3] 1996 National Transit Database table 26.

RTD provides round-the-clock bus service. In the early morning hours (1 AM - 4 AM), RTD operates one route, Route 15, on East Colfax. More than a dozen routes provide service until 12:30 am and resume service at 4:30 am.

RTD operates a complex route structure. Routes include:

- 52 local and 12 limited-stop routes in the Denver Metro area that operate throughout the day along major arterials. Many of these routes run through downtown Denver. Contract bus operators operate 23 local routes and four of the limited stop routes.
- 48 express routes that operate during rush hours along major highways into the two transportation terminals in downtown Denver (Civic Center and Market Street Stations) or to the I-25 & Broadway terminal at the light rail line. Contractors operate 27 of these express routes.
- A Mall Shuttle that provides free service with short headways using low-floor buses along a 1.9 mile-long pedestrian mall in the downtown. The Mall Shuttle operates in an auto-free zone (16th Street) which connects the two terminals used by the Regional and Express routes (Market Street and Civic Center Stations).
- 20 regional routes which use "over-the-road," or intercity type equipment, on lengthy runs into surrounding communities. These regional routes depart from Civic Center and Market Street Stations in Downtown Denver, and from the RTD terminal in Boulder. Figure 1 shows the Market Street Station, several Mall Shuttles, and, on the left, the stationary supervisor's booth used to check schedule adherence using CAD/AVL equipment installed there.

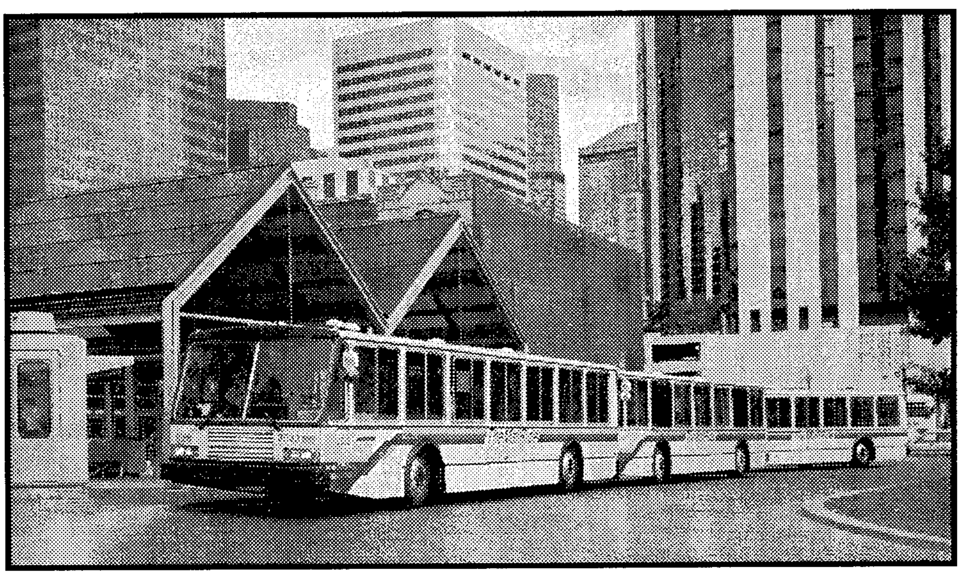

**Figure 1. Market Street Station**

- 15 local routes in the Boulder area and 8 routes in the Longmont area. Contract bus operators operate all of the local routes in Longmont, two weekday local Boulder routes, and the weekend local Boulder routes.
- Special shuttle routes to major athletic events.
- 5 express routes to the Denver International Airport (these routes are known as "Skyride").

Table 1 shows, that between 1992 and 1996, RTD ridership increased and passengers are making longer trips. The RTD service also increased during this time. Even though RTD was installing the new CAD/AVL technology on its entire fleet during this time, ridership and service increased. The "growing pains," which accompany the installation and shakedown of the use of new technology, were transparent to the riders as evidenced by the increase in ridership in excess of increased service.

RTD generated ridership growth, in excess of the new service added, due to a number of factors. RTD tailors its service to meet users' needs by offering an increasing number of express bus routes and transit service to activity generators such as new centers of employment and retail. RTD has worked with large employers in the area to foster and encourage use of transit passes.

**Table 1. RTD Transit Service, 1992 and 1996[4]**

| | 1992 | 1996 | Change (%) |
|---|---|---|---|
| **Ridership** | | | |
| Passenger trips (unlinked) | 58,865,700 | 65,378,977 | 10 |
| Passenger miles (thousands) | 238,649 | 283,686 | 16 |
| **Service Coverage** | | | |
| Route Miles | 2,350 | 2,685 | 14 |
| Number of Routes | 153 | 173 | 13 |
| Service Area (sq. mi.) | 2,304 | 2,406 | 4 |
| Population (millions) | 1.9 | 2.3 | 21 |
| **Operations** | | | |
| Vehicle Hours (thousands) | 1,991 | 2,305 | 14 |
| Vehicle Revenue Hours (thousands) | 1,510 | 1,749 | 14 |
| Vehicle Miles (bus) | 30,705,800 | 36,440,772 | 16 |
| Service hours provided by contractors (%) | 23 | 27 | 17 |
| P.M. peak bus requirement | 652 | 681 | 4 |
| Base service bus requirement | 320 | 346 | 8 |
| Employees | 1,929 | 2,079 | 8 |
| Bus Fleet | 781 | 828[5] | 6 |

[4] Castle Rock Consultants produced the system evaluation of the Denver CAD/AVL and they report detailed information about the CAD/AVL system and service measures of effectiveness and efficiency (MOE's).

[5] At the end of 1998, the bus fleet was increased to 884.

There were many changes in the Denver metropolitan area between 1992 and 1996. The new Coors Field baseball stadium opened in lower downtown Denver in 1993. RTD offered extra Shuttle bus service for each game to satellite parking lots and to RTD Park and Ride lots. Because games often coincide with the PM peak for scheduled bus operations, RTD expanded their bus fleet to meet service needs. RTD retained 55 older buses, originally slated for retirement, as a reserve fleet, to operate additional game-day service. The radios on these buses operate in "fall-back"; i.e., they use the pre-CAD/AVL communication equipment and procedures. As newer, CAD/AVL equipped vehicles join the fleet, they will replace these buses.

RTD introduced Light Rail Line service in October 1994 and, as a result, restructured bus routes to provide feeder service to the new rail line. Express and regional lines that formerly terminated at the Civic Center Station now terminate at stations on the Light Rail line. RTD restructured several local bus routes to serve as cross-town light-rail feeders.

The Colorado Department of Transportation (CDOT) opened a High Occupancy Vehicle (HOV) lane on I-25 from Union Station north in 1994. CDOT equipped the Dispatch Center with video cameras so that the dispatchers could monitor HOV lane activity in real-time.

The new Denver International Airport (DIA) opened in February 1995. RTD instituted new express bus routes to serve DIA.

Even with these changes, RTD improved schedule adherence between 1992 and 1996 while expanding service. Table 2 shows RTD's schedule adherence in 1992 as compared with 1996.

**Table 2. RTD Schedule Adherence, 1992 and 1996***

| | % routes early (more than 1 minute ahead of schedule) | % routes on time | % routes late (more than 5 minutes behind schedule) |
|---|---|---|---|
| 1992 | 5.19 | 88.02 | 7.12 |
| 1996 | 5.3 | 89.6 | 4.5 |

*RTD defines on time as from one minute early to 5 minutes late.

## 2.2 THE CAD/AVL SYSTEM AT RTD

In March 1992, the RTD Board of Directors announced their decision to obtain a satellite-based system, using AVL and Global Positioning Satellite (GPS) technology with differential error correction, to track all their transit vehicles, including service vehicles.[6] This satellite-based

[6] By contrast, London Transport Buses (LTB) selected beacon technology recognizing that their buses "ply along a fixed line of route and service controllers, rather like railway signal control box operators...(and showing) buses along a single scale line ...(which) will readily show gaps and bunches" (Linton, Dec., Jan. 96-97). LTB tested this technology on 700 buses, operated by private carriers, and plans to scale up this technology to the 6,500 buses covering their service area by 2000. Chicago Transit Authority also selected a modified sign post technology for their Bus Service Management System which is currently being implemented in two phases.

system reports vehicle locations within 100 feet using GPS. It is supplemented with dead reckoning (odometer-sensing only) in areas where vehicles do not receive GPS signals clearly.[7]

Denver RTD selected the "SmartTrack" AVL system, manufactured by the Westinghouse Electric Corporation, who also provided the systems integration.[8] The backbone of dispatch operations is the "SmartTrack" Vehicle Management (VMS) provided by E-Systems. The "Smart Track" dispatch equipment has dual computer screens that are located side-by-side at each dispatch console. The CAD screen is the control center. It prioritizes radio calls and has "pull down" option menus. The Automatic Vehicle Location screen shows a scalable map and vehicle status. RTD had the AVL screen adapted to incorporate RTD's own "train card" program and headways.

The CAD/AVL system uses the Motorola Centracom Series II Plus Radio Consoles. The new radio equipment includes an intercom between the dispatch consoles and between the Boulder and Denver dispatchers, a "voted" multi-channel transmitter and repeater control, the ability to patch between radio frequencies, a secure channel for supervisors, and the capacity to store the last ten bus numbers in active memory. The radio consoles have nine channels, two for data, and the remainder for voice transmission, including five voice channels for buses.

CAD/AVL installation began during the summer of 1992. The repeater microwave system was installed by September 1992 and the service area was mapped during the summer and fall of 1992.

RTD installed new radio equipment on all the vehicles, including buses leased by RTD to the contract carriers and contractor-owned buses. Installation of equipment on the buses began in 1993. When RTD began installing equipment on the buses, they anticipated being able to install the equipment at a rate of five buses per day. Buses with the new radios were used in revenue service immediately after installation.[9] The CAD/AVL system experienced numerous technical issues. There were many upgrades to the software and hardware. Final acceptance of the CAD/AVL system occurred in April 1996.

CAD/AVL equipment was installed in the street supervisor vehicles. Initially, supervisor vehicles were equipped with Mobile Data Terminals (MDT's), laptop computers with monochrome screens made by GRID. Figure 2 shows the GRID laptop in use in a supervisor vehicle. Street supervisors use the MDT to review headway information, request information about a route, or vehicle, from the CAD, send and receive text messages, and to request a voice channel to a bus.

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[7] For a more detailed description, see Appendix A which presents RTD's description of the CAD/AVL system excerpted from the Dispatchers User's Guide provided by E-Systems, Final Version, 11/20/95. Appendix C describes the communication equipment at RTD prior to CAD/AVL installation.

[8] RTD obtained the CAD/AVL system from the Westinghouse Electric Corporation initially. Westinghouse later sold the corporate CAD/AVL capability to TMSI which was acquired by E-Systems. Raytheon acquired E-Systems. Westinghouse retained the CAD/AVL equipment warranty.

[9] RTD's initial contractor, Westinghouse, installed all the vehicle hardware at one time, but bypassed the in-vehicle logic unit (IVLU) to provide radio-only service initially. RTD decided to use this strategy as a conservative approach to developing full system CAD/AVL capability. Caskey, 1993.

**Figure 2. Mobile Data Terminal**

The supervisor vehicle is equipped with a stand for the laptop placed between the operator and passenger seats. In practice, street supervisors tended to place the laptop on the dashboard or on the passenger seat. Supervisors pick up an MDT when they report for duty. At the end of their shift, the supervisors return the MDT to the Supervisor's Room for battery recharging.

The radio in the supervisor's vehicle monitors the supervisor's channel as well as the bus and maintenance truck channels. Street supervisors use the supervisor channel to communicate and, typically, set it on priority so that an incoming message for a supervisor overrides other transmissions.

RTD installed transit control heads (TCH) in every bus. Figure 3 shows the TCH mounted in a RTD bus. Bus operators use the TCH as their primary interface with CAD/AVL.[10] The TCH has a Liquid Crystal Display (LCD), keypad, internal speaker, and covert microphone. The TCH is mounted to the right of the steering wheel on the dashboard. Bus operators rotate the TCH to adjust its viewing angle and the brightness level of the screen.

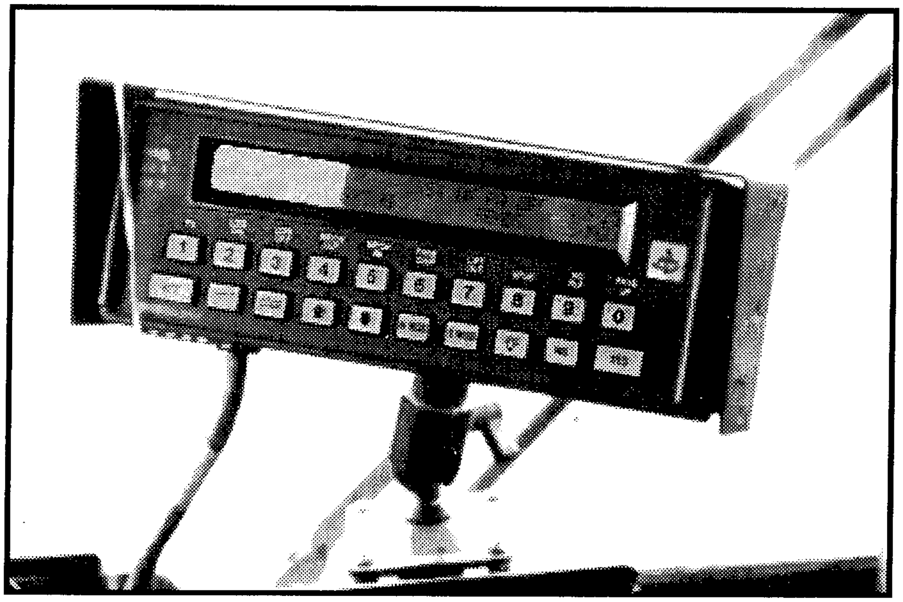

**Figure 3. Transit Control Head**

When buses lose communication with the GPS satellites, or the TCH fails, the radio system reverts automatically to pre-CAD/AVL radio communication procedures, "fallback" mode, using the handset.[11] In "fallback," operators use pre-CAD/AVL radio procedures to communicate with dispatch.

Bus operators can activate the SA using a hidden switch if they decide that circumstances require its use. The switch is located to the left of the operator on the interior bus wall and its location varies depending on the make and model of the bus. The SA opens a covert microphone on the bus (in the TCH) and makes the bus's in-vehicle logic unit (IVLU) send continuous location updates to dispatch, but freezes normal TCH functions. Only the dispatcher can clear or remove an SA from the CAD when an operator has activated it.

[10] Appendix B lists the buttons on the TCH and the functions for each.

[11] Prior to CAD/AVL implementation, on-board bus radio equipment consisted of a radio hand-set and external speaker located to the left of the operator. To communicate with the dispatchers, operators would have to pick up the hand-set, listen to make sure the radio was not in use, press the transmit button, and wait for the dispatcher to make a voice acknowledgment of the bus number before speaking into the mouthpiece.

Operators are prompted to test the SA when they take the bus out of the garage for the first run of the day, or, if the bus has been shut down for a long period of time. Operators must complete the test procedure within 30 seconds or the TCH will transmit a silent alarm. If an operator tests it in error, the bus sends an alarm to dispatch. There was an average of eight false SAs during the site visit days in 1996. Many were due to operator error when logging on to the TCH.[12]

[12] Castle Rock Consultants report detailed information on the incident response time for silent alarms and the actual number of real and false silent alarms transmitted using the CAD/AVL system.

# 3. DISPATCHERS

## 3.1 STAFFING

RTD has an eleven-person dispatch staff. The staff is composed of one supervisory lead and ten dispatchers. There were nine dispatchers in 1992 and the work group had one lead and eight dispatchers. The number of dispatchers has increased 22% since the implementation of CAD/AVL.[13]

The additional dispatch position in Boulder is unchanged. The new light rail line has its own dispatch facility and staff.

In 1996, there were five dispatchers on duty during peak hours compared with three dispatchers in 1992. Figure 4 shows the number of dispatchers on duty during a weekday in 1992 and 1996. The number of dispatch hours provided per weekday has increased 46%. The increase in dispatch hours was needed to staff peak hour operations. Early-morning and late-evening staffing levels have remained the same.

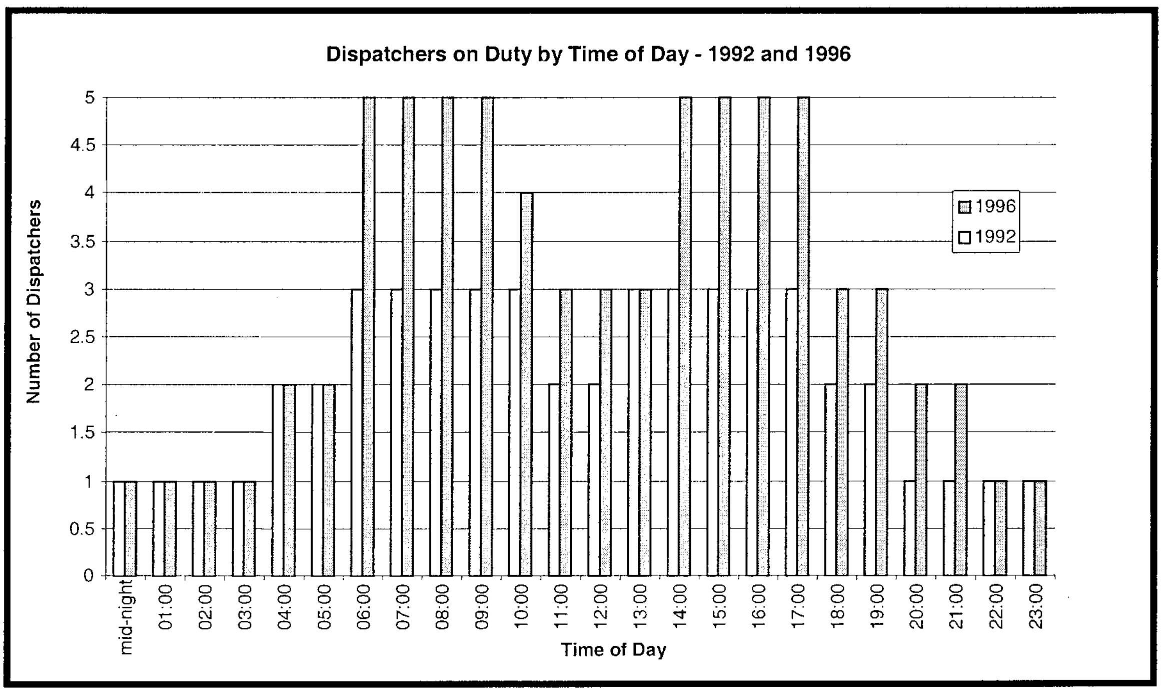


**Figure 4. Dispatchers on Duty by Time of Day**

[13] There is low turnover in the dispatch positions. Vacancies usually occur due to retirement. To become a dispatcher, or a street supervisor, a candidate must have been a bus operator for two years and, during the most recent 12 to 24 months, have had a "clean" work history. Prior experience as a bus operator is necessary because RTD, and the dispatchers themselves, view their position as that of a "fixer-upper." Dispatchers believe that this common experience creates a similar knowledge base.

Dispatchers work four ten-hour shifts per week.[14,15] Dispatchers and street supervisors are the only RTD employees who work the "10-4" schedule.[16] The "10-4" program was instituted prior to CAD/AVL installation. Initially the dispatchers were concerned that their workload might increase and require reversion to eight-hour shifts but that did not happen.

The lead dispatcher for operations works split weekday shifts at one of the two supervisory consoles, both of which are active. During busy periods, this lead dispatcher also answers calls. RTD has added additional duties to a second dispatch position to handle administrative functions, i.e., adjusting the software parameters for CAD/AVL and operating the "playback" feature during any slack time. "Playbacks" show whether there was a bus provided as scheduled and if the scheduled service was delivered.[17] The second lead dispatcher does "playbacks" upon request from other RTD departments, such as Customer Service, and may be asked to do several "playbacks" per day. Many RTD departments use the playback capability to resolve questions.

## 3.2 PROCEDURES

Dispatchers must carry out a series of actions to respond to a call. For example, when a bus operator calls, the dispatcher sees a message showing the bus number on the CAD incident management screen ranked by priority. Using a mouse, the dispatcher selects the vehicle calling from the incident list and refers to the AVL screen for its location. When the dispatcher mouse clicks the bus number on the CAD, the CAD emits a prompt to the dispatcher to initiate voice communication. The dispatcher uses a foot pedal, or the mouse, to open the voice channel. Figure 5 shows the dispatcher's console with the CAD/AVL equipment.

Dispatchers code calls using RTD's problem codes. Dispatchers enter the problem codes on the CAD while the incident is open. Information is automatically transferred to the RTD's main computer operating system, which they refer to as the "VAX" when a problem code has been assigned. Dispatchers assign problem codes quickly because, if it is a maintenance problem, the information becomes available in real-time to the maintenance department.

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[14] Dispatchers receive one-half hour break per shift but often do not use it. During their break they are expected to stay in the vicinity of the Dispatch Center. The dispatcher on the "graveyard shift" often uses the break time to complete and organize paperwork for the day shift.

[15] Dispatchers bid for shifts at the "vote" but tend to keep the same shifts. If there are uncovered shifts, dispatchers can work them as overtime. They are assigned extra shifts by their date of hire. Dispatchers may not work back-to-back shifts. RTD covers vacation and weekday relief dispatch positions using an RTD employee category, "Group II's," i.e., operators who have been cross-trained as dispatchers.

[16] The Manager of Dispatch and Street Supervision is responsible for the dispatchers and street supervisors who are non-union salaried employees.

5 RTD's Schedule Planning and Customer Service departments use data generated by the CAD/AVL system to evaluate route performance and to respond to customer complaints regarding service. For example, parents of a high school student complained that their child was late for school due to a late bus. RTD staff extracted information from the CAD and showed that the bus ran on time.

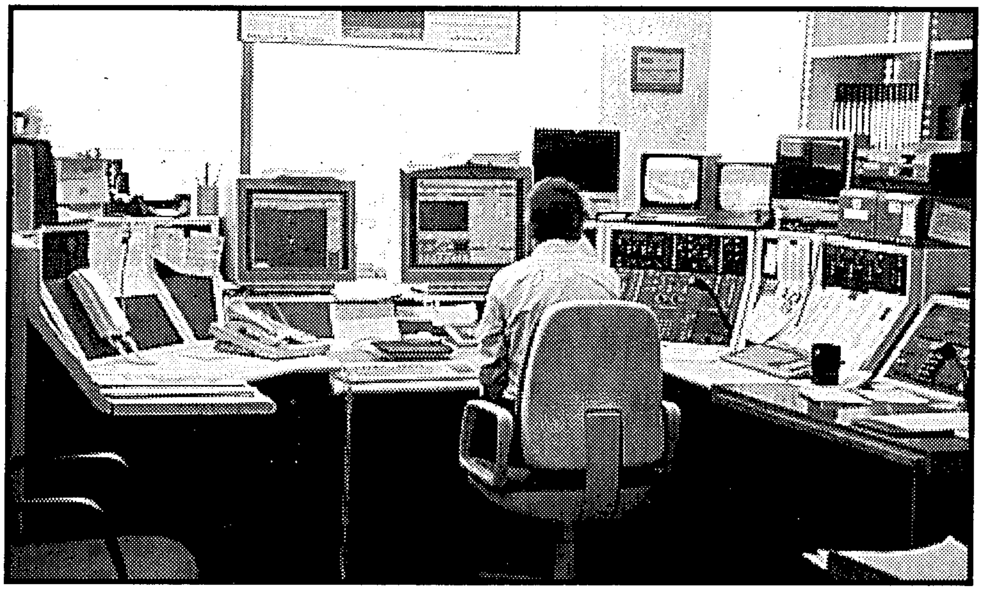

**Figure 5. Dispatcher's Console**

The dispatchers' CAD/AVL work procedures better match their work requirements. Dispatchers often have calls that must remain open for a length of time and the CAD/AVL system has eliminated their need for memory devices. Dispatchers can park "open," or "on-going," calls on the CAD incident management screen for as long as necessary, providing a visual reminder of an open incident.[18] Even after an incident has been closed and removed from the CAD, dispatchers can recall it to add information to the record or to obtain information about it. With these enhancements, dispatchers can respond more efficiently to unusual service demands due to weather or special events.

The lead dispatcher can reconfigure the dispatchers' workstations quickly, using software commands to respond to operating needs. The lead dispatcher can define which console receives which category of calls, i.e., by routes, vehicle types.

The CAD/AVL system has made communication more efficient. The dispatchers make less use of intermediaries. Dispatchers used to have to relay messages from street supervisors to bus operators. Now supervisors can call buses directly using their MDT.

Dispatchers have real-time location information because the AVL screen shows the real-time location information for RTD vehicles. The bus IVLU transmits its location every two minutes and the CAD screen updates the bus route assignment and operator information.[19] Dispatchers do not need paper records of bus numbers because the CAD displays this information.[20] Dispatchers often need to locate maintenance vehicles.[21] Dispatchers use the AVL screen to

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[18] Dispatchers said they park calls "to take the call off the sheets" if they are unfinished. While the lengths of time calls are parked ranges from one minute up to one hour, all calls are finished and closed.

[19] Previously, this information could only be obtained by voice contact with the bus operator.

[20] If there is a need for a paper copy, it is possible to print the information displayed on the CAD.

[21] During peak periods, RTD stations two maintenance trucks downtown and has a third truck on call for emergencies.

determine quickly which maintenance vehicle is closest to a disabled bus and to direct it to provide service.

Dispatchers use the CAD/AVL system to make bus operations more efficient. Because the CAD/AVL system shows the location of all buses on a particular route, they can use this information to respace service and adjust headways in real-time. The dispatchers can track on-route performance. The CAD/AVL system notifies dispatchers about late or off-route buses.[22] When an operator reports to the Dispatch Center that they are in front of a "follower" bus, the dispatcher can tell the bus operator what to do. Dispatchers can communicate with buses individually, by route or, collectively, as groups of routes.[23] They send text messages to buses, which is a particularly useful format for relaying detour information.

Dispatchers still use the RTD's legacy VAX mainframe to display the "blocks" and "train card" information, although the CAD screen also has this data.[24,25] Figure 6 shows the CAD/AVL's dual screens and the screen for the legacy VAX at the dispatcher's console. Dispatchers preferred to continue to use the VAX screen because this frees up space on the CAD screen to display other information.

The dispatchers do not have to transfer their paper log entries into the computer database. Although the CAD/AVL system eliminated the need for a paper log, some dispatchers still make notes on their paper log as a backup.

RTD does not have fixed parameters for RSA. Typically, the RSA alerts the dispatcher when a bus is operating 15 minutes early or 25 minutes late. The dispatchers adopted these reporting thresholds to reduce the number of off-schedule buses shown on the AVL screen.

The CAD/AVL system improved RTD operations when user demand increased sharply. Sporting events boost the demand for RTD service. The CAD/AVL system has been useful when RTD operates "load and go" service from "Park & Ride" lots to the sport stadiums. Dispatchers can tell the street supervisors at the "Park & Ride" lots where the shuttle buses are.

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[22] RSA parameters are set or changed before the dispatcher logs onto the console. In 1996, the CAD/AVL system was set at 200 feet. A bus showed up as off route when it was two-and-a-half times (200 feet) off route. For example, the CAD/AVL system showed a bus off route if it is at least 500 feet away from the route.

[23] When dispatchers select routes by route number, CAD/AVL shows up to 8 routes at once.

[24] Assignments and schedules are termed "blocks" and "train cards." Blocks refer to block number, "a number used in identifying a particular time space of a bus on a route." Train card refers to an operator's piece of work including the end point of the route and where the bus should be at a particular time. It is "a card or sheet carried by a bus operator containing the specific time schedule and other information for a particular bus on a specific route." RTD, Trailblazer, 24th Edition, September 1996, pp. A73, A75.

[25] The term VAX refers to a line of minicomputers, suited by use as mainframes, made by the Digital Equipment Corporation (which has been acquired recently by Compaq).

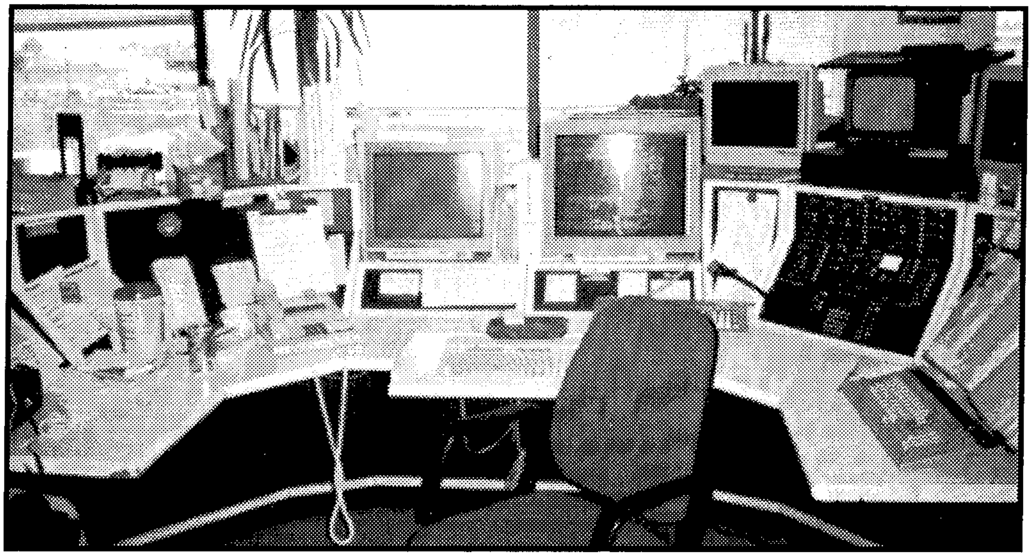

**Figure 6. CAD/AVL and Legacy VAX Equipment at a Dispatcher's Console**

Snow emergencies generate a peaking of demand for dispatch service and the volume of calls to dispatch may double. The CAD/AVL system did not "lose calls" in snow emergencies because the bus calls did not drop out of the radio system. The CAD retained all the messages and dispatchers responded to them by priority.

Boulder dispatch has its own radio channel. RTD dispatchers use this channel to hold connections between Boulder and Denver buses. Denver dispatchers can contact Boulder buses and Boulder dispatchers can contact Denver buses. Previously, only Boulder dispatchers could talk to Boulder buses. They contacted their buses in the Denver metro area by telephoning the Dispatch Center and asking to have their message relayed.

The installation and operation of the CAD/AVL system changed the dispatchers' work practices and dispatch operations as summarized in Table 3.

## 3.3 WORKLOAD

Dispatchers described their work as complex, at times disciplinary, and as providing a personalized service. One dispatcher referred to himself as a "fixer upper." Another dispatcher described his job as follows, "... (have) all these support systems and (it is) up to the dispatcher for how to use them; dispatcher makes the determination." Dispatchers said that they "...like being involved in the whole mess, being involved in trying to resolve problems." The content of the communications showed that dispatchers also provided reassurance to the bus operators.

Dispatchers reported that they feel stress having to "...handle emergency type calls," "accident, or worse fatality," "...snowstorm is bad time (because)... getting call after call to point of nothing you can do." Another dispatcher said that he disliked "...day-to-day breakdowns...(because responsibility is) to keep service running...with as little delay as possible." Another dispatcher said he found it "...most stressful when operator does not use correct radio procedure...can handle it if calls are coming fast when correct radio procedure used."

**Table 3. Changes in Dispatch Responsibilities and System Capabilities**

**New Dispatcher Responsibilities**

- Log onto CAD/AVL system at start of work shift
- Lead Dispatcher sets CAD/AVL parameters

**Eliminated Dispatcher Responsibilities**

- Determine location of bus and relay to supervisors (Supervisors use MDT to locate bus)
- Transcribe paper logs into VAX (The CAD/AVL system automatically transfers data to the VAX

**Altered Dispatcher Responsibilities**

- Send messages to buses selected by route or other subgroup. (Previously, messages could only be sent to a specific bus, or to all buses.
- Send text messages useful for transmitting detour information to buses on a route.
- Locate a bus, supervisor, or a maintenance truck without voice contact with operator.

**New Dispatch System Capabilities**

- Communication between buses and dispatchers from Metro and Boulder divisions.
- Ability to receive/respond to Silent Alarm calls from buses.
- Ability to playback prior operation of a specific bus.
- Display stuck buses during snow emergencies.

Initially, the dispatchers expressed concern about their ability to become familiar with the CAD/AVL system quickly enough to operate it correctly. They described the CAD/AVL system as very different and wondered whether they would "...be able to grasp it all in a short time and keep service going." They said they were "...worried about the process" of changing over to the CAD/AVL system. They expressed concern as to whether, after the installation of the "locator" system, the dispatch workload would become heavier and would require that they revert to eight-hour work shifts.

During the transition to the CAD/AVL system, the dispatchers had to operate both the CAD/AVL system and the former radio system simultaneously. As CAD/AVL equipment was installed on the buses, they were "cut over" to the CAD/AVL system. The number of buses using the new equipment increased each day. Because their attention was divided, dispatchers reported that, at times during this transition, they might have received calls on the CAD/AVL system that they neglected.

Dispatchers who had worked with the former equipment and the CAD/AVL system accepted the CAD/AVL installation and liked its ability to locate buses immediately during emergency situations. They praised the CAD/AVL equipment's ability to retain all calls that are received, even during intensely busy periods.

The incidence of radio calls to the Dispatch Center were extracted from the "Dispatchers' Daily Activity Record."[26] Figure 7 shows the number of calls recorded in the Activity Record during a typical day in 1996, as compared to 1992. The number of calls peaked during the early morning and late afternoon commuting hours. More than one-quarter of the calls to the Dispatch Center occurred during the afternoon peak hours, which constitute only one-eighth of a day.

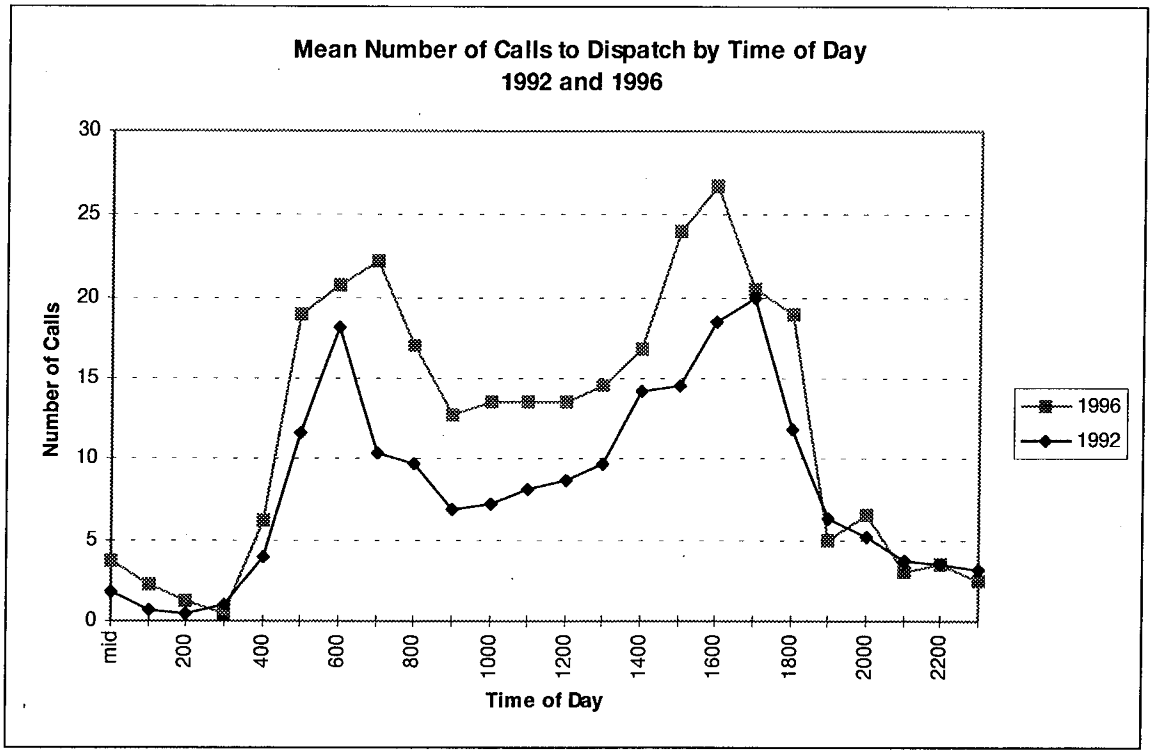


**Figure 7. Calls to Dispatch by Time of Day**

The calls to the Dispatch Center came from a variety of sources. Figure 8 compares the distribution of the source of calls to the Dispatch Center in 1992 to 1996. The relative proportion of calls from supervisors has declined because the supervisors now obtain information about buses' operational status from the MDTs in their vehicles and, as a result, can work more autonomously.

[26] Dispatchers actually receive more calls than are shown in the Dispatcher Daily Activity Record. This Record reports incidents that have been assigned a problem code by the dispatcher. The calls included in the Record relate to maintenance, safety, or passenger information.

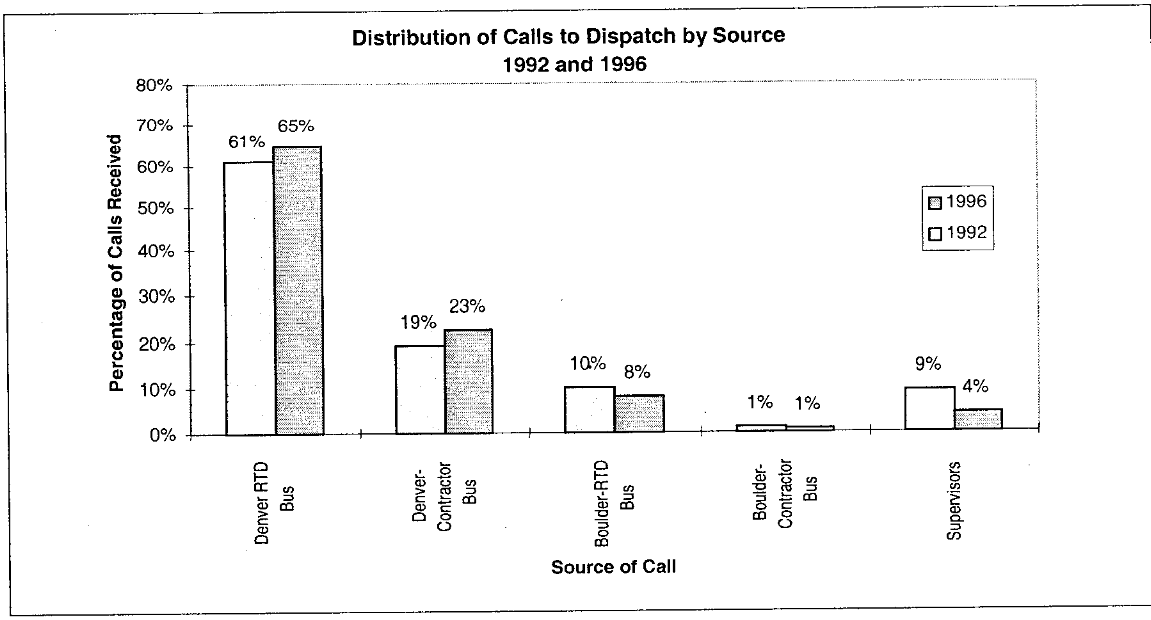


**Figure 8. Distribution of Calls by Source - 1992 and 1996**

Although the volume of calls to the Dispatch Center increased, the incidence of calls by day of the week is similar. Figure 9 shows daily mean frequency of weekday calls to dispatch in 1992 and 1996. The mean number of calls per weekday to the Dispatch Center in 1996 was 300, an increase of 34% from a mean of 224 in 1992. The mean number of calls for all seven days increased from 188 to 254 by 1996.

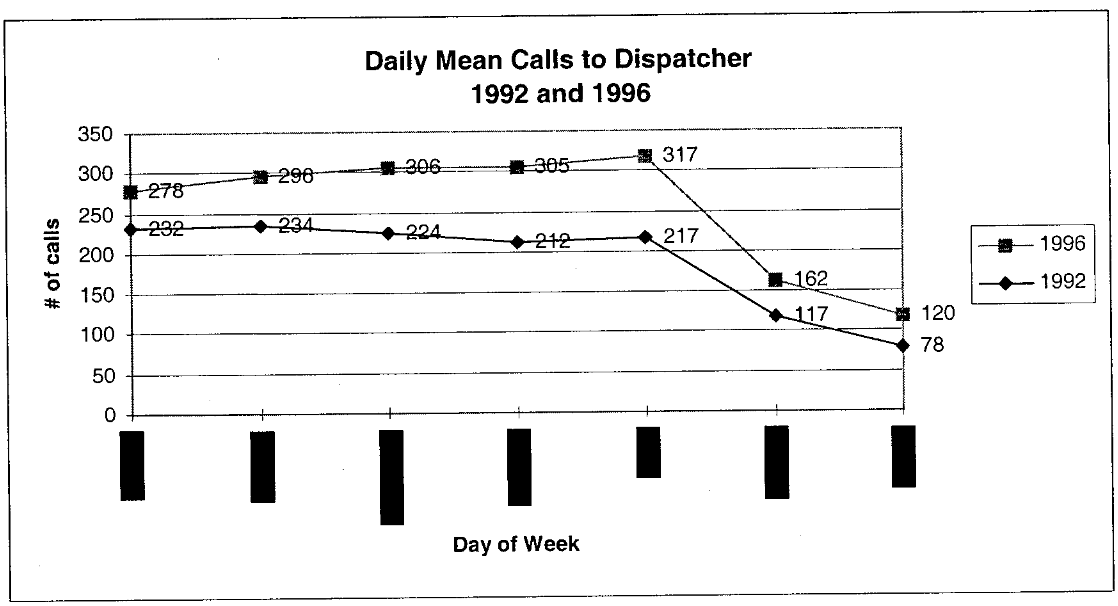


**Figure 9. Daily Mean Calls to Dispatcher – 1992 and 1996**

The number of calls to the Dispatch Center has continued to increase since 1996. By 1999, the Dispatch Center reported receiving approximately 400 calls per day. The number exceeds 800 per day during snowstorms.

The dispatchers contact RTD maintenance equipment (service vehicles on the street that respond to maintenance calls), police, and contractor bus dispatchers. The frequency of contacts between dispatchers and maintenance and police remained the same.

The dispatchers also are in contact with the providers of contract bus service. The lead dispatcher assigns contractor buses to one console and rotates dispatcher assignments between consoles to distribute the work equitably.[27] Dispatchers relay the information received from contractor buses by telephone to contractor dispatchers and, as a result, perceive the contractor bus workload as heavier. The Dispatch Center contacted the contractor dispatchers an average of 19 times per day in 1992 as compared to 37 in 1996, almost a 100% increase.

The increased capacity of the CAD/AVL system may encourage RTD bus operators to request more information for customers. The twenty categories of calls, shown in Figure 10, account for two-thirds of all the calls to the Dispatch Center. Bus operators most often called the Dispatch Center to request services that RTD categorizes as "Policy Information/Direction," for example, inquiries about RTD's policy on transfers. Almost one-quarter of the radio calls, 23% were in this category in 1996, compared to 11% in 1992. Bus operators more often requested that another bus be held for connecting passengers in 1996, increasing to 9% of the calls in 1996 from 1% in 1992. The incidence of calls for "operator training and controls" increased from 2% to 3% and this included accidental silent alarm calls.

Figure 11 shows that the dispatchers processed more radio and phone calls in 1996. Dispatchers received fewer calls from supervisors because they can retrieve real-time information from their MDT.

Figure 12 quantifies the time dispatchers spent on the activities they perform. Their time has been reallocated. Dispatchers spent more time talking on the radio and phone per call in 1996 but less time on paper and computer data entry.

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[27] RTD wants all contractor communication to go through their dispatchers as a way to monitor contractor performance. The contract operators can be levied fines for service delays.

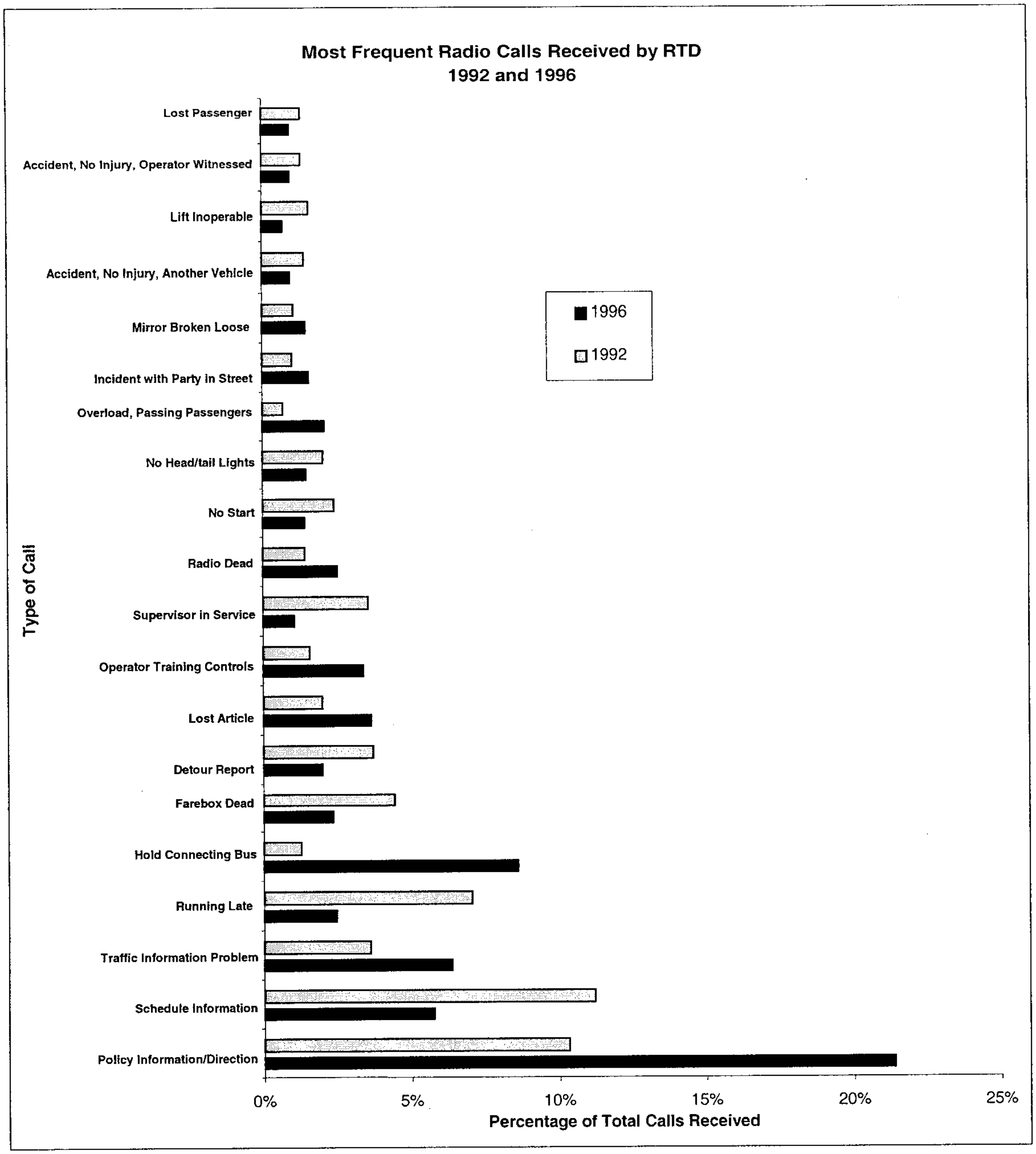


**Figure 10. Most Frequent Radio Calls Received by RTD – 1992 and 1996**

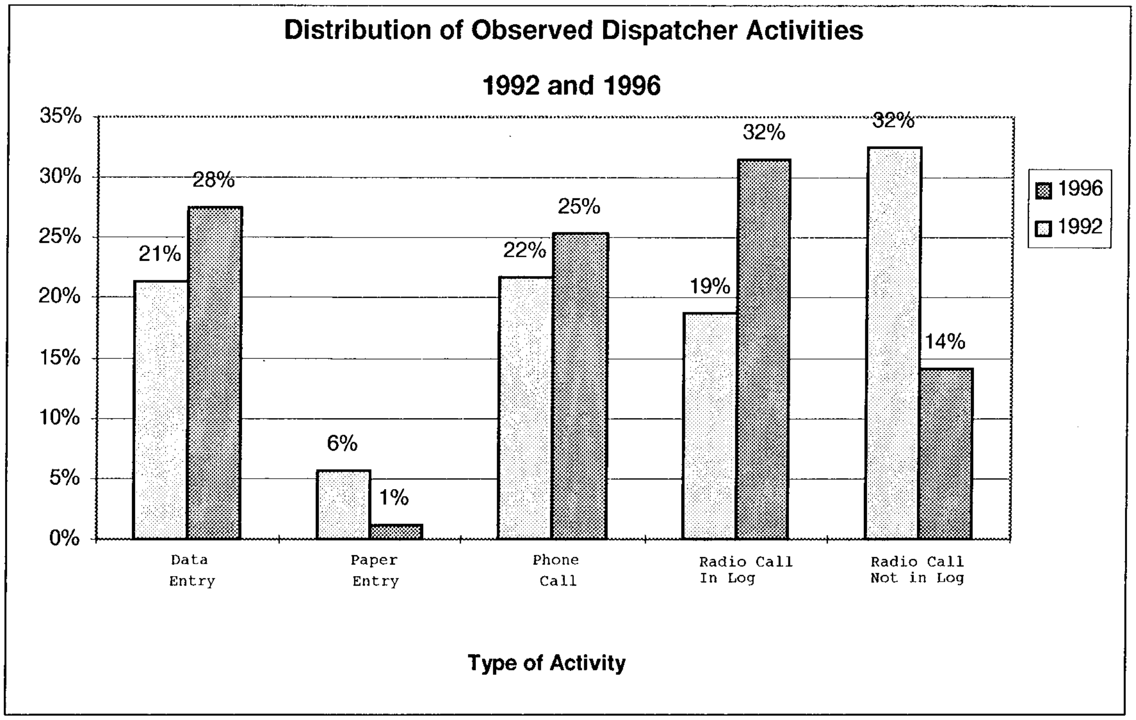


**Figure 11. Distribution of Observed Dispatcher Activities**

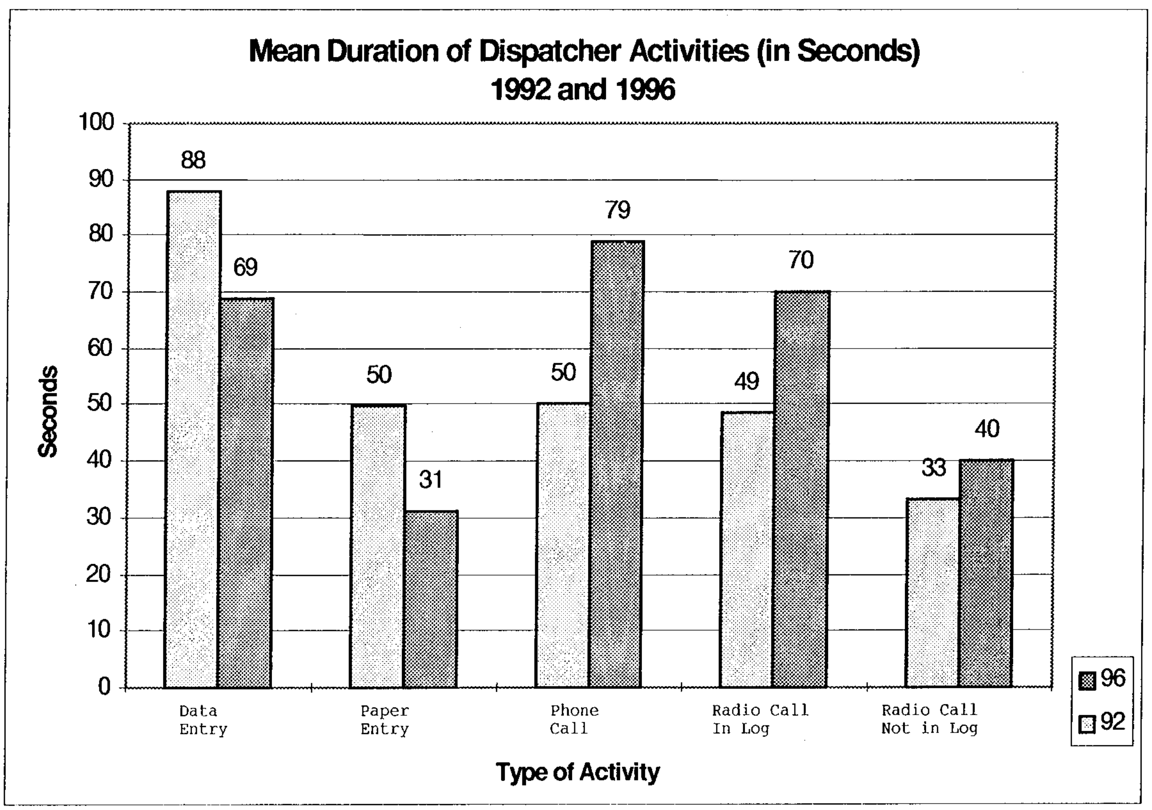


**Figure 12. Mean Duration of Dispatcher Activities (in Seconds) – 1992 and 1996**

## 3.4 TRAINING

The first CAD/AVL console was placed in the Dispatch Center in August 1992 for test purposes. Corporate trainers held two training sessions to train the dispatchers to use the console and the CAD and AVL screens. In the first session, a trainer from Motorola acquainted the dispatchers with the use of the new Centracom Series II Plus Radio Console. The radio equipment was installed in conjunction with the Westinghouse CAD/AVL but can be, and initially was, operated separately.

At the second training session, a Westinghouse representative taught the dispatchers how to use the CAD/AVL screens, including how to use the "mouse" to access the "pull-down" menus. This training session required two days. Teaching the dispatchers how to use the "mouse" required considerable time.[28]

Dispatchers received a third training session to learn how to integrate use of the two screens and the console. The dispatchers said they were pleased with the training and the equipment. They said that the "operation of the console" for the new Motorola equipment was not too different from their prior procedures and equipment. Following these training sessions, RTD installed CAD/AVL consoles in the Dispatch Center and in the maintenance area.

## 3.5 USABILITY

The inherent usability of the CAD/AVL system has improved the dispatchers' efficiency even though they use more keystrokes to enter data. The CAD/AVL system propagates important data items throughout the system once they have been entered. For example, CAD/AVL "auto-fills" the bus number in the data entry sequence on the "create incident" window.

The dispatchers monitor five screens. The CAD/AVL has two side-by-side screens but dispatchers use one mouse for data entry which transitions seamlessly between the screens. They access bus schedule information from the legacy VAX system that has two screens. They also monitor the Operations Center's security cameras on a fifth screen.

Each dispatch console has three keyboards. In addition to the CAD/AVL keyboard, the dispatchers use two keyboards for the VAX. Because the three keyboards are adjacent, dispatchers were observed to confuse them occasionally during times of high workload. The keyboards and the workstation controls are not backlit.

The CAD/AVL system uses windows software and pulldown menus. The dispatchers said that the pull-down menus could block critical information. The dispatchers can move and resize windows but the active window has the predominant position. The essential information on the CAD screen is not located in one window. The dispatchers have chosen not to get schedule information from the CAD because its window can obscure other information. They also can access the legacy VAX display for schedule information. High priority alerts are located in the

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[28] In human factors research on data entry devices, air traffic controllers have found it easier to use a "trackball" than a mouse.

central display areas. At the request of the dispatchers, the vendor redesigned the data elements in the CAD current incident window to match the column headings in the paper log.

The dispatcher controls the pace of the data entry and the computer does not impose time limits. The CAD/AVL system gives feedback to the dispatcher to indicate that the computer has initiated the command, for example: "voice channel opened." The CAD screen flags incorrect entries using a message in the message window. Dispatchers use system features, such as the edit feature, to correct data entry mistakes. Destructive commands are only accessible from the lead position as part of their capability to change settings.

Dispatchers select how much detail they want to show on the screens. The AVL display can display a maximum of eight routes at one time. Icons represent vehicles. Because one route can have many buses, dispatchers typically do not choose to display several routes simultaneously due to screen clutter and to improve system-processing speed. Typically, the AVL display shows supervisor vehicles, maintenance trucks, "extra cover" and special buses.

Dispatchers adjust the displays to improve their screen contrast. Sunlight does not wash out the screen colors on the screens. The Dispatch Center has window shades to adjust for glare.

The AVL screen has four levels of street definition. Figure 13 shows the AVL screen. The AVL uses red lines to represent streets and the dispatchers said that they found these lines disorienting. Some dispatchers selected the lowest level of street definition to reduce clutter and improve system response time.[29]

The CAD screen has a blue background with white letters in the headings and yellow letters for fill-in fields. The white letters on blue background can be difficult to read. Human factors research suggests that yellow would be a more effective color for letters on a blue background (Cardosi and Murphy, 1995). Red is used for emergency icons but is also used for map information. Usability would be enhanced if each color has only one meaning.

The CAD screen has two levels of size coding; the larger size is used for forms to be filled in and the smaller for function keys. Text is displayed in uppercase for the forms to be filled. Formats within data fields are consistent from one display to another. Figures 13, 14, 15, and 16 show the AVL screen, the CAD screen, the CAD screen with the vehicle information menu, and the CAD screen with the incident queue, respectively.

The CAD/AVL system uses auditory alerts when immediate action is required. The auditory alert is also displayed visually on the CAD screen. The CAD screen emits one beep for a new call or message. A Priority Request to Talk (PRTT) call emits two beeps and, the highest priority, a silent alarm, emits a constant sound. Auditory alerts cannot occur simultaneously but they can occur in close proximity to one another.

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[29] Harper, Fuller, Sweeney and Waldmann (1998) reported on a project to design a replacement real-time bus information system in Dublin which showed that controllers (dispatchers) preferred linear presentations of routes rather than topographically authentic displays using map overlays. They report that the inclusion of topographic accuracy reduced the controllers' ability to quickly assess route conditions.

There is a fairly high level of background noise and music at the Dispatch Center. The phones and radios are in constant use and the five consoles are located near to each other. The dispatchers did not mention any difficulty with the background noise and it did not appear to interfere with their work.

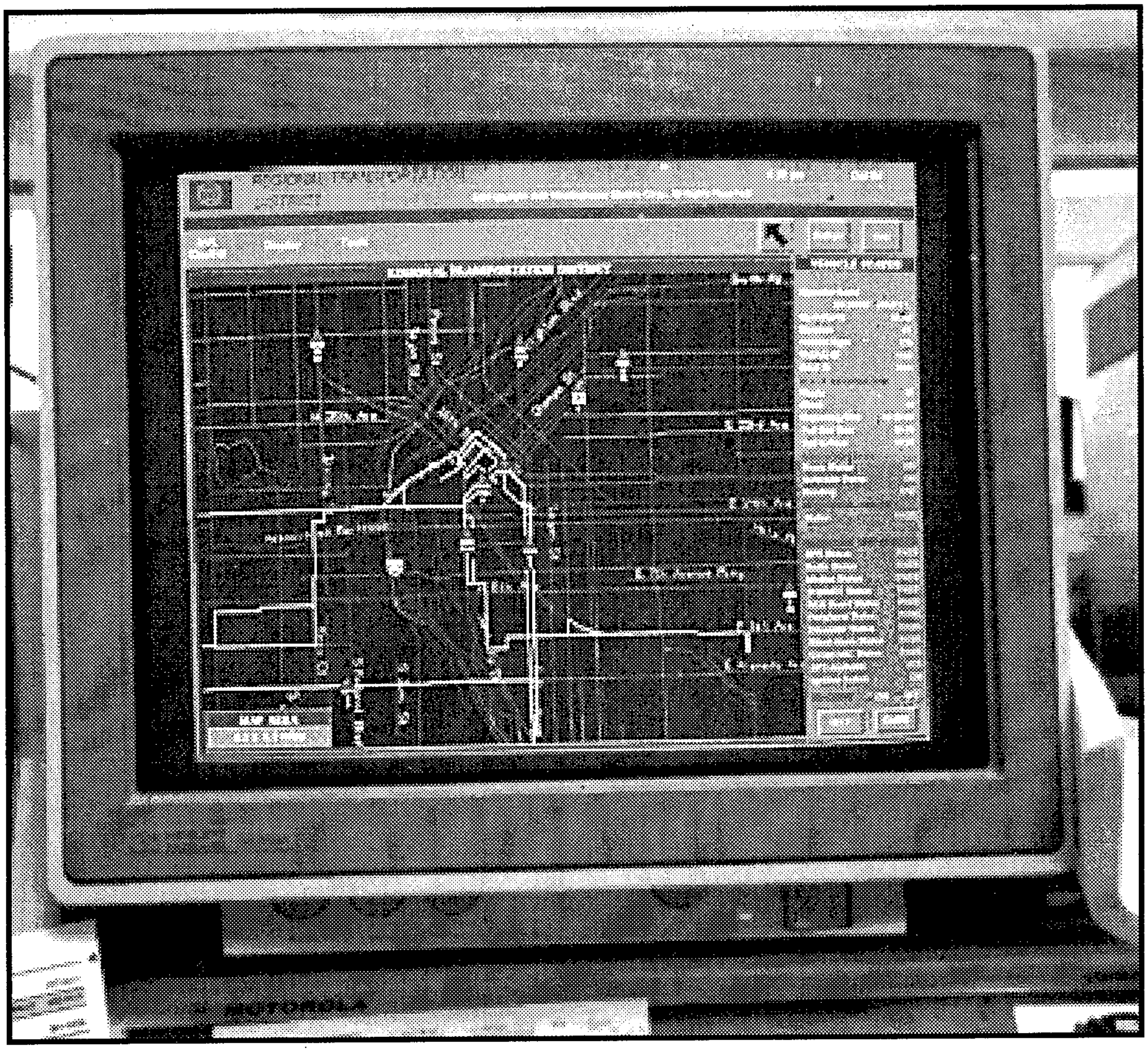

**Figure 13. Automatic Vehicle Location Screen**

Despite the ambient noise, the dispatchers can recognize the incoming messages. The transmitted speech varies in clarity due to interference and location. Each radio frequency has its own volume control. One controller asked for her auditory alerts to be lengthened in duration so she could identify alerts at her console from any place in the room.

Although each dispatcher works at a console, they describe themselves as needing to work together. When work at one position becomes too heavy or intense, the dispatcher can not step away to request help. They need "sight lines" to each console so another dispatcher, or the lead, can step in to provide assistance. The dispatchers also need the capability of transferring calls from one console to another. This feature was not present initially, but was introduced in an upgrade (Long, Ow, Caskey and Casey, 1994).

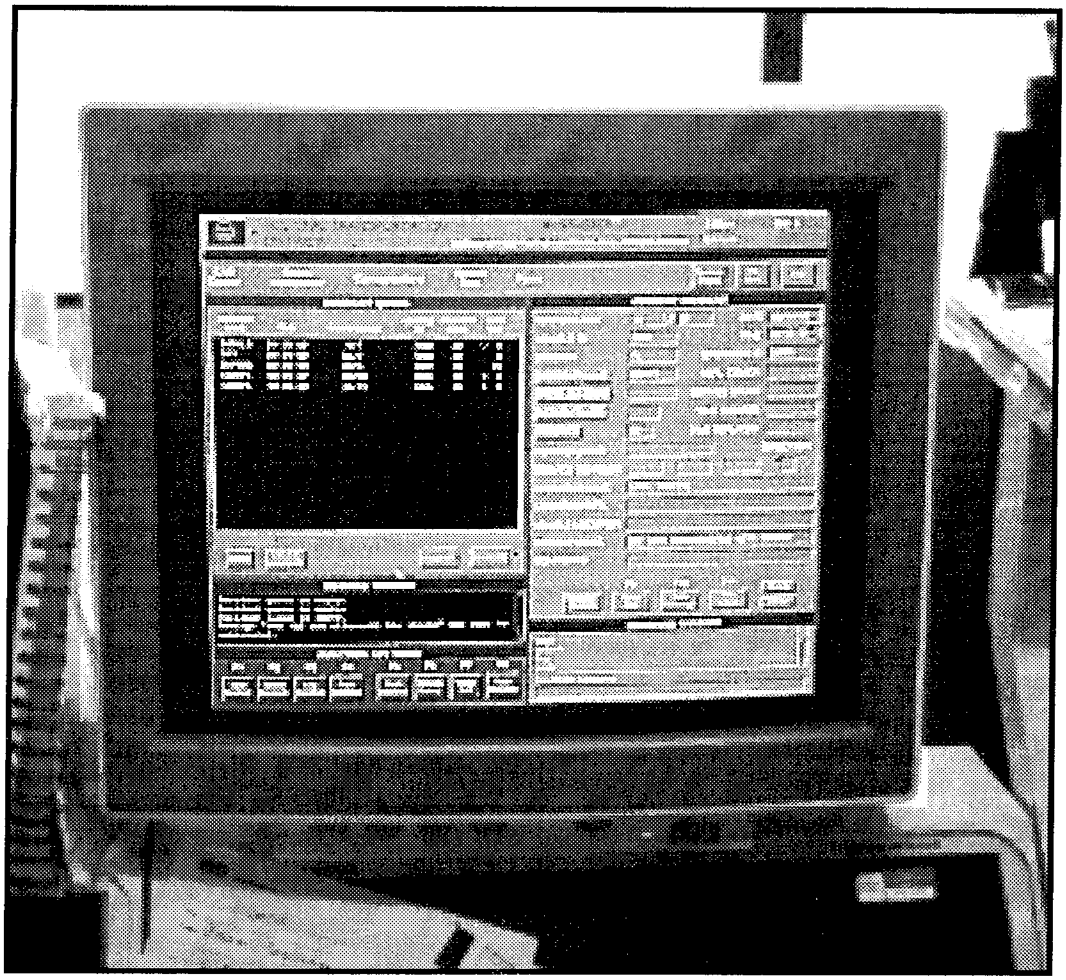

**Figure 14. Computer Aided Dispatch Screen**

The dispatchers said that they did not like the height of the new consoles because it prevented them from seeing another at work. They disliked the separate and linear arrangement layout of the new consoles as compared with their previous "side-by-side" arrangement. Figure 17 shows the arrangement of the new consoles at RTD's Dispatch Center. Dispatchers would like the consoles to be closer together so they can see and hear the activity at the other consoles.

In 1997, RTD added a sound cue to announce incoming calls to the dispatchers. Dispatchers can adjust the sound cue's volume. The Boulder dispatchers particularly needed this enhancement to the CAD/AVL console because they also perform clerk duties that take their attention away from monitoring the screens.

Because the dispatchers sometimes need a printed record of the computer-logged entries, RTD has added a printer to print out CAD/AVL information.

There may be a need for a large AVL screen, visible to the entire room, for use during emergencies when the activity level is significantly increased, or during snow emergencies, to permit a quick assessment of the system status in real-time.

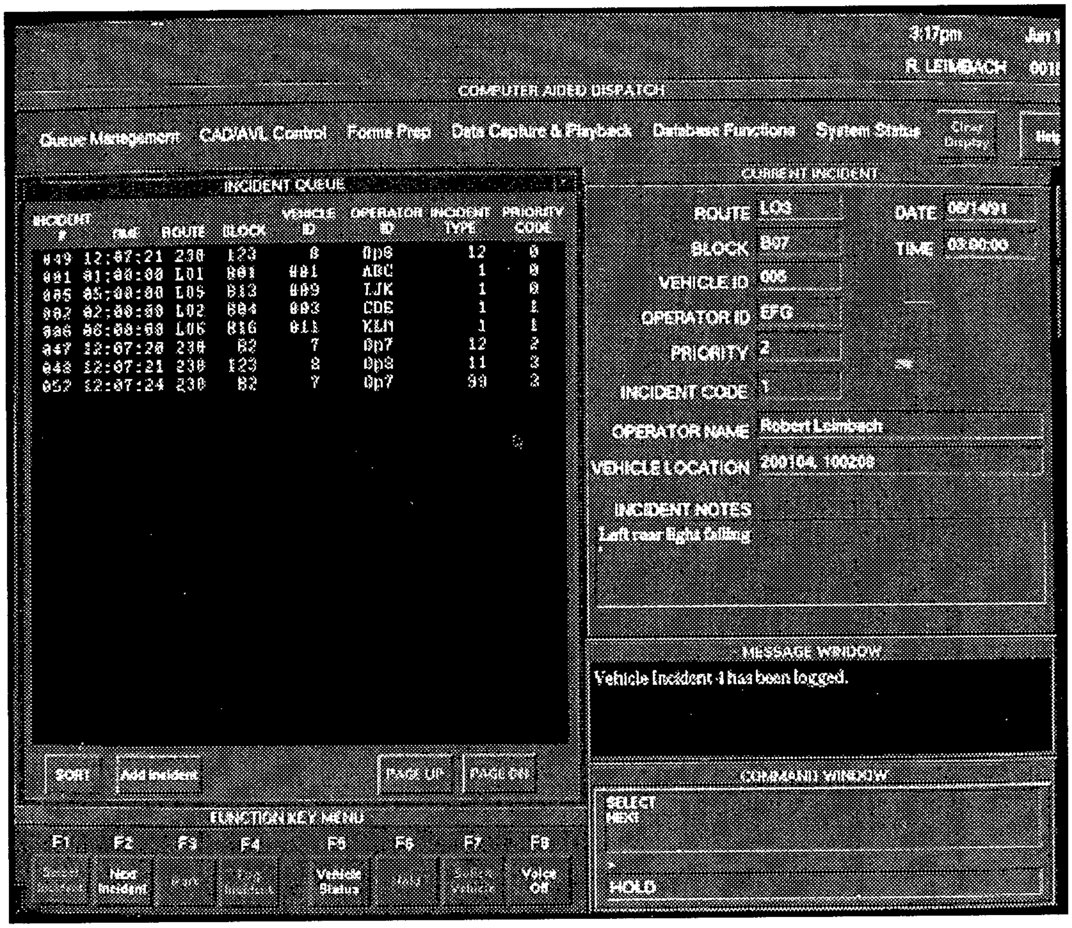


**Figure 15. CAD Screen Vehicle Identification Menu**

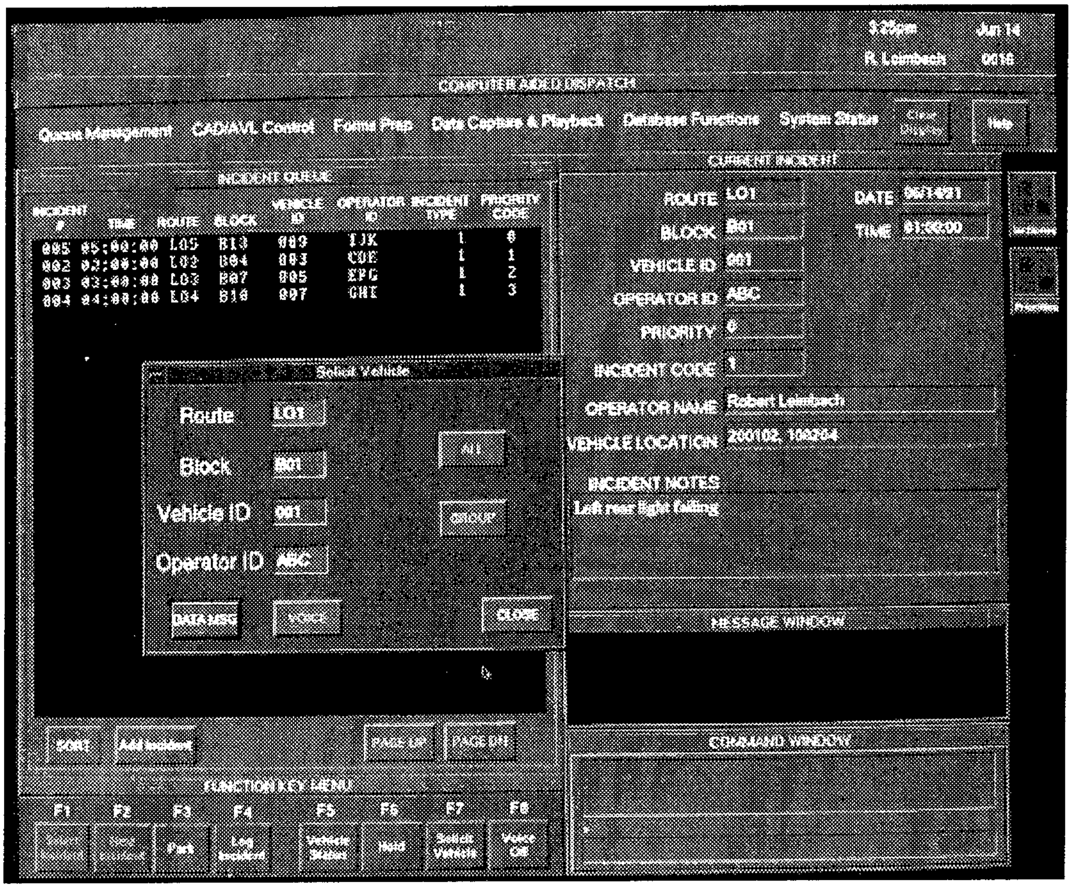


**Figure 16. CAD Screen Incident Queue**

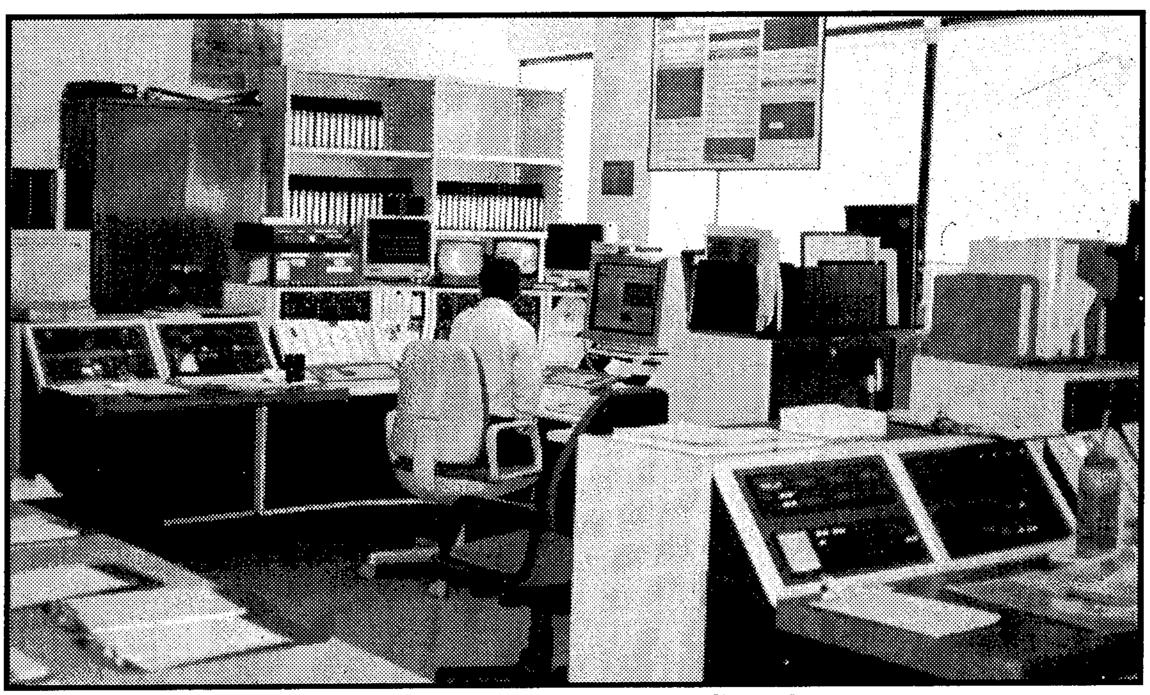

**Figure 17. New Dispatcher Consoles**

# 4. STREET SUPERVISORS

## 4.1 DESCRIPTION

The number of street supervisors and their assignments did not change as a result of introducing the CAD/AVL system. In 1996, Denver RTD had 25 street supervisors, plus two "leads," for a total of 27, which was an increase of two full-time supervisors since 1992.[30] The additional supervisors cover vacations and extra duty shifts. Prior to hiring the two additional street supervisors, "Group II" RTD employees covered these assignments. Because RTD installed CAD/AVL consoles at the Civic Center and the Market Street Stations, (the two downtown terminals and end points for the Mall bus), RTD reduced the number of stationary supervisors assigned to the Sixteenth Street Mall from two to one.

By 1999, the number of street supervisors had increased to 27, plus two leads, for a total of 29. In addition, RTD assigns seven street supervisors to the Boulder division. The lead street supervisor at the Boulder division performs a combination of dispatch, street supervision and division supervision duties.

There are street supervisors on duty 24 hours a day, seven days a week. Supervisors work ten-hour shifts and a four-day week. The number of supervisors on duty throughout the course of the day has not changed; there are slight fluctuations in coverage during the day. Staffing drops to one on duty between 1 am and 3 am. Figure 18 shows the staffing for a typical Wednesday in October 1996 as compared to a typical Wednesday in October 1992.

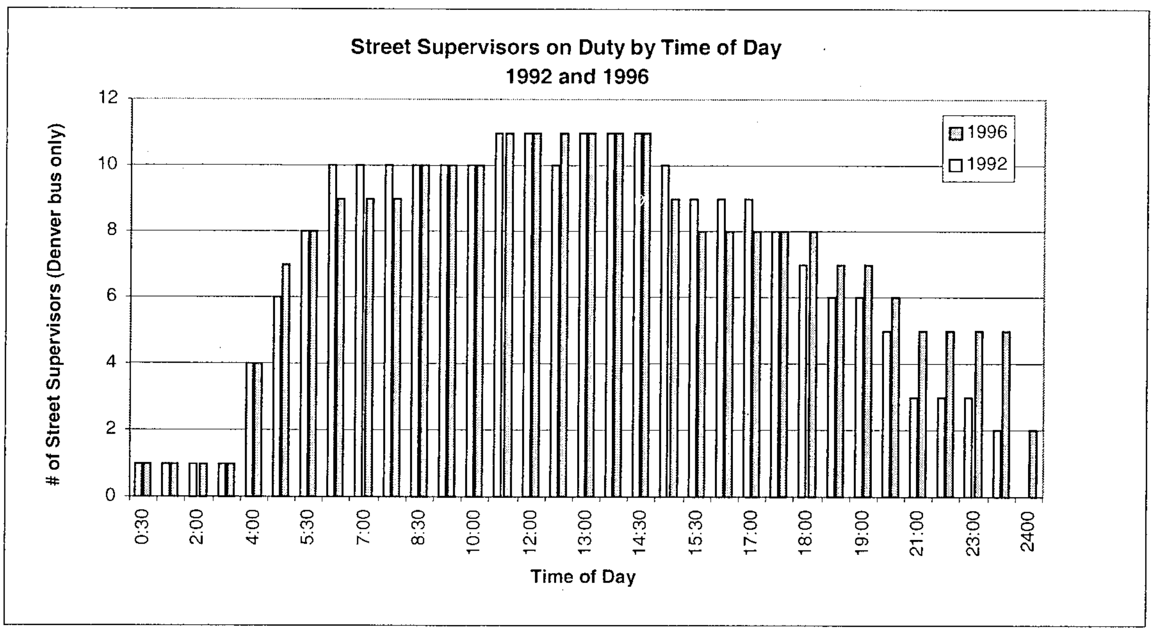


**Figure 18. Street Supervisors on Duty by Time of Day**

[30] There is low turnover in the street supervisor positions and openings tend to occur due to retirement.

RTD has 11 or 12 street supervisors on duty during the peak ridership hours, including two contractor street supervisors in cars. The street supervisors are assigned to geographic sectors, termed Mall, Downtown, Free, and Outer. Figure 19 shows the hand-drawn map that RTD uses to depict the geographic sectors used for supervisor assignments. Although the map is not to scale, the outer areas are large; the Northwest sector extends thirty miles.

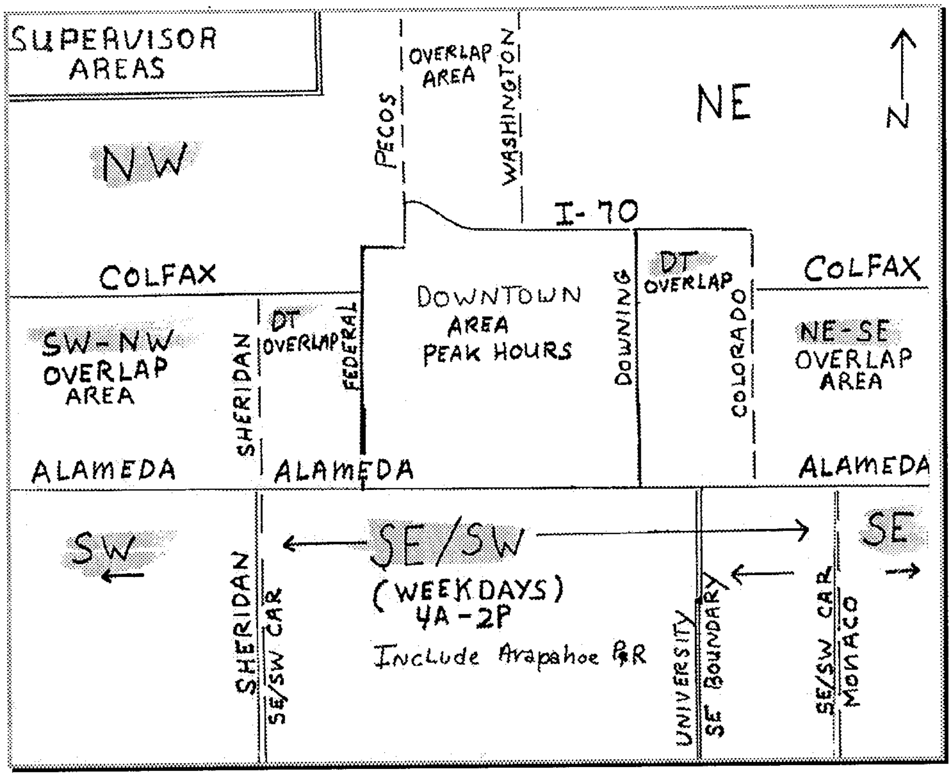


**Figure 19. Geographic Sectors**

Supervision coverage by area changes by the time of the day. Street supervisors cover the geographic sector assigned to them until 9 or 10 o'clock at night and then start to move toward the downtown. Each supervisor shift has a unique set of duties because service demands and incidents vary by time of day and day of week. Their duties also reflect the different types of activity centers in each sector.

RTD assigns two street supervisor vehicles to the downtown area at all times. There is a third street supervisor vehicle, which roams the downtown. Because the Civic Center Station operates at capacity during the peak commuting hours, RTD also assigns a "starter" to monitor operations.

The street supervisors' room on the first floor at the Operations Center is their base of operations. The lead street supervisors have their offices adjacent to this room. Street supervisors park their vehicles, Chrysler Caravans (to be replaced by Jeep Cherokees) outside this room. They use this room to meet, receive information and training, and to check in and out. However, the street supervisors do not spend much time in the supervisors' room because their job is to be in the field.

## 4.2 PROCEDURES

Street supervisors send and receive "canned messages" using the MDT in their vehicle. When the MDT receives a text message, it places the message in the Received Messages window and beeps. The MDT beeps at 30-second intervals until the supervisor views or deletes the message. Street supervisors said they use the MDT to communicate with the Dispatch Center more often during the peak service hours to avoid overloading the Dispatch Center.

Street supervisors use the MDT to perform a variety of tasks. By entering a bus number or route and block on the MDT, they can locate a bus and determine whether it is ahead or behind schedule. Street supervisors look at the bus schedules and extra board assignments on the MDT screen. They can also do the following: review headway information from the database on the hard drive; request specific information about a route or vehicle; request to use a voice channel to speak to a specific bus; and select, edit, and fill out forms electronically.

The initial MDTs had limited capability. They had 2 MB RAM, an 80 MB hard drive and a DOS operating system. RTD replaced them with off-the-shelf Pentium laptops with 120 MHz 32 MB RAM, and 1-gigabyte hard drives. The replacement MDTs use a windows operating system to permit multitasking.

Table 4 summarizes how the street supervisor procedures have changed as a result of operating CAD/AVL.

**Table 4. Changes in Street Supervisors' Responsibilities and System Capabilities**

**New Street Supervisor Responsibilities**

- Log onto MDT in supervisor vehicle.
- Ride light rail vehicles to check for fare adherence.
- Assumed breath alcohol technician responsibilities - Breath Alcohol Technician ("batman")

**Eliminated Street Supervisor Responsibilities**

- Report location to Dispatcher.

**Altered Street Supervisor Responsibilities**

- Use real-time schedule information from MDT to check schedule/route adherence (replacing loose-leaf binders).
- Use MDT to enter reports electronically, i.e., Park and Ride counts, traffic checks, incident reports, accident reports.
- Communicate with bus directly (instead of using the dispatcher as a go-between).
- Send/receive text messages (instead of speaking on the radio). Useful for detour information and personnel matters considered sensitive.

Street supervisors listen to the radio in their vehicle all the time. Their radio monitors the supervisors' channel, bus channels, and the maintenance truck channel. Street supervisors keep the supervisor channel set to priority and, when messages come on this channel, they override the other channels. Typically, they monitor the bus frequencies constantly to anticipate and respond to problems in their area before being asked to do so by a dispatcher. One street supervisor said, "better you keep it on scan so if something comes up in your service area, you can start heading that way."

The street supervisors receive more information from both the radio channels as well as from the MDT. They can still listen in on the "party line" to hear communications from bus operators. Because CAD/AVL reduces their requirement to perform traffic checks, they have been able to assume a greater variety of duties.

The street supervisors' tasks vary considerably. They said that the dispatchers "call us for anything" and, in response, the street supervisors "...determine, with dispatch, whatever is needed for service." "A street supervisor provides the response to the emergency on the street and is the one who calls the shots." Supervisors must be "ready to respond to the public" and are "responsible for correct information." They sum up their job as "basically a communication person..." They describe themselves as "knowing the system" and are "on the street in contact with the public and with the operators."

Street supervisors dislike seeing a problem and not being able to do anything about it. They said that the "task of street supervisor is to make sure the buses are running properly." The "street supervisor also ought to be there to help, to check park and rides; sit at main time points and check for time, cruise, be visible." The street supervisor should "note bus stop problems, park and ride problems and is required to make a number of contacts per day with operators as a goodwill thing."

Street supervisors report that they can do their jobs better using CAD/AVL because they have more information. Because they have more information, they have become more effective members of the RTD's field management team.

## 4.3 WORKLOAD

The street supervisors said that the CAD/AVL system has been helpful and that "it doesn't seem hard." They view the CAD/AVL system as a way to look at the bus schedule electronically and to assess the quality of the bus service. "With a 'locator system' (there will be)...no need to sit there and can tell if a bus will be late." They commented that the CAD/AVL is a "great system" and it "makes the job so much easier.

In 1992, on a typical weekday, the street supervisor staff accumulated 1,158 miles and responded to 374 activities. In 1996, they logged 1,274 miles and responded to 322 activities per weekday. Total daily mileage of the street supervisor vehicles increased 9%. On a per supervisor basis, they averaged seventy miles per shift in 1992 and eighty in 1996, an increase of 14%.

Certain street supervisors had assignments that covered more territory; one-quarter of the supervisor logs recorded more than 100 miles per shift. A street supervisor observed that the "downtown car may do 20 to 60 miles per day patrolling routes downtown...(but) may do 100 miles when they have to transport a passenger who missed the last bus to Evergreen."

Street supervisors in the downtown sectors averaged 43 miles per shift in 1992 as compared to 62 in 1996, a 44% increase. Supervisors assigned to the outer sectors increased their mileage by 7%, 101 miles in 1992 as compared to 108 in 1996. The increased mileage reflects the expansion of their duties. In addition to shifting one supervisor from the 16th Street Mall, the new bus service to the Denver International Airport expanded RTD's service area.

Street supervisors[31] averaged slightly less than forty contacts per day with dispatchers in 1996 and more than forty contacts per day with dispatch in 1992. Each street supervisor contacted dispatch an average of 2.5 times per day in 1992 and 2.3 times in 1996.

Figure 20 enumerates the categories of activities that supervisors performed during a typical day.[32] Activities include traffic checks at a certain location, car counts at a particular park and ride, etc. The count of activities may underestimate the actual frequency of occurrence due to individual differences in the amount of detail in the log narratives. The total number of contacts between bus operators and supervisors increased 108%, from 74 to 155. Surveillance activities increased 70%, from 40 to 68. Route checks decreased 50%, from 131 to 65, while time checks decreased 72%, from 85 to 24.

Figure 21 disaggregates supervisor activities and shows what the average supervisor day was in terms of contacts. The average number of route checks per street supervisor dropped from eight in 1992 to slightly more than two in 1996. Personal contact with bus operators doubled, from slightly more than five in 1992 to almost ten in 1996. Time checks dropped from five in 1992 to an average per shift of two in 1996.

The types and frequency of activities they performed was similar across geographic sector assignments. (Figures 22 and 23).

[31] This includes contractor street supervisors.

[32] Street supervisor activity obtained from log data are categorized as number of routes checked, contacts with operators, time checks, surveillance checks at park and ride lots, checks at garages, checks at downtown stations, disabled buses contacted, detours checked or created, accidents checked, incidents involving lost and found, incidents with "other" i.e., removing sick passengers from buses, giving transfers to bus en-route, moving operators from garage to garage, and delivering supplies.

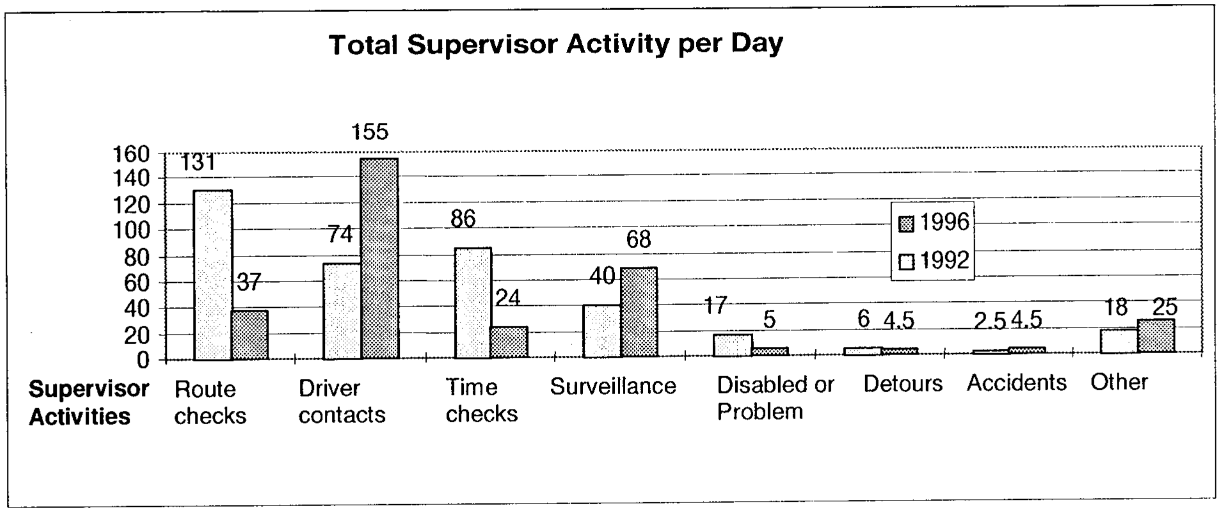


**Figure 20. Total Street Supervisor Activities per Day, 1992 and 1996**

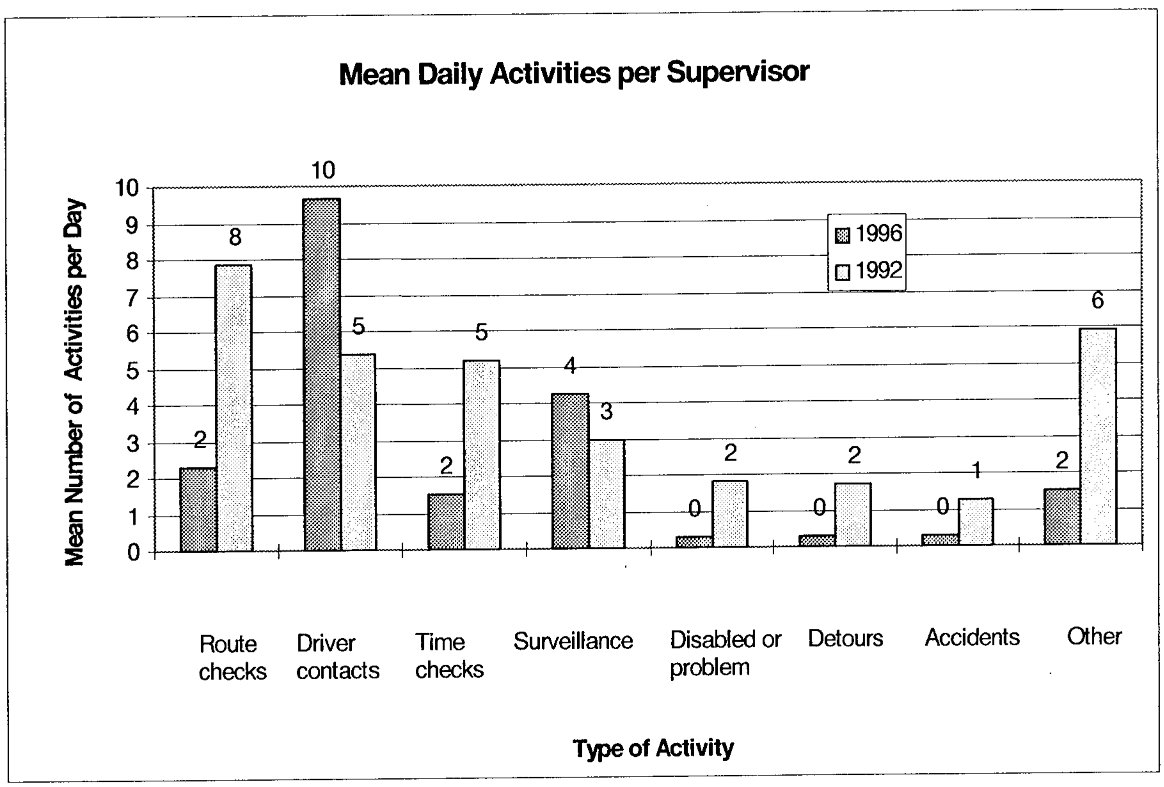


**Figure 21. Mean Daily Activities per Street Supervisor**

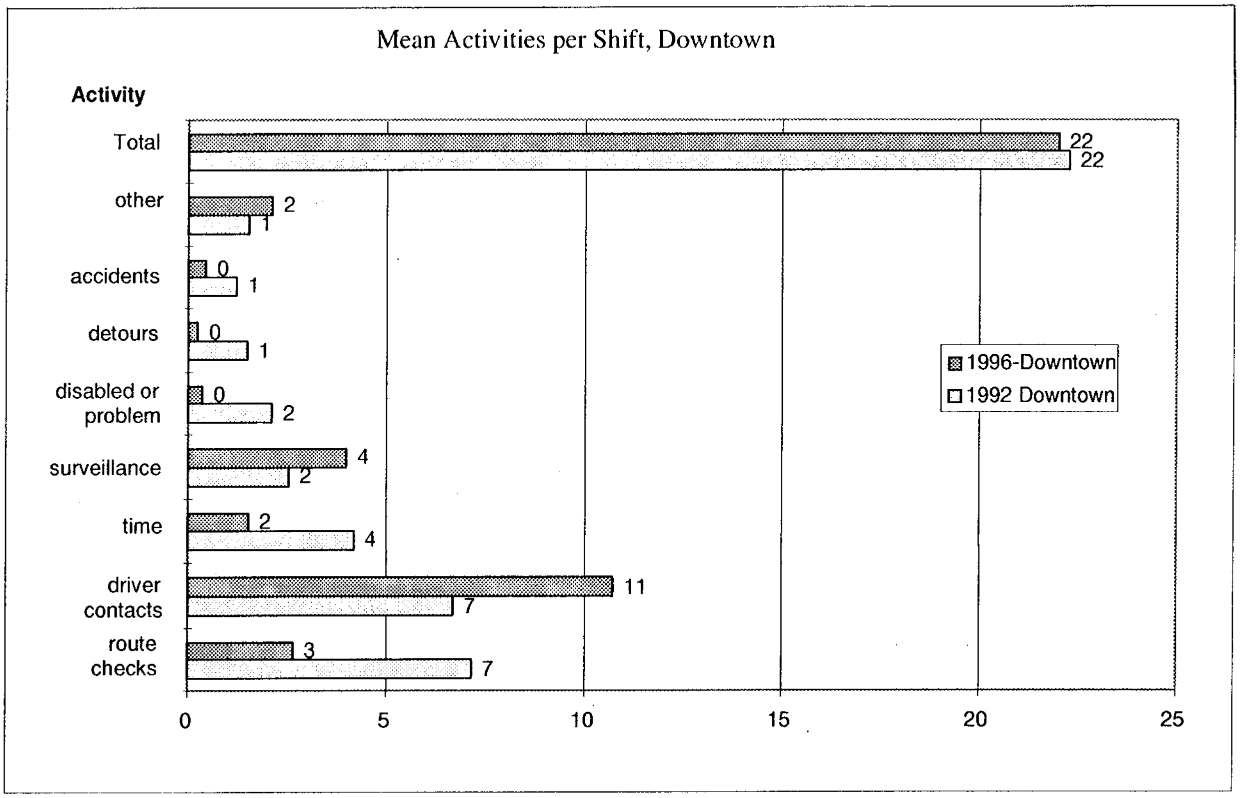


Figure 22. Mean Number of Activities per Supervisor Shift, Downtown Sectors

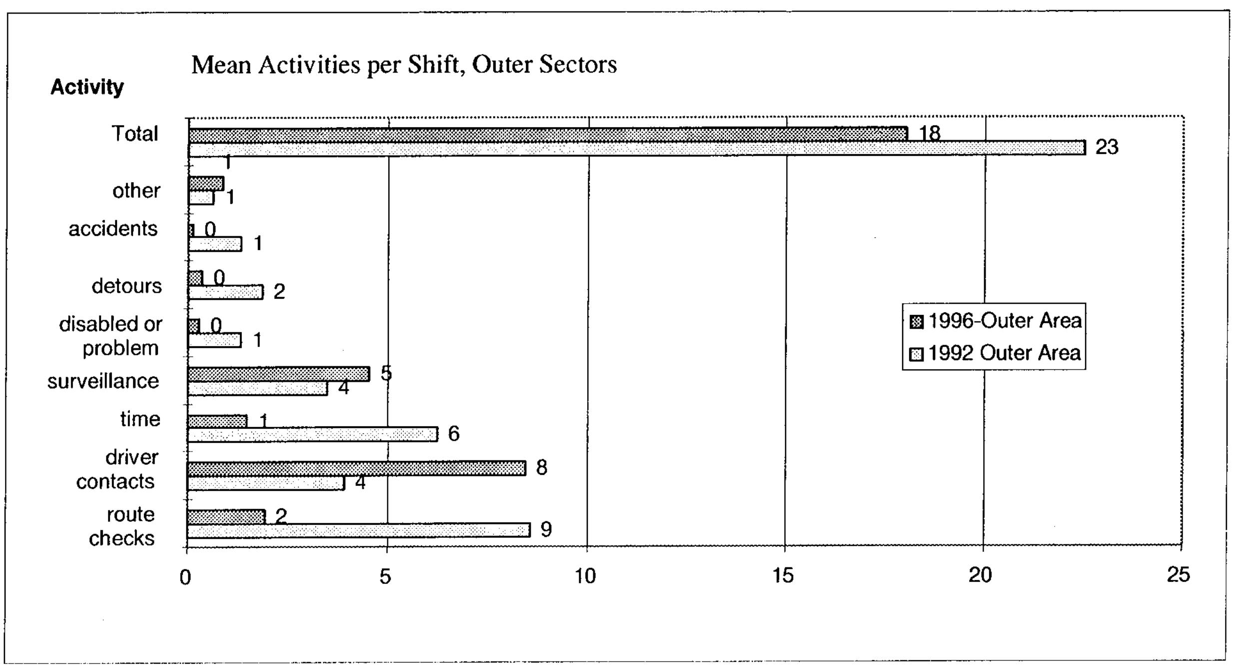


Figure 23. Mean Number of Activities per Supervisor Shift, Outer Sectors

## 4.4 TRAINING

The street supervisors learned to use the MDT on the job. They also had to learn to operate the TCHs in the buses to be able to assist bus operators. RTD trainers briefed them on use of the TCH using the training cart. They practiced using the TCH on a "radio cart" in the supervisors' room.

## 4.5 USABILITY

Street supervisors use the MDT to locate buses and talk to an operator without using a dispatcher as an intermediary. They like the capability of the MDT to give them information without having to request it from others. They also like the variety of information they can access quickly such as bus number, location, badge number, roster of operators, route and block for an operator.

The MDT has function keys for frequently used commands. Street supervisors can correct data entry errors on the MDT and can change a message before sending it to the Dispatch Center. The MDT gives feedback to indicate that it has initiated a command. The MDT design does not require street supervisors to recall infrequently used data-entry commands because they can scroll through them.

The MDT reduced the street supervisors' need to use paper schedule information. It also reduced the frequency of their communication with the Dispatch Center to request real-time bus location information.

Display clutter on the MDT is not a problem. The brightness level of the display screen is adjustable. The street supervisors use the MDT's in their vehicles in varying lighting conditions, including glare. Street supervisor vehicles have adjustable gooseneck-type lights clamped onto the dashboard that the supervisors tend to use frequently.

Street supervisors report that they found the MDT easy to use. "Everything fell into place," said one supervisor. RTD trained the supervisors to use the MDT and to use word processing software. They provided eight hours of instruction on each topic.

RTD also had "the radio people" show the supervisors how to "hook up" the laptops. There was a lot of informal instruction among the supervisors; for example, supervisors showed other supervisors how to log on. One supervisor, who described himself as a computer novice, said that he now feels lost when the system goes down because he is so comfortable using it.

# 5. BUS OPERATORS

## 5.1 STAFFING

RTD employed approximately 1,040 full-time equivalent bus operators, not including contract operators at the end of 1996. By the end of 1998, RTD had 999 full-time and 147 part-time bus operators. The 1998 total, 1,146, represents a 5% annual increase in the number of bus operators. Even with this rate of increase, RTD has fewer bus operators than authorized and has continued to hire bus operators in 1999.

Bus operators typically begin work at RTD as part-time employees and convert to full-time employment. While the turnover rate of part-time operators was estimated at 40% in 1997, the turnover rate for full-time operators was only 3%.

In 1996, RTD staffed the approximately two hundred express runs during the peak hours with "trippers," part-time operators hired to do these "trips." By 9 am in 1996, the morning peak hours were over and the "morning trippers were back in the garage." After 9 am, RTD provides "regular service" and "all the expresses and the part-time operators have gone in." By 1998, RTD had increased the frequency of its mid-day service on the express routes to serve DIA and other destinations.[33]

Bus operators use dispatch services from one of two sites, the Dispatch Center and Boulder.

## 5.2 PROCEDURES

The CAD/AVL system has changed how bus operators communicate with the dispatchers. Bus operators have to select a button to initiate communication with the Dispatch Center and dispatchers respond to bus operators' requests by priority rather than chronology. Operators select a button on the TCH to initiate communication. Figure 24 shows the TCH installed in a RTD bus. The bus operator can correct data entry errors because the TCH requires the bus operator to select a YES or NO button to confirm the message before it will be transmitted.

When a dispatcher or supervisor sends a message to a bus, the TCH beeps and a light emitting diode (LED) light illuminates to attract the bus operator's attention. The TCH continues to flash and beep until the bus operator acknowledges the message. To view a message, the operator must press N MSG to view new message, use the TCH arrow key to scroll to and through the entire message, press YES when the "Yes to ACK" message appears, and, when "save message" appears, press YES to save the message and clear the screen, or enter NO to delete the message.

If a voice message is sent to a bus, the TCH LCD shows a "voice call" message and sounds an auditory alert, a loud beep. The beeping continues until the operator picks up the handset and begins speaking. There is a left-side mounted radio handset and external speaker for voice communication.

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[33] RTD has increased the number of express trips. At the end of 1998, RTD operated 250 express trips, a 25% increase, on 48 routes.

When a dispatcher receives a message from a bus, the TCH displays a message indicating that the transmission has been received. Initially, the CAD/AVL system lacked an "end-to-end acknowledge" which caused uncertainty for the bus operators. The "ACK" message (acknowledge) shown on the LCD on the TCH was added to the system (Long, Ow, Caskey, and Casey, 1994).

When the Dispatch Center receives a coded message, a request to talk RTT, or a priority request to talk, PRTT, the LCD on the TCH shows MSG RCVD (message received for coded messages) or VOICE REQ RECVD-PLEASE STAND BY for RTT or PRTT. The operator must press the YES button on the TCH to clear the message before another message can be sent.

The TCH has the capability to receive and store lengthy messages. Formerly, bus operators had to transcribe these messages leading to transcription errors. Bus operators find the storage feature especially useful for route detours. They also can refer their relief operator to the stored detour information and communicate this information more quickly and accurately.

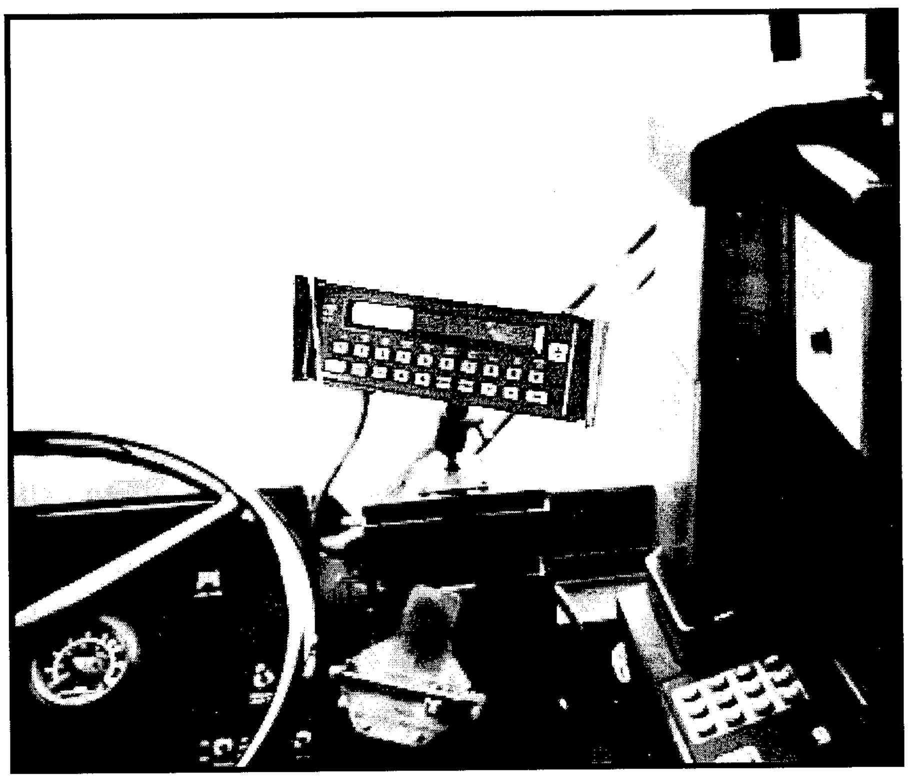

**Figure 24. TCH Installed in Bus**

The CAD/AVL system has a SA. When an operator presses the SA switch, the dispatcher's AVL screen will show the location of that bus. The SA activates a covert microphone in the bus and locks up, or freezes, the TCH functions.

The SA shows the bus operator that it is working when the colon in the time display on the TCH disappears momentarily (while the message is being transmitted). The colon turns solid when the covert mike is open. Only the dispatcher can clear a SA once it has been activated.

Bus operators must log onto CAD/AVL using the TCH before they start work. If they make an improper entry, the LCD on the TCH shows an error message, for example, LOGON AGAIN - BAD OPERATOR ID. Operators must completely test the silent alarm within 30 seconds or the bus will transmit a silent alarm to the Dispatch Center. When one operator relieves another, the relief operator is not prompted to test the alarm. If they do, an alarm will be transmitted.

False emergency alarms, due to operator error in logging on, occurred often following the introduction of the CAD/AVL system. Sometimes, in a dark garage, an operator may have logged on in an illegal manner and they cannot reset the SA.

Bus operators have been instructed to use the SA only when they physically cannot pick up the handset or, to do so, would cause harm to them or to the passengers. RTD instructed the bus operators to transmit a PRTT to get the fastest voice response from dispatch. Previously, RTD buses did not have an emergency alarm despite unsuccessful attempts to install them and bus operators had to speak "on the air" and describe the threat.

The TCH has a digital clock. Bus operators like this feature because it has reduced their need to request time/radio checks from the Dispatch Center. However it is still mandatory for bus operators to have their own timepiece. This is required because, if the bus IVLU goes into "fallback," it will not reset the time on the TCH when the satellite signal resumes. Bus operators report that they notice passengers contorting themselves to look at the time on the TCH.

Prior to CAD/AVL, Motorola radios were the communication equipment on the RTD buses. Bus operators used a "push to talk" analog system and had to key up the microphone on their console and say their bus number to contact the Dispatch Center. Operators would pick up the handset; listen to make sure the radio was not in use; press the transmit button; wait for the dispatcher to make a voice acknowledgment of the bus number; and speak into the mouthpiece with a message. Operators received their assignments by "block number" but they were monitored by their bus number.[34] Dispatchers responded to calls as they were received, regardless of the nature of the call.

When the TCH fails, or buses lose communication with the GPS satellites, bus radios revert automatically to the fallback mode. In fallback, operators use the pre-CAD/AVL radio procedures to communicate with the dispatcher.

Table 5 lists the bus operators' procedures that have been eliminated, changed, or added due to the introduction of the CAD/AVL system.

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[34] RTD uses the term "block number" or "train number" to identify specific spaces or pieces of work.

**Table 5. Changes in Bus Operators' Responsibilities and System Capabilities**

**New Bus Operator Responsibilities**

- Log onto TCH and test SA as prompted by text on TCH.
- Categorizing emergency severity and use SA with covert microphone

**Eliminated Bus Operator Responsibilities**

- RTD changed the operators' practices during snow conditions. They use the STUC button on the TCH and can chain up. (They used to have to request authority to put on chains.)
- No longer need to monitor communication on radio handset for clear air to make radio call (Does not apply to fallback mode).

**Altered Bus Operator Responsibilities**

- Multiple ways to initiate communication with dispatcher (instead of communicating using the radio handset). Operator can select RTT, PRTT, or pre-coded messages.
- Can receive and store text message from dispatch. Especially useful for route detours. (Previously, bus operators heard an "all-call" on the radio and, if it pertained to their route, or they were called by dispatch, they would have to transcribe the instructions.)
- Time is displayed on TCH. Because the TCH shows the system-wide time, there is no need to request a time check. Buses in loop extra service still advised to perform time/radio check. (Reduced need for time/radio checks from dispatch.)

## 5.3 WORKLOAD

Bus operators view themselves as public servants. Bus operators used a variety of adjectives to describe the job of driving an RTD bus. But, they typically first mention "challenging customers (i.e., riders)." They view their job as stressful and frustrating, at times. Stress is a consequence of dealing with more volatile and hostile riders, increasingly more difficult traffic conditions, and weather. Frustration comes from growing numbers of inconsiderate automobile drivers and schedules that are too tight to meet because of both traffic growth and customer demand. "Now you just got to rip and run from one route to another."

When asked about the CAD/AVL system, bus operators described it as having a "silent button so they can press it and (dispatch)... can hear everything." The bus operators said that, with CAD/AVL, "...they (dispatchers) can tell if your are 'one minute hot' (and)...can tell if (you are) more than 10 minutes behind."

When asked why the old system was replaced, bus operators first mentioned that the new system allowed "more control over the operators" and could be used to track them. "In other words, big brother is watching." Other reasons given for making this change over were enhanced safety and a better emergency response system. This latter reason, however, is controversial. Currently, the safety and security features are not perceived to be working up to their potential. This is primarily due to a response time issue. The bus operators' uncertainty about how the security features work led them to perceive the SA system to be unreliable, although they consider it an improvement.

Although the bus operators were critical of various aspects of the CAD/AVL system, their overall conclusion was positive. This positive assessment was confirmed by a cross-section of operators, regardless of experience level or age. They view the CAD/AVL system as an improvement over the former system but whose potential has not been reached.

Despite an increase in the absolute number of contacts between buses and the Dispatch Center, the actual incidence per bus is low. Bus operators have infrequent contacts with dispatchers and street supervisors and the frequency has not changed with the CAD/AVL system. Using total-vehicle miles, it is possible to calculate the incidence of calls to dispatch per total-vehicle mile. In 1996, there were 2.8 calls to dispatch per thousand total-vehicle miles operated compared to 2.7 in 1992.

## 5.4 TRAINING

The keys to achieving the CAD/AVL system's potential are training and experience. Newer operators who have most recently completed training and only trained on the CAD/AVL system know how to use it.

RTD used three full-time instructors, as well as 17 non-revenue service instructors when they trained the bus operators to use the CAD/AVL system. The latter are "relief" operators reassigned from bus driving on an "as needed" basis. They worked in training 80-90% of their time when CAD/AVL became operational in 1994-1995.

In 1997, RTD had 62 revenue service instructors who teach the new operators on the road during the fourth and fifth weeks of their six-week training program. All the instructors are rotated through the classes for the new operators once or twice a year to stay current on any changes.

RTD's training philosophy pairs classroom instruction with hands-on experience. They use lectures, workshops, simulated and on-the-road practice, a simulated TCH or "radio cart, and a revenue service bus configured for instruction."[35] Figure 25 shows one of the RTD's custom-made radio carts.

New operators train using the TCH and practice calling the Dispatch Center from the training bus. They use the "radio cart" to simulate a "hands-on" experience. The "Lead" dispatcher gives new bus operators a tour of the Dispatcher Center and shows them how dispatchers receive and handle radio messages.

All veteran bus operators receive one-hour refresher training annually in groups of 6 to 8. These refresher classes are held in the garages using the "radio carts."

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[35] RTD custom made these carts at an estimated cost of approximately $3500. The radio component accounted for $3000 of the cost of the carts. RTD has several radio carts; there is also one in each garage and one at the District shops.

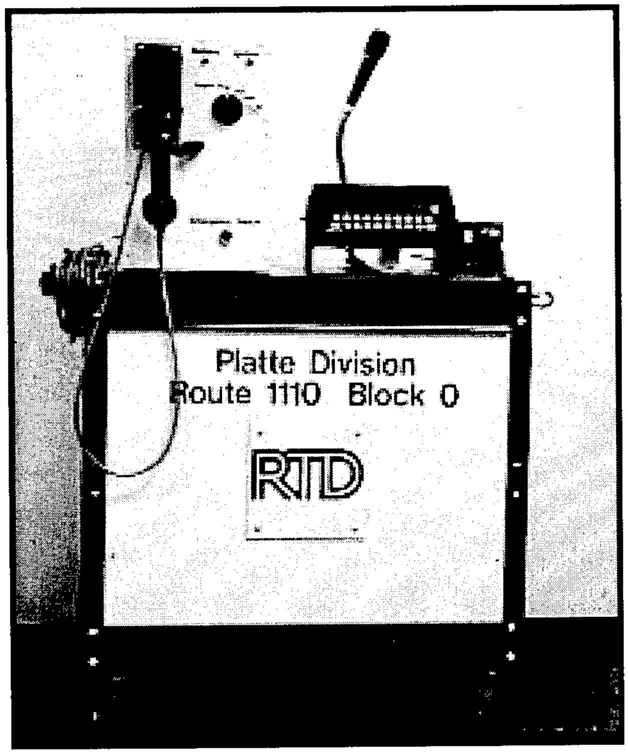


**Figure 25. "Radio Cart"**

When there are system failures, RTD communication reverts to the "fallback" mode. The training instructors teach the bus operators what to do when they go into "fallback."[36] Operators know they are in "fallback" because the TCH emits a tone and the TCH display reads "fallback." In "fallback," the operator picks up the handset and listens for clear air.

Fallback occurs due to bus faults, as well as, system faults. When "fallback" occurs due to poor reception, "fallback" tells the bus operator that the bus is not in communication with the satellite. Fallback can also occur due to a low power supply. Operators are instructed, if they have a power failure, to pull over and to try the third throttle. Operators do not have to log on after they experience a fallback episode.

The training classes emphasize that, when one operator relieves another, after first entering his/her identifiers, they should next check for old messages stored in the TCH. The former practice was for the operator to tell the information to the relief driver. The TCH has the capability to store messages that should be checked.

A number of issues arose during training. Some operators had difficulty determining how to categorize a situation, i.e., whether the situation calls for an RTT, PRTT, or a SA. Initially, they often did not realize that using a PRTT would contact a dispatcher faster than a SA. Some operators have difficulty understanding that, once they have sent a pre-coded message, they don't have to press RTT.

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[36] Dispatchers estimate that each bus operator will get 3 incidences of communication failure per week.

The operators' TCH shows a text message, "message received," as a confirmation which appears on the TCH LCD display. Some operators said that they "feel like that they have not done their job unless they talk to the dispatcher and tell them what the problem is." They do not realize that the purpose of the CAD/AVL system was to cut down on the voice traffic. They feel that if they have a serious problem they will get a quicker response.

## 5.5 USABILITY

Bus operators expressed strong opinions on the design and configuration of the CAD/AVL system. They did not believe that the system was designed with the operator in mind. They perceived it to be inconvenient to operate at best and a safety hazard at worst. "The old one was safer to deal with. With this one it takes your eyes off the road, hands off the wheel, deal with button, beeping is distracting...." "To be honest, I think sometimes it is a big hassle for me, when they send messages over and I'm in traffic and they keep beeping at me..., it really distracts me and irritates me... I'm trying to read and drive at the same time." "It's a safety hazard. It doesn't belong on a moving vehicle."[37]

The primary need that the CAD/AVL system fulfilled for the bus operator is a better way to communicate. However, several factors worked against achieving the most effective utilization of the CAD/AVL system. The retrofit of two types of equipment - TCH and radio hand set - into the current bus inventory detracted from the CAD/AVL system and inhibited its effective use.

There are differences between the dispatchers' responses to situations and the bus operator's use of the CAD/AVL system. The high degree of judgment each party exercise in using the CAD/AVL system contributed to this variation in responses. Part of this may be due to the lack of explicit protocols for use and/or misunderstanding between bus operator and dispatcher in terms of expectations.

The demands of bus operations made it challenging for operators to uniformly and consistently categorize events. Bus operators must discriminate between unexpected incidents and classify them by their gravity in selecting whether to use the RTT, or the PRTT buttons, or to activate the SA. Similarly, for routine requests, bus operators must classify their request using the pre-set buttons on the TCH to transmit the pre-coded messages.

Bus operators needed time to learn and practice with the TCH as evidenced by the initial number of errors. Bus operators also needed time to learn how to log onto the TCH and test the SA as prompted by text on the TCH. They made errors initially but the incidence has diminished with time.

The following lesson was emphasized in the training classes. When an operator makes a relief, after first entering their identifiers, they should next check for any old messages in the TCH. The instructor noted that they have not emphasized this enough. The common practice was for

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[37] This is an example of the bus operator's need to control information flow during times of high workload and stress. Bus operators suggested that these messages be converted into text so they do not have to acknowledge them immediately. Spelt and Scott (1998) also noted that there is a need for principles for managing information emanating from multiple devices for operators of vehicles with ITS equipment.

the operator to convey information orally to the relief. The TCH has the capability to store messages that the relief operators should check.

Bus operators triggered SA's inadvertently and this has been a problem. Often, in a dark garage, the bus operator did not put on the interior lights when they logged on. One of the bus operator instructors admitted that he inadvertently set off a silent alarm and was referred to the Instruction Department for remedial training. This occurred when he logged on to take over a bus that was in service and he tested the silent alarm, even though he was not prompted to do so (as is the case when the bus is first pulled out in the morning). Based on this experience, RTD's Instruction Department emphasizes that the operator should read the prompts on the TCH display and realize that these prompts tell the operator what to do. Technology has since evolved so that future systems could have a self-testing measure for the SA rather than having to correct the problem through training.

The bus operators have reduced the volume of voice communication using the STUC button. During snow emergencies, bus operators receive a cash payment for putting on chains but they must notify dispatch. Because the former communication system had limited channel capacity, bus operators often had trouble reaching dispatch. RTD revised their procedure and, when operators hit the STUC button on the TCH, they have "de facto" permission to chain up. The dispatchers will call them later as time permits to "clear" the call. However, by transmitting information using pre-coded buttons, bus operators do not tie up the radio during high demand periods.

CAD/AVL has eliminated the bus operator's need to monitor communication on radio handset for "clear air" to make radio calls.

The experienced, as well as the inexperienced, operators offered similar accolades and criticisms for the CAD/AVL system. There are a variety of human factors and technical problems that made the equipment difficult to operate initially and which initially compromised its recognized potential. RTD has provided additional instruction to the bus operators to address these concerns. The provision of additional, and refresher, training has helped the bus operators learn to use the CAD/AVL system successfully.

# 6. CONCLUSIONS

## 6.1 OVERALL

RTD undertook a massive task when it installed the new CAD/AVL system. RTD introduced the CAD/AVL system across its entire operation at once. The CAD/AVL system had to support a high level of service and to provide service to cover an extensive geographic area.

RTD's objective was to better manage transit operations by reducing the time needed to react to problems, provide more support to field operations through an SA capability, as well as to upgrade its communications. RTD has met these objectives because it can locate buses and direct assistance to them referencing their actual location. All calls are retained and receive a response. RTD provides the public access to information about real-time system operation through the use of kiosks installed in stations that draw data from the CAD/AVL system. Due to the CAD/AVL system, the RTD transit system has become more open to both employees and users because they now have real-time information about all transportation operations.

### 6.1.1 Start-up Training

RTD employees have had first-hand experience with adopting, and using, this new technology to perform their daily responsibilities. They learned lessons during the development and early use of the system. Bus operators, street supervisors, and dispatchers now use the CAD/AVL system extensively. Their experience suggests that employees need continuing training, support, and assistance during the transition to the use of a CAD/AVL system.

### 6.1.2 "Playback" Capability

The CAD/AVL system offers more than just real-time information. The ability to store and replay data has turned out to be an important feature. This "playback" capability gives RTD better oversight of past, as well as, current system operation. RTD has become more efficient and accurate in investigating problems by replaying an event to reveal how it actually happened and to see what service was delivered. The dispatchers perform the "playbacks" and they are contacted by an increasing number of entities, both inside and outside of RTD, requesting this information. RTD's Customer Service frequently requests "playbacks" from the CAD/AVL.[38] RTD's Scheduling Department uses it to see whether buses met scheduled time points.[39]

### 6.1.3 Need for "Source Code"

RTD did not acquire source code and said that this lack of the source code "is killing us." For example, RTD has paid outside vendors to rewrite the source code to make the MDT software work with the MS Windows operating system. The CAD has an environment window and the

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[38] If Customer Service receives repeated complaints, the Dispatch Center then directs a street supervisor to check out the actual event on the street.

[39] However, if a transit agency operates routes with very tight headways, the CAD/AVL system may not be useful because the bus operator cannot compensate for the lack of flex in the schedule.

dispatchers would like to expand it to report measurements of temperature, outside conditions, and road conditions.

## 6.2 BUS OPERATORS-OVERALL

To make technology accessible, it is important to recognize that bus operators differ in their employment status and experience. Bus operators work for either RTD or one of several contract service providers. RTD operators work at one of its divisions, i.e., the Boulder, Denver, Longmont, or the light rail division. Some operate different vehicle fleets such as the free Mall Shuttle or the light rail vehicles. Other operators have part-time schedules (and high turnover) while others have full-time jobs (and low turnover). This heterogeneity has implications for training and instructional material. Instructional materials and delivery formats should be relevant to the users.

### 6.2.1 Bus Operators-Variable Response Time

Bus operators do not like the variable response time they receive from dispatch to their call. The previous radio system provided immediate verbal dispatcher feedback, but, sometimes, lost queued calls.[40] The CAD/AVL system's variability occurs due to the way that calls are received and answered at dispatch. When a bus operator makes a call, the bus sends the call every 10 seconds until the bus TCH receives an acknowledgment (ACK) message from the CAD. The call waits in the CAD queue to receive the dispatcher's verbal acknowledgment. Because CAD does not lose calls, the dispatcher does not have to answer immediately, so the time to respond verbally can vary widely. If, during this wait, another bus sends an SA, the dispatcher's mandate to respond to it further slows the processing of pending calls. Field-tests with the CAD equipment show that the mean time required to process a Request to Talk (RTT) is two minutes.[41]

### 6.2.2 Bus Operators-Silent Alarm

RTD has found it challenging to introduce and implement the SA in revenue service. Bus operators did not understand how the SA operated; in particular they tended to forget that the covert mike in the SA precluded a verbal response (often for several minutes). Because the SA connotes instantaneous awareness, the time intervals required for transmission, acknowledgment, and disabling the SA have created misunderstandings and confusions between bus operators and dispatchers. For example, when a bus sends an SA, it takes the dispatcher up to 30 seconds after

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[40] RTD tested response time as part of system acceptance and tested the following components: silent alarm, silent alarm being recognized at dispatch, and acknowledged being received back by bus under different traffic loads; during pull out, pull in, and at mid-day. RTD retests every time they reconfigure and every two months. They also test the GPS accuracy. Time cannot exceed two seconds and usually within hundredths of seconds.

[41] RTD tested response time as part of system acceptance for the silent alarm, for the silent alarm being recognized at dispatch, and acknowledged being received back by bus. These tests were done under different traffic loads and during pull out, pull in, and at mid-day. RTD retests every time they reconfigure, every two months, and they also test the GPS accuracy. Time cannot exceed two seconds. However, these tests measure how well the equipment works and do not measure message transmission time from the sender to the recipient.

the operator pushes the SA button, to open the covert mike. As a result, there is no sound transmitted to the Dispatch Center immediately after the operator has pushed the SA button.

RTD trains its bus operators to look for the light on the right side of the TCH to illuminate and for the colon in the digital time display to cease flashing. These cues tell the bus operator that the covert microphone is open and transmitting what the bus operator says.

There are times when the CAD/AVL system is off-line, either system-wide, or sporadically, due to maintenance or failures. Bus operators want the SA capability to continue to operate in fallback.

Bus operators expressed concern about the adequacy of their training on the use of the SA.

They disliked the location of the SA button in the bus because some of the physically larger operators have hit the SA button inadvertently. The microphone for the SA is located on the TCH, which is mounted on a stalk on the dashboard at the front of the bus. As a result, the gain must be turned up as high as possible for the dispatcher to hear what is happening throughout the bus. The sound transmitted from the bus can be so amplified it is difficult for the dispatcher to understand.[42]

### 6.2.3 Bus Operators-False Silent Alarms

If an SA is bogus, the dispatcher must wait two minutes before it can be downgraded. During these two minutes, the dispatcher cannot talk on the radio. By contrast, prior to CAD/AVL installation, bus operators could send the equivalent of a "Mayday" call to dispatch that was acknowledged immediately. If the Mayday was sent in error or the situation was resolved, the operator could communicate this resolution and the communication system was freed up.

The SA is hard-coded in the CAD and the dispatchers cannot change its priority. The priority assignments for the buttons on the TCH tend to remain in place and were not changed often. For example, an RTT was ranked at 19 and PRTT at 10. The STUC button was given a higher priority during the winter. The lead dispatcher can call up any dispatcher's screen and show all the incidents under a certain numerical priority threshold.

### 6.2.4 Bus Operators-Emergency Communication

Bus operators feel uncomfortable using the PRTT which they were told to use in serious, life-threatening situations on the bus. They prefer to use the SA but they are taught to use SA only when **their** life is threatened. Operators said that they use the SA when they do not want to be seen reaching for, or talking on, the handset. Dispatchers have noted that there are situations that do not threaten the operator where use of a PRTT would result in a faster and less disruptive response.

[42] A bus operator suggested that the covert mike be wired throughout the bus.

### 6.2.5 Bus Operators-Location of Radio Handset

The handset on a bus connects using a magnet. When the handset is disconnected, the line stays open and occupies a channel. When a bus operator hangs up the handset improperly due to its awkward location (requiring an operator to reach up and behind his or her seat), the line will stay open. The bus operators suggested the adoption of aviation-style lightweight headsets. They said that they would be more comfortable using PRTT if they had headsets rather than handsets.[43]

### 6.2.6 Bus Operators-Text Messages

Text messages from the CAD/AVL system are a practical and efficient way to give instructions to bus operators. Bus operators often work long, sometimes unfamiliar, routes and may be at risk of getting lost. They occasionally need information as how to maintain route service despite road detours. Bus operators can access this information from the TCH and it will remain in memory for the relief operators to access. Operators like stored detour information because they do not have to transcribe it.

### 6.2.7 Bus Operators-Public Visibility of Features

Field personnel, especially bus operators, value official representations of RTD. They view any official representation of RTD, i.e., the digital clock on the TCH, as backing them up to the public. This occurs even though the time shown on the TCH is not considered official RTD company time.[44]

## 6.3 STREET SUPERVISORS-OVERALL

When RTD proposed acquiring a CAD/AVL system, there was an expectation that its use might reduce the need for street supervisors. This has not happened. Instead, use of the CAD/AVL system has substantially enhanced the supervisors' ability to perform their tasks. The CAD/AVL system has proved to be a valuable tool for supervisors.

The number of street supervisors at RTD increased by two between 1996 and 1998. They now perform a greater variety of tasks. Because RTD service has expanded, and now includes light rail, they have more routes and service to support. In fact, street supervisors report that they benefit substantially from using the CAD/AVL system because they have more real-time information and can perform their jobs better.

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[43] RTD commented that lightweight headsets could present a problem due to the usage they would get. RTD must replace about 20 handsets per month despite their weight and strength.

[44] If there is a power failure, RTD downloads the system clock from the GPS satellite and the CAD/AVL system sends the bus IVLU a reset. When bus operators pull out of the garage, they are supposed to have their own watch, which should be set according to the clock in the garage.

### 6.3.1 Street Supervisors-Real-time RSA (Route Schedule Adherence)

Using the MDT (Mobile Data Terminals), street supervisors are equipped to regulate system operations and protect the system against poor operation such as early departures. They can do real-time RSA by looking on the screen and they report that this gives them a sense of "being able to be in three places at once." Having more knowledge gives them more control over system operations. Contrary to expectations, street supervisors find that the street location information is very useful to them; by contrast, they reported that they do not use the street location information as frequently as the dispatchers do and as had been anticipated (possibly because of system limitations).

### 6.3.2 Street Supervisors-Work Mix

In 1992, three-fifths of the street supervisors' activities involved route and time checks. Because the CAD/AVL system gives information on system performance at time points, the distribution of street supervisors' activities has changed. They perform fewer route and time checks and more operator checks. Their added responsibilities include Light Rail fare collection checks, increased security requirements, increased Blood and Alcohol Testing, and coverage of larger geographic areas.

### 6.3.3 Street Supervisors-Training Considerations

The street supervisors said that, initially, most of them were not computer literate. They said that they had difficulty learning computer commands and could not remember how to use the function keys. RTD has adopted a Windows operating system to make the supervisors' laptops user-friendlier. RTD trains the street supervisors how to use the laptops' operating system and word processing programs.

### 6.3.4 Street Supervisors-Hardware (MDT)

The laptops provided for the supervisors' MDTs are now (in 1999) in their third generation. The first generation of laptops, 20 MHz MDTs, cost $3400 each and had 2 MB RAM, an 80-MB hard drive and used a DOS program written in C. RTD replaced them in 1997 with Pentium laptops with 120 MHz, 32 MB RAM, 130 MHz, and a 1-gigabyte hard drive, at a cost of $1,500 for a Compaq Armada 1130T product. [45, 46] The replacement laptops use Windows and are multitasking. Because they are commercially available, replacing them will be cheaper than maintaining them or buying "hardened" waterproof units.[47] The second generation of MDTs did not hold up in field operations. RTD has replaced them with the third generation equipment, which are 233 MHz Compaq Armada 1700 laptops with Windows 95.

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[45] RTD authorized a $350K equipment upgrade in 1997 that included $50K for replacement laptops. The remainder of this upgrade included $150K for the new server and $140K for replacement workstations.

[46] RTD bought extended warranties at $100 per laptop for three years for the replacement of off-the-shelf laptops.

[47] RTD wanted to locate a cover for the keys to prevent damage to the laptops from spills. RTD also wants to protect the trackball and plans to use an optical trackball that is the only practical one in this environment.

## 6.4 DISPATCHERS-OVERALL

Since the CAD/AVL technology was introduced, the dispatch workload and hours worked have increased more rapidly than the number of staff. The dispatchers report a variety of reactions to the CAD/AVL system. Newly hired dispatchers, who were trained on CAD/AVL from the start, liked it without reservations. Dispatchers, who transitioned from the old system to CAD/AVL, were not as enthusiastic initially, but became much more enthusiastic.

The CAD/AVL system increased the volume of communication with dispatchers because it does not drop any calls due to limitations in radio channels. The dispatchers are doing more communication and since all calls remain in the queue. Call retention may have mixed consequences for the dispatchers. It is likely that calls, dropped previously, were not high priority because the initiators would have continued to try to find an open radio channel to make their call. As a result, the dispatchers may be responding to more, unimportant, calls and may spend proportionally more time attending to less critical calls.[48]

### 6.4.1 Dispatchers-Real-time Decisions

Dispatchers like real-time information and their new ability to make decisions based on simultaneous display of all necessary information. Dispatchers are able to monitor the location of supervisors' vehicles and maintenance trucks and to quickly determine the closest supervisor, or truck, to send to an incident.

### 6.4.2 Dispatchers-Enhanced Quality of Service

Dispatchers use RSA to provide information to buses to protect scheduled bus "meets" but they do not use RSA for system operations. The dispatchers set the RSA parameters. Usually, RSA information is not relayed to a bus until the bus is ahead (15 minutes) or behind (25 minutes) schedule. The dispatchers set broad parameters because they believed tighter tolerances would flood the AVL screen with schedule adherence problems.

Several categories of employees value schedule performance information. Bus operators finds it useful to know if a bus departed early to correct the schedule. Dispatchers need to know when buses are behind schedule and can remedy this by notifying the other buses that meet these buses. By contrast, information about being behind schedule does not help bus operators because they cannot remedy the problem.

### 6.4.3 Dispatchers-Mediation between Service Providers

Dispatchers continue to have responsibilities to both RTD and to the contract operators. There is frequent telephone contact between the RTD dispatchers and the contractor dispatchers. Contractor buses only communicate with RTD dispatch. RTD dispatchers relay information, by telephone, from contract bus operators to contractor dispatchers. Dispatchers make radio calls to contractor buses and telephone contractor dispatchers, and must contact contractor street

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48 Although these calls are not critical, dispatchers provide instructions to the bus operators that the latter need, appreciate, and find particularly supportive especially when they are novices.

supervisors through the contractor dispatcher. This part of their work reflects their responsibility to mediate and coordinate between infrastructures. The RTD dispatchers do this to assure service compliance.

Dispatchers have more efficient communication between RTD Divisions. They can communicate directly with Boulder Division buses but reported that they have used this new capability infrequently.

### 6.4.4 Dispatchers-Work Processes

The implementation of the CAD/AVL system makes work assignments malleable. Dispatcher assignments depend on workload and the number of dispatchers on duty. The dispatchers' workload can be distributed as in the past, i.e., by route, bus number, division, region, or it can be restructured. The lead dispatcher can change work allocation as needed and can manage and adjust it for each dispatcher using software options. Any dispatcher can take the lead position and they alternate assuming this position to retain their familiarity with the lead's functions.

The "Dispatchers' Daily Activity Record" was linked to the CAD/AVL system but has retained the same format. The CAD database automatically transfers information to RTD's VAX mainframe. This has reduced the amount of paper notes dispatchers must keep. Formerly, each dispatcher entered information into the "Dispatcher's Daily Activity Record" from their written logs.

## 6.5 SUMMARY

In conclusion, the responsibility of the organizational units of the dispatchers, street supervisors, and bus operators' work has remained the same. However, there are new capabilities. Dispatchers have immediate access to real-time location information for all vehicles in the fleet. Supervisors now can obtain real-time information and depend less on the dispatchers to obtain information. Operators have more accountability to maintain schedules and routes.

The size of the dispatch staff has increased. The supervisor staff remained constant, but its responsibilities have increased. There was no reduction in operator staff based on communication change.

The CAD/AVL system offers significant potential to RTD for further advances in monitoring and managing its service. RTD has recognized that the information generated by the CAD/AVL system is valuable to other organizations as well itself. RTD is exploring the potential for applications of the data generated both internally and for the Denver metropolitan area.

# 7. RECOMMENDATIONS

## 7.1 INFORMATION FLOW

Anticipate how the information generated by a CAD/AVL system will be used when designing future systems. A CAD/AVL system generates a significant amount of information critical for many aspects of transit operations. The designer should anticipate how information flows within an organization and identify who needs what information. All elements of a transit system (planning, maintenance, training, and customer service) should have access to CAD/AVL data.

## 7.2 CAD/AVL DESIGN

Consult representatives of all user groups at the operating property. Keep them "in the loop" in developing the system design and in selecting equipment. Assemble representative user teams to test new features.

Obtain a system with expansion capability. No new system will ever have all the desired features. The CAD/AVL system design must permit transit operators to add additional desired features economically.

## 7.3 COMPUTER SYSTEMS

Engage a computer system administrator from the beginning of system development. CAD/AVL operations require staff with computer skills starting during the design stage.

Use commercial-off-the-shelf hardware and software where possible. This will allow better use of the existing computer skills of employees and result in reduced training requirements.

Although it might be difficult to accomplish, there is merit in acquiring the source code when custom software is developed. This will make it possible to economically reconfigure when unforeseen problems occur. Transit operators should avoid acquiring "black box" technology.

Anticipate the need to train non-computer literate employees.

## 7.4 TRANSITION

It is very important to disable any feature that does not work properly, until it does. To ensure employee confidence in a new system, all features must work properly. There are significant consequences for failing components. RTD had to disable elements and, also, had to retrain users when elements did not perform as expected.

## 7.5 CAD/AVL USERS

Ensure that the operation of any critical new feature is clearly understood by the employees before it is put into service. Use of features, not understood, results in unrealistic expectations, inappropriate use, and lack of confidence.

Employees must understand what causes delayed responses and, under what conditions, a verbal confirmation of a request to a dispatcher may not be possible. Response times are critical to the credibility of the CAD/AVL system.

Bus operator-to-operator communication capability should be considered. If it is provided, it should be accomplished under carefully controlled procedures.

Use pre-programmed text messages where appropriate. This can reduce the workload on the operators and the dispatchers as well as transmission congestion.

The use of the communication system to alert dispatch and law enforcement agencies must be unobtrusive. This is particularly critical where there is the potential for physical threat due to criminal activities. There are situations where the potential threat to security does not warrant use of the SA (which disrupts other communication). For reasons of unobtrusiveness, convenience, and cleanliness consider the use of lightweight headsets similar to those used in commercial aviation.

Test equipment with the intended users under actual operating conditions to determine their suitability. The keyboard design and the visibility of the LCD screens reduced the effectiveness of the TCH units.[49] The position of the radio handset was often inconvenient. The initial LCD screen was not sunlight legible and the vendor provided an improved version. The improved version was better but the operators still wanted more legibility. RTD and the vendor tested several different models but were unable to find a more enhanced LCD.

Consult operators with regard to the features that will be available on the TCH and their configuration. The requirements for, or value of, a given feature may not be established until the system is operating. Critical items, such as TCH, should be reconfigurable economically.[50] This might be difficult but it would be valuable.

Develop standard communication protocols for the CAD/AVL system. Many commercial modes of transportation use communication protocols to reduce the message errors and transmission congestion.

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[49] Because of the size of the bus operators' fingers, they tended to hit several buttons at once or erroneous keys. RTD has brought this to the operators' attention during training session. In addition, the TCH has a confirmation button that must be pushed to send a message.

[50] Operators mentioned their need for a "clean" cancellation switch for their use so that they can cancel an inadvertent button push on the TCH without consequences or of having it recorded.

Explore the potential usefulness of "non-traffic" information as the CAD/AVL system develops. For example, street supervisors and the maintenance staff would find information on the vehicle's mechanical condition useful, e.g., engine temperature, or engine problem codes.

Provide a means for operators to identify the names and functions of the dispatchers with whom they communicate. This personalization will enhance communication and cooperation.

New systems should consider providing features that Denver RTD had not originally planned. At the time of system design, some potentially desirable features could not be anticipated, others were not technically, or economically, feasible.

Integrate the CAD/AVL system controls and displays with other bus controls and displays into a multi-functional unit. RTD tried to find a way to integrate the TCH with the farebox and the destination signs but the equipment options were very limited. For example, in future systems, the TCH functions could be integrated into the bus operator's workstation to reduce clutter.[51]

A display of the information provided by the CAD/AVL system that is visible to passengers. The operators perceive that the CAD/AVL system is an important source of company authority in the field.

An overlay for the dispatchers on the AVL screen showing the street supervisors' districts.

The street supervisors need the same information update rate that dispatchers have.

The street supervisors would like to have the same AVL screen that the dispatchers have, including the icons and streets. A map could be stored in the MDT but sending location information requires copious memory and enhanced speed in the laptops.

Provide more detailed information to the street supervisors on streets and cross-streets including directions, i.e., east and west of the grid system, together with the street name.[52] Ensure that no streets are missing from the database.[53]

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[51] Bus operators' have a high rate of occupational injury and illness. Recently, attention has been given to designing an optimal bus operators' work station in terms of the relationship between the seat, steering wheel, and pedals (You, et al., 1997). However, there is a need to identify the optimal way to locate the controls and displays especially as new technological capabilities are added to the bus operators' workstations. Another issue is the limited number of manufacturers of bus equipment. RTD spent significant time trying to identify better equipment alignment. Their limited design options kept them from identifying more optimal solutions.

[52] Denver has many very long streets and inclusion of the direction would better orient the supervisor to the location.

[53] Examples include access roads and ramps to highways, and newly opened housing developments.

# APPENDIX A.

# RTD'S DESCRIPTION OF THE CAD/AVL SYSTEM

"The SmartTrack VMS is a complete vehicle management system providing voice and data communication between dispatchers and vehicle operators, incident management, vehicle location tracking, route/schedule adherence tracking, data collection, report generation, and status monitoring. SmartTrack consists of three major components: SmartCAD Operations/ Dispatch Center, Communications Subsystem, and AVL Vehicle Subsystem.

The SmartCAD Operations/Dispatch Center includes all the hardware and software necessary for dispatch operations and systems maintenance. Central to the Operations/Dispatch Center is the SmartCAD system, which provides the Computer-Aided Dispatch (CAD) and Automatic Vehicle Location (AVL) displays (located side-by-side) used by dispatchers to manage the transit fleet.

Using the CAD, the dispatcher can initiate data and voice communications, process incidents, monitor vehicle/system status, access system data, and control system operation through configurable parameters. The companion AVL screen displays a map of the coverage area (including streets, parks, rivers, etc.) overlaid with vehicle location information, timepoints, route traces, and landmarks, etc. in the coverage area. The SmartCAD system performs four major operational functions: system management, communications management, incident management, and vehicle management.

The Communication Subsystem provides the communications backbone for voice and data communications between dispatch, bus operators, street supervisors, and maintenance personnel. The communications subsystem equipment is distributed between the Operations/Dispatch Center and the remote sites, and consists of the Central Electronics Bank (CEB), voters, trunking central controller, Data Channel Controllers (DCCs), base station modems, base station/repeaters, and microwave system.

The AVL Vehicle Subsystem centers on an Intelligent Vehicle Logic Unit (IVLU) that provides satellite-based GPS (Global Positioning System) location information and communications for each vehicle on which it is installed. An associated Transit Control Head (TCH) provides the user-interface (i.e., keypad and display) for the bus operator. Each IVLU-equipped vehicle receives route and schedule information from the CAD at operator login.

The IVLU uses this information, along with GPS location data, to determine route and schedule adherence (RSA). The IVLU periodically transmits vehicle location and RSA status to the Operations/Dispatch Center, where the information appears on the dispatch CAD/AVL display. The bus operator maintains schedule and initiates communication with dispatch using the TCH.

System Management functions performed by the SmartCAD system include control of system access, control of system timing, maintenance of the relational database, data archiving and retrieval, creation and generation of operational reports, and monitoring and reporting of system status. Each of these functions is described in detail below.

To provide System Security, the SmartCAD system maintains employee rosters, route/block lists, and vehicle databases. The system performs unique user name and password association at dispatcher or vehicle operator logon, with vehicle operators having their unique operator identifier checked against a database of valid users as well as cross-checked against the route/block entered at logon with scheduled bids/picks. The system notifies dispatch of all illegal or incorrect logon attempts made by vehicle operators. The lead dispatcher, or systems manager, controls dispatcher user IDs, passwords, and system access levels. Multiple access levels enable the owner to selectively grant control over system parameters such as route and schedule adherence thresholds as well as over dispatcher work assignments.

To provide System Controls, the lead dispatcher, assuming the necessary system access levels, can modify user adaptable parameters such as dispatcher work assignments (by route, group, region, or division), incident priorities, radio call groups, schedule deviation, thresholds (global or individual route), and other system parameters.

There is a System Time that is GPS universal time (synchronized to Universal Time Coordinates, or UTC) and provided by the GPS Reference Locator at the Operations/Dispatch Center to ensure time synchronization. Clocks in each IVLU-equipped vehicle and at each fixed-end communication site synchronize to GPS time via local GPS receivers. The SmartCAD system continually broadcasts GPS system time to the fleet at a pre-defined rate (nominally at 15-second intervals) to ensure time sync if there is a loss of GPS. The system automatically corrects for changes in local time (offset from UTC time) due to the onset or end of daylight savings time for all displays.

The SmartCAD system utilizes a Relational Database Management System (RDBMS) to collect operational data from the vehicle fleet; fault and maintenance data from vehicle, fixed-end communications, and CAD/AVL equipment; and dispatch-entered incident data. SmartCAD gives the lead dispatcher and system programmer database query and on-demand or scheduled report generation capability.

The SmartCAD system receives and logs all vehicle incidents, location reports, and system status reports for a complete 24-hour period. The RDBMS maintains this information on-line for 72-96 hours, after which the system administrator may archive the data on magnetic tape. Prior to archiving, the system generates summary data on a daily, weekly, and monthly basis. This summary data is used to generate summary reports for dispatcher activity, incident activity, and coach schedule adherence.

The SmartCAD system provides the capability for interfacing with customer Management Information System (MIS) databases. Route and schedule data are loaded into the SmartCAD system through the TMS Data Entry System (DES). This data is used to display current route and schedule to dispatchers (via the CAD/AVL displays) and to customer Information System personnel. Route and schedule data consists of time point, shape point, and bus stop data for each transit system route/block (run) and trip. At logon, each vehicle receives route and schedule data via radio link for use in route and schedule deviation processing. Other MIS data, such as employee rosters, vehicle databases, problem codes, etc., are loaded directly into the SmartCAD DBMS from the MIS computers.

The SmartCAD system collects System Status results on a periodic basis to ensure the system is meeting performance. These include the results of internal built-in-tests along with direct measures of system performance and loading. The following equipment is monitored on an off-line basis so as not to interfere with system operation:

- Digital microwave subsystem: radios, muxes, and channel banks
- Fixed-end Radio Frequency communications subsystem: base station/repeaters and Central Electronics Bank
- Dispatcher CAD/AVL workstations
- Host computers
- Data Channel Controller
- IVLU: TCH, GPS, odometer, radio, etc. (per vehicle)

The system maintains summary status information for display on the CAD. The information includes the number of currently active (i.e., logged-on) vehicles (per vehicle type of coach, supervisor, maintenance support, and light rail), the number of currently active routes in the system, the incident filtering system, and the total number of off-route/schedule vehicles.

The SmartCAD System maintains detailed Vehicle Status information for each active vehicle. This status information includes the current route/block, operator ID and name, scheduled pull-in/pull-out times, time of last report, current location, alarm status, RSA status, communications status, and detailed vehicle equipment status. The dispatcher can view vehicle status information from either the CAD or AVL display.

Communications Management functions for the SmartCAD system include overall communications control, voice call management, and data message routing and voting.

The SmartCAD system manages all voice activity on the assigned voice channels. Voice Call Management functions include:

- Call group definition and management
- Allocation of voice channels on an as-needed basis
- Coverage area hand-off and transit steering control
- Voice call set-up, including call type selection, call group or vehicle selection, IVLU command messages, and communication equipment setup commands

The system provides for definition of call groups based on vehicle IDs, routes, groups (i.e., vehicle, route, division groups), and divisions.

The SmartCAD system manages voice channel allocations. The system maintains site coverage information for each vehicle using vehicle location reports received from IVLU. This information facilitates optimal site selection for transmit steering of each voice call. The system continuously updates site coverage information using messages received from each vehicle.

The dispatcher can choose from a number of different call types: normal two-way or "party-line" (for group and fleet calls) voice calls. The dispatcher selects call type using the CAD display at the time of call setup. In addition, supervisor vehicles can initiate direct-access, vehicle-to-vehicle communication with no intervention required by the dispatcher.

The SmartCAD system automates the voice call setup process through pull-down menus and simple mouse or keyboard operations on the CAD Display. Dispatch call setup involves selection of call type (i.e. normal) and call list (i.e. individual, group, or fleet). For an individual call, the dispatcher may identify the vehicle by vehicle number, operator ID, or route/block number. The dispatcher can place an individual call to the vehicle in the Current Incident Window using simple keystrokes or mouse clicks. The system provides all necessary commands to the communications subsystem and IVLUs necessary to complete each call. Should a vehicle in a requested group call be currently engaged in a voice call, the dispatcher is notified and given the option to cancel the call request or proceed with the call in lieu of the busy vehicle.

In emergency situations, following activation of the Silent Alarm switch by a bus operator, the dispatcher can set up a call to monitor audio activity on the vehicle via a covert microphone embedded in the TCH. This call is set up with simple keystrokes or mouse clicks once the incident from the affected vehicle is in the CAD Display Current Incident Window (just like an ordinary private call). The covert microphone may not be monitored in the absence of such an Alarm.

The SmartCAD system manages data communication between the IVLU-equipped vehicles and dispatch. Data communications consists of IVLU command messages, route and schedule downloads, vehicle location reports and status messages, canned and free-form text messages sent from a dispatch CAD display to a vehicle's TCH, and canned text messages received from a vehicle's TCH.

Incident Management functions for the SmartCAD system include display, processing, queuing, prioritizing, filtering and logging of all incidents received into the system. These incidents include messages initiated by the vehicle operator or dispatcher, or incidents generated automatically due to equipment failure, illegal vehicle operator action, or route or schedule deviation. Each dispatcher may retrieve or display or update all logged incidents from the last 24-hour period.

Each incident within the SmartTrack system is given a unique Incident Type which may be used to/for sorting and report generation. Incidents generated and recorded within the Smart Track system include:

- Emergency Alarms
- Request to Talk/Priority Request to Talk
- Schedule deviation (two levels)
- Route deviation (two levels)
- Pull-in/Pull-out schedule violation
- TCH canned text messages to dispatch
- Mobile Data Terminal (MDT) canned text messages to dispatch
- Vehicle operator logon/logoff
- Invalid operator logon (i.e., invalid badge ID or route/block; Bids/Pick mismatch)

- Vehicle status change (i.e., equipment failure, loss of communications, etc.)
- Fixed-end equipment failure

Whenever an Emergency Alarm incident is received from a bus, the system performs a number of special operations: the Emergency Alarm incident is displayed in the appropriate dispatcher's Incident Queue, an alarm tone is sounded, and the system allocates additional position reporting slots to the vehicles' IVLU to increase its reporting rate. When the dispatcher places the emergency incident in the Current Incident Window, the AVL Display zooms to the alarmed vehicle and begins automatic tracking. AVL zoom level is selected such that at least two supervisory vehicles appear on the AVL Display along with the alarmed vehicle. Monitoring of the vehicle's covert microphone is enabled. Covert microphone monitoring begins only after the call is requested by the dispatcher.

The SmartCAD system accepts two levels of route and schedule deviation thresholds which are set by the lead dispatcher, with each deviation type having a different priority and use in the system. One threshold is used to control reporting of deviations by each vehicle; this threshold is typically set low to ensure detection and recording of all deviations. The second threshold controls display of deviation incidents to the dispatchers; this threshold is typically set high enough such that reported deviations do in fact warrant dispatcher intervention.

The SmartCAD system manages the progress and status of each vehicle within the Smart Track system. The system validates all vehicle registrations and operator logon/logoffs and maintains the current active status of each vehicle. As vehicle operators logon, the system controls the downloading of the appropriate route and schedule data and any applicable system-wide or route-specific parameters.

The system tracks the progress of each revenue vehicle along its intended schedule. Pull-out and pull-in violations are detected and reported to the appropriate dispatcher Incident Queue according to thresholds set by the lead dispatcher. Time of passage at each system time point is recorded in the databases for purposes of report generation and schedule optimization.

The SmartCAD system routes all vehicle location reports to the dispatcher, based on the routes selected for display by each dispatcher. All vehicle location reports are saved on-line for at least 24 hours and are available for playback to a properly configured AVL display.

The AVL map display provides dispatch with a graphical overview of fleet operations. Vehicles appear on the map as icons tagged with identifying information. The icon color reflects the vehicle status (i.e. normal, emergency, ahead of schedule, behind schedule, etc.)."

(Source: Excerpted from the Dispatchers User's Guide provided by E-Systems, Final Version 11/20/95)

# APPENDIX B.
# THE TCH KEYPAD[54]

**NUMERIC KEYS (top row of TCH)**

- 1-PA-Public Address system, activates the PA system on buses. Not currently operative after reviewing it in revenue service.
- 2-LOG ON-used to initiate CAD/AVL Log-On procedure.
- 3-LOG OFF-used to Log-Off from CAD/AVL.
- 4-MECH OUT-used to report a mechanical problem that puts a bus out of service. Dispatch receives coded text message.
- 5-MECH-IN-used to report a mechanical problem when a bus can remain in service.
- 6-FARE DSP-used to report a Fare Dispute. Dispatch receives coded text message.
- 7-OUT-used to report a wheelchair-lift stuck Out. Dispatch receives coded text message.
- 8-STUC-used to report a bus Stuck in snow/ice. Dispatch receives coded text message.
- 9-NO RLF-used to report that the Relief operator is not there. Dispatch receives coded text message.
- 0-PASS UP-used to report that a bus is full and additional Passengers cannot board. Dispatch receives coded text message.

**FUNCTION KEYS (bottom row of the TCH)**

- RTT-used to initiate a Request To Talk. After pressing RTT, the bus operator must wait for the dispatcher to acknowledge the message and then the operator communicates using the handset.
- PRTT-used to initiate a Priority Request To Talk. After pressing PRTT, the bus operator must wait for the dispatcher to acknowledge the message and then the operator communicates using the handset.
- CODE-used to initiate canned, pre-coded messages. Operator presses CODE button and uses the arrow keys to scroll to the desired message. If the operator knows the number assigned the code, the operator can press CODE and the number to initiate the message. The first 10 messages repeat those assigned to TCH keys: the remaining messages are:
  - 20 PASS REQ INFO-used to report a passenger request for information.
  - 21-GOING OFF ROUTE-used to report a bus going off route.
  - 22 SUPV NEEDED-used to report a request for a supervisor.
- UP ARROW/DOWN ARROW-The arrow keys are used to adjust audio volume, display contrast and brightness and to scroll through messages (when used with light bulb key).
- N MSG-used to view New Text Messages.
- O MSG-used to display stored Old Text Messages. The bus operator can retrieve old text messages (up to 10) sent to the TCH since initial logon.
- LIGHT BULB SYMBOL-used with the arrow keys to control LCD brightness.
- NO-used to send a "no" response as prompted.
- YES-used to send a "yes" response as prompted.

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[54] To send a message, the operator presses the appropriate numeric key (0-9). The functions are written in capital letters above the key. To assist the operator to correct data entry errors, the TCH requires a yes/no confirmation before the key press is transmitted.

# APPENDIX C.
# DESCRIPTION OF PRIOR COMMUNICATION EQUIPMENT AT RTD

The satellite-based CAD/AVL system replaced the existing communications system. RTD prepared the following description of the equipment they had in 1992:

"The RTD radio/data communications system has been in operation for more than 14 years. The service is licensed to operate on eight UHF channels and is controlled via three dispatch consoles and one lead dispatch console (located at the Dispatch Center at RTD's Operations Center). This system includes bus and supervisory/maintenance mobile radio/data equipment, repeaters, microwave, multiplex equipment, computer resources and dispatcher stations.

RTD operates six UHF channels with dispatching conducted from two locations, the Operations Center and Boulder. Two channels are dedicated for Denver bus operations use and are dispatched from the Operations Center. One bus channel is dedicated to both the Boulder and Longmont Divisions. One channel is dedicated to supervisory use and is dispatched from the Operations Center. The remaining two channels are used primarily for maintenance and support functions and are dispatched from the Operations Center.

Two Motorola CentraCom I control consoles are installed at the Operations Center. Each contains controls for four radio channels and a MetroCom I encoder/decoder panel. Also installed in the Operations Center are three Motorola T1600 desk top single channel controllers for the support and supervisory channels as well as a Dictaphone 4000 audio recorder. There are two desktop base stations used for monitoring two independent bus carriers (contract operators) operating in the 800 MHz band. An additional Motorola T1600 is provided for monitoring the support channel during snow emergencies.

RTD currently operates a Prime 6650 computer system to accept manual inputs from dispatchers and to provide management reports. Each of the two dispatch positions at the Operations Center has two PRIME terminals, one for input of data and system events and one for database retrieval (schedules, bus versus route/run/operator, etc.)

The microwave equipment is not "hot-standby." In the event of microwave station failure, this communication link with the Dispatch Center is lost. If the control station fails (used to access the supervisory channel), it is possible to maintain communications through dispatcher use of a portable radio."

(Source: Radio/Data Communications-Technical Specifications for Regional Transportation District, Denver, Colorado, November 20, 1990.)

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