Automatic Vehicle Location and Computer-Aided Dispatch Systems: Design and Application Considerations

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Abstract

Automatic Vehicle Location (AVL) systems can track transit vehicles in real time. Computer-Aided Dispatch (CAD) software is used to monitor transit operations and assist management of transit operations. Together with AVL systems, CAD software can be used to replace a disabled vehicle by dispatching another vehicle, or meet fluctuating travel demand by adjusting transit headways, schedules, and routes. AVL and CAD technologies can vitalize transit by directly improving on-time performance, increasing transit efficiency through providing dispatchers with location, direction and status information, and reducing operating costs through reducing dependence on transit field supervisory personnel. Direct benefits to travelers can include higher reliability of travel times and reduced stress in dealing with transit unreliability. This study explores the development, availability, and impacts of AVL/CAD technologies as reported by AVL vendors and transit implementers. The study defines the key features, functions, and performance characteristics of AVL/CAD technologies that can influence the level of benefits realized. The AVL/CAD implementation context is ex-

explored by examining where, when, and for what users these systems are being implemented. The results of two surveys are reported. To explore the availability of AVL/CAD systems, technology suppliers were surveyed. Suppliers identified the features, functions, and performance of available AVL/CAD technologies. To determine the extent of AVL/CAD deployment, transit operators were surveyed regarding their experiences with AVL/CAD technologies and the subsequent impacts on travelers and transit agency performance. This research provides a systematic method for evaluation of AVL/CAD systems and reports the perceptions of AVL/CAD vendors and transit implementers regarding available products and their impacts. The results suggest a need for better tools to characterize and quantify the impacts and benefits of AVL/CAD systems.

Introduction

Advanced Public Transportation Systems (APTS) can increase transit efficiency, improve transit level of service, reduce costs, and temper declining transit use in the United States. A promising set of APTS technologies are Automatic Vehicle Location (AVL) systems and Computer-Aided Dispatch (CAD) software. AVL systems track transit vehicles in real time and transmit the current locations and schedule adherence information either to the driver or to a central control. CAD software integrates transit operations by giving transit dispatchers and supervisors decision support tools to manage the operating environment. Together, AVL and CAD can be used to respond quickly to transit operational problems; examples include dispatching a vehicle to replace a disabled vehicle or otherwise adjusting transit headways, schedules, and routes to improve the level of service. Integration of AVL systems with other APTS technologies can be potentially beneficial. For example, by integrating AVL with silent alarms and driver warning devices, transit security can be improved, crash propensity reduced, and response times in incident situations shortened.

Currently, many transit agencies are testing and deploying AVL/CAD technologies. The purpose of this study is to explore the available technologies and identify the possible impacts (benefits and costs) of deployment. Results from

surveying AVL/CAD technology suppliers and transit agency implementers are reported. The first section of this paper provides a literature review of AVL/CAD technology and implementation. Based on an apparent gap in the existing literature, the second section proposes a conceptual structure to characterize both the technological attributes and the impacts of technology implementation. This structure is used in both a technology supplier survey and a transit agency survey to determine the value of AVL/CAD implementation. The survey methodology is reported in the third section, and results of the survey are described in the fourth section. Finally, conclusions on the applicability of the conceptual structure and on the current state of AVL/CAD technology are made.

Background and Literature

The research of Casey et al. (1996) has provided a recent review of AVL and CAD technologies more specifically, and recent APTS projects more broadly. Their work builds on an earlier study by Schweiger, Kihl, and Labell (1994). Casey et al. (1996) report that AVL systems are increasingly being used in transit and trucking fleets, police cars, and ambulances for computer-based vehicle tracking. They also identify at least 58 AVL systems that are in operation, under installation, or planned in the U.S. Lister, Schweiger and Keaveny (1995) provide an account of AVL/CAD technology (to be) deployed in Detroit, Michigan.

A detailed description of AVL technologies and a list of relevant references is provided in Khattak et al. (1993). AVL technologies include a location technology (sometimes more than one technology is used) and a communication mechanism for transmitting location data from the vehicles to a central dispatching unit. The incoming information is displayed for dispatchers on computer monitors. AVL can be integrated with other APTS technologies, such as passenger information systems, automatic passenger counters, or silent alarms. Alternative AVL technologies include (1) proximity beacon/signpost, (2) satellite-based Global Positioning System (GPS) (3) radio navigation/location, and (4) dead reckoning. Communication technologies can include two-way radio, on-board cellular telephones, and satellite communication services. AVL location

and communication technologies may be used singly or in combination, depending on their performance and flexibility and on transit agency needs.

The current industry trends indicate that transit agencies are increasingly choosing GPS technology compared with proximity beacons. However, Casey et al. (1996) report that, at the time of their review, the proximity beacon (signpost) was the most common AVL technology in use with transit agencies. The beacons are placed along transit routes. Either the beacon or the vehicle has a unique ID. If the beacon has a unique ID, then it sends out a signal detectable by a transit vehicle fitted with a receiver. When the vehicle is asked by the central unit to report its position, it transmits the ID of the last beacon passed and the distance traveled since passing the beacon. When vehicles have unique IDs, the beacons receive signals from vehicles upon passing and transmit the information to the control center (typically via wired communication systems). This method reduces the need for reserved radio frequencies but is relatively limited in terms of locating vehicles in real-time.

Casey et al. (1996) report that, out of the 17 planned or implemented beacon systems in North America, 14 are operational; of the 40 planned or implemented satellite-based GPS systems, 10 are operational. Seven transit agencies have planned or implemented other systems (dead-reckoning, ground-based radio, or one of these supplemented by signposts or GPS), out of which 4 are currently operational. These data indicate that, while signpost systems exceed GPS systems in current operation, those in the planning stages are now installing GPS. The lower cost of GPS and its improved location accuracy (e.g., by using differential GPS) are often cited as important features guiding its selection for transit AVL systems.

To locate transit vehicles, GPS uses signals transmitted from orbiting satellites to receivers on transit vehicles. These signals are then either processed on-board the vehicle or directly transmitted to a dispatch control center. GPS performance does not degrade significantly during adverse weather or due to increasing vehicle fleet size. Access to satellite signals is provided free of charge; therefore, the major cost item is the receiver technology installed on the vehicle and

the communication cost (to communicate the vehicle location to a control center). The disadvantage of GPS is that tall buildings, tunnels, and foliage can result in "loss of lock," i.e., loss of signals from the satellites. In such situations, supplementary systems such as dead reckoning may be used. Dead reckoning is based on calculating the vehicles' position through distance traveled and direction from an initial known position. Odometers are typically used to measure distance and a compass is used to measure direction. Dead reckoning accumulates errors along distance traveled due to mechanical factors. Another popular method is differential GPS where a receiver is placed at a known location. The difference between the site and the GPS-measured location is used to improve locational accuracy. Differential GPS still suffers from the "loss of lock" problem. In some cases, a combination of dead reckoning and differential GPS are used.

The radio location methods are based on measuring waves propagating between vehicles and stations. However, due to wave interference from other sources such as transmission lines, the use of radio frequencies has declined. Nonetheless, Casey et al. (1996) report that, in the Los Angeles area, a private vendor has strategically placed transmitting and receiving towers and is using triangulation to determine vehicles positions (see Khattak et al. [1993] for a description of triangulation). Vehicle positions are transmitted to several subscribers (a transit agency, package delivery, ambulance service, and sanitation service), who make the system economically viable.

Once the vehicle has received its position data, the data are transmitted to a dispatch center by polling, where the dispatcher periodically requests each vehicle to identify its location. Another popular method of transmitting the data is exception reporting, where each vehicle reports its position only if it is running off-schedule or off-route. Transit agencies sometimes use a combination of periodic polling and exception reporting (Casey et al. 1996).

Computer-aided dispatch is a transit software that can perform and integrate transit operations. The key CAD functions are monitoring operations and providing decision support to respond to delays and disruptions of service. The

decision support system may recommend service improvements such as adjustment of vehicle headways, dispatching replacement or additional vehicles, or reporting to appropriate authorities in case of incidents and on-vehicle emergencies. The AVL technology provides the necessary real-time vehicle location information to the CAD software.

In spite of this fairly good knowledge of AVL/CAD technology, there is only limited reported evidence to date on the benefits to transit agencies and travelers. Goeddel (1996) reports on the benefits of APTS technologies, including AVL/CAD systems. Goeddel evaluates the benefits of several AVL/CAD system implementations (e.g., Baltimore, Kansas City, and Toronto), where improved on-time performance, reduced layover times, and ultimate fleet reductions were possible. The author then extrapolates these benefits to all federally-funded transit agencies to calculate the total benefit of APTS deployment in the United States. However, very few of the recent AVL/CAD implementations in the U.S. have been subsequently evaluated to determine the benefits and cost-effectiveness of these technologies.

Conceptual Structure

Technology Deployment

The literature and research to date lacks a formal structure for transit technology assessment. In response, this study identified a structure to classify and investigate the availability and deployment of AVL/CAD technologies. First, the attributes of the technology are based on defining design dimensions in terms of their features, functions, and performance (Table 1). The existing literature discusses extensively the features and functions of AVL/CAD systems. Moreover, AVL technical performance may be evaluated in terms of accuracy, frequency of information updates, maintenance and flexibility in routes served, and cost. For CAD, the important evaluation criteria are the display attributes and the content of information given to dispatchers at the operations center.

In the actual deployment, AVL/CAD technologies have application dimensions (that vary across space, time, and users). The reasons and strategies for AVL/CAD deployment are not likely to be similar among transit agencies. Some

Table 1
Dimensions of AVL/CAD Features, Functions, and Performance

<i>Technology</i>	<i>Classification</i>		
	<i>Features</i>	<i>Functions</i>	<i>Performance</i>
Dead reckoning	Distance & direction measurement (odometer & compass)	Tracking	Tracking accuracy Frequency of information updates Maintenance
Proximity beacon/signpost	Signposts & vehicle transmitter	Tracking	Flexibility (route)
Radio determination	Radio signals Vehicle to stations	Tracking	Cost
Satellite-based GPS	Satellites & vehicle receivers	Tracking	
Computer-aided dispatch	Display, platform, map base	Real-time monitoring, scheduling & dispatching	Display medium information content

transit agencies may deploy AVL/CAD because of their need to replace an aging system (for instance, a radio system) and/or decisionmakers may allocate new funding to upgrade dispatching based on the perceived value of these new systems. Furthermore, the spatial, temporal, and user dimensions of AVL/CAD technologies need to be considered carefully before deployment decisions are made. For example, the areas (particularly terrain), the populations served (commuters vs. persons with disabilities), and the frequency that transit agencies provide service on various routes are important dimensions to consider (in where, when, and for whom AVL/CAD systems are deployed). The application dimensions relevant to CAD are the quality and display of location information for supervisors who make operations decisions, e.g., scheduling and adjusting headways and routes. Overall, the application dimensions of space, time, and users are the

factors that determine the impact of the technology in achieving transit system and traveler benefits.

Impacts

The impacts of deploying AVL/CAD systems are defined in terms of evaluation criteria (or evaluation dimensions)—efficiency, service quality, cost, time savings—and distribution dimensions—how these impacts are realized across space, time, and users.

Evaluation Criteria

AVL/CAD technologies can have direct, indirect, and simultaneous impacts on operators and travelers. Specifically, AVL systems are expected to have strong direct impacts on transit operators. The magnitude of direct operator impacts depends on the technology design dimensions, technology application dimensions, and the implementation context. The expected impacts are:

- improved dispatching and scheduling and, therefore, improved on-time performance;
- rapid response to service disruptions and emergencies;
- enhanced driver and passenger safety/security;
- better ability to monitor driver and vehicle performance; and
- improved planning functions including selection of routes, stops and service frequencies.

When AVL is used in conjunction with other technologies, it can reduce maintenance costs, e.g., due to quicker detection of mechanical problems on vehicles. In addition, an important but mostly indirect benefit of AVL/CAD systems to a transit agency can be increased ridership (and revenue). The direct expected traveler benefits due to AVL/CAD technologies include:

- increased transit reliability and reduced frustration with uncertain wait times;
- travel time savings and reduced uncertainty in travel times due to improved content and quality of transit information; and
- improved satisfaction with transit service.

Distribution Dimensions

The impacts from individual AVL/CAD technologies can vary across individuals/groups both within the agency and across travelers (e.g., by location and time of travel). Some AVL/CAD technologies may influence travelers differently by design. For example, if AVL/CAD systems are implemented for ADA (Americans with Disabilities Act) service, then the impacts and benefits are targeted toward ADA-eligible individuals, such as the infirm and otherwise disabled. Alternatively, if the AVL provides real-time information on fixed route services to those with special electronic traveler information devices, the AVL/CAD system benefits are targeted only to this select group.

Methodology

The literature review indicates that AVL/CAD technologies are still under development. However, their impacts, including net benefits, are still uncertain. The structure presented in the previous section describes one means of characterizing these technologies and their likely impacts. To illuminate the current experiences and impacts, AVL/CAD technology suppliers as well as transit agencies that have adopted AVL/CAD were surveyed.

The suppliers' survey obtained information about the availability of APTS technologies (Khattak et al. 1997). In this paper, the supplier responses to AVL/CAD technologies are reported. Based on the conceptual structure described above, the survey inquired (from technology suppliers) about AVL design dimensions and supplier attributes. A separate transit agency questionnaire focused on AVL/CAD technology application dimensions and impacts. The transit agencies surveyed had either deployed or were planning to install AVL/CAD systems.

Suppliers Survey

A total of 40 questionnaires was received from about 250 distributed, resulting in a (relatively low) 16 percent response rate. The survey consisted of three main sections:

- Context and background of vendor—this included the country of affiliation, years in business, number of employees, and percentage of products manufactured in the U.S.
- Technology Attributes—this identified the APTS technologies sold by the vendor (classified according to their features, functions, and performance) and the scope of their application in transit agencies.
- Impact—the expected benefits and impacts of the vendor's largest-revenue APTS technology on the performance of transit agencies and on the experience of travelers.

A copy of the survey is provided in Khattak et al. (1997).

Transit Operators Survey

In addition to the supplier survey, a total of 120 AVL/CAD questionnaires was sent out to various transit agencies operating in the U.S. and Canada that were reported in the literature as having implemented or planning to implement AVL/CAD systems. The questionnaires were directed to the management with instructions in the cover letter to consult with appropriate agency individuals if any of the answers were not known to the respondent. The transit agency survey consisted of four parts:

- Context of Transit Agency—information about the transit agency and its operating environment.
- Technology Attributes—information about the AVL/CAD technology being used by the transit agency.
- Technology Implementation—issues related to selection and implementation of their AVL/CAD technology.
- Impact—experiences of the transit agency with AVL/CAD technology.

The responses of the transit agencies are summarized according to these four parts.

To increase the response rate, a reminder letter was sent about three weeks after the initial surveys were mailed. A total of 29 responses was received, for a response rate of about 24 percent. Also, of the 29 respondents, 5 indicated that

they had no AVL/CAD system or did not indicate the technology of their system. However, to determine perceptions regarding AVL/CAD systems, their responses to other questions, if applicable, are included in this paper. Also included are those who do not currently have AVL/CAD, but are planning to install or are presently installing these technologies.

Results

The responses of AVL/CAD vendors and transit agencies are summarized as case studies rather than a statistical sample of representative implementers. That is, the experiences in individual cases are of interest and are reported. Descriptive statistics are presented, but no statistical modeling of the data is performed.

Analysis of the AVL/CAD Suppliers

Automatic Vehicle Location Systems. Among the 40 APTS technology suppliers who responded, 18 are vending AVL systems, making it the most popular APTS system being marketed (Khattak et al. 1997). AVL features that were investigated included the tracking technology and performance (accuracy and frequency of location information update). Satellite-based AVL systems (with GPS/NAVSTAR, GPS with dead reckoning or map matching, and differential GPS) and systems that use dead reckoning methods are most common. Six vendors use one of the above-mentioned two methods. A proximity beacon/signpost system (with sharp transmissions) is sold by three vendors. Two AVL systems use radio determination (one using certain radio frequencies and the other the Omega system).

All systems were reported to be reasonably accurate. Twelve vendors claim that their systems can track the location of a transit vehicle to less than 30 feet. Two can track the vehicle between 31 and 100 feet. One system tracks the vehicle between 101 to 200 feet and the accuracy of one system is greater than 200 feet.

The frequency of location information updates was investigated. One system updates the information continuously. Four vendors reported updating the information between 1 and 10 seconds. Two update the information every 30

seconds, and three systems update the information every 60 seconds. Two vendors reported that they can update the information according to customer preference; and, in one system, it depends upon data loading and system configuration.

Computer-Aided Dispatch. Vendors were asked about demand-responsive CAD systems. Among the original 40 respondents, 7 vendors are involved in selling CAD systems. In terms of technical capabilities of the CAD systems for geographic referencing, only one vendor uses an Etak data base, two use TIGER, and the others use proprietary map data bases. Different functions are provided by demand-responsive CAD systems. Five vendors provide passenger trip scheduling (two based on historical information and three based on real-time information). Six vendors provide vehicle and crew scheduling, routing, and dispatching functions (three each based on historical and real-time information). Passenger account status is supplied by three systems (two based on historical and one based on real-time information). Also, passenger service monitoring and reporting, e.g., pick-ups and drop-offs, is supplied by five systems (three based on historical and one based on real-time information); and four systems provide the function of checking the ADA eligibility of passengers (two each based on historical and real-time information).

Regarding additional technology features, three demand-responsive CAD systems consider traveler preferences. One provides transit vehicle location information to travelers in real-time. Four provide advance reservations. Five systems respond to immediate requests, while four respond to standing orders. Only three systems can be linked to other sources of information, e.g., traffic or special events information. Overall, passenger trip scheduling, vehicle and crew scheduling, routing, and dispatching are considered important by the CAD suppliers.

Integration with Other APTS Technologies. Generally, AVL can be integrated with CAD and with other APTS technologies that include:

- Silent alarms—in an emergency, silent alarms can be triggered by the driver.

- Advanced Traveler Information Systems (ATIS)—ATIS can provide:
 - pre-trip information to travelers,
 - in-terminal information, and
 - in-vehicle real-time information.
- On-board sensors and logic/control unit—vehicle performance such as engine temperature, engine oil pressure, and other engine conditions are monitored and they are flagged if out of limits.
- Traffic signal priority—the system automatically performs this function.
- Automatic passenger counters.
- Automated fare payment systems.
- Annunciation systems and “next stop” destination signs.

The vendors reported that, on average, about 7 different APTS technologies can be integrated with either AVL or CAD systems (including mutual AVL/CAD integration). APTS technologies mentioned by the vendors that can be integrated with AVL/CAD include in-vehicle, pre-trip and en-route information systems; automatic passenger counters; and signal priority systems. Most AVL/CAD technologies seem to offer substantial flexibility in integration with other systems.

Companies were asked to list APTS technologies that are currently integrated or “bundled” with their latest system. On average, about four additional APTS technologies are integrated with the AVL package.

Analysis of the Transit Operators Survey: Demand for AVL/CAD Systems

Several questions in the transit operator survey asked about the operating environment for the transit agency. A majority of the survey responses were from transit agencies operating in urban areas: 18 of the 29 respondents were from large urban areas, five from small urban areas, and one from a suburban area. Five respondents either did not indicate the type of operating area or operated in more than one environment.

When asked to rank their agency’s objectives and goals, most agencies indicated that providing safe transportation was their highest priority followed by

providing reliable transportation, and then providing economical transportation. By counting the ranks given by respondents to each goal, they can be grouped into the following categories:

- High Priority—provide safe, reliable and economical transportation.
- Medium Priority—improve transit accessibility, convenience/comfort, and mobility for special groups (e.g., handicapped and lower income individuals).
- Low Priority—relieve traffic congestion, coordinate with other transportation modes, and minimize environmental impacts.

Technology Design Dimensions. A majority of the respondents (13 agencies) indicated satellite-based GPS system as their main vehicle tracking method. Proximity/signpost technology was the second most used technology (5 agencies). Standard two-way radio was the main communication technology (15 agencies), followed by trunked radio (4 agencies). Two respondents indicated that they use a satellite system and dead reckoning, and one respondent indicated using dead reckoning and proximity beacons for tracking vehicles. One respondent reported using cellular phone and trunked radio for communication. This may reflect transit agencies' need to supplement the primary AVL technology when topographic variations reduce tracking accuracy.

As expected, satellite-based GPS technology has been deployed relatively recently (6 GPS systems were deployed within 1 year and another 6 between 1-5 years) compared to proximity beacon/signpost technologies (2 such systems were deployed between 1-5 years ago, and another 2 more than 5 years ago). These findings are consistent with Casey et al. (1996).

AVL systems' ability to locate vehicles disaggregated by tracking system type was examined. One satellite-based GPS system was reported to track vehicles within 30 feet, 6 could track vehicles between 30-100 feet, and another 5 between 101-200 feet. Two agencies reported that their proximity beacon/signpost technology could track vehicles within 30-100 feet, and 1 agency each between 101-200 and greater than 200 feet. There is significant variation in the locational accuracy of AVL systems as perceived by the users. Interestingly (but

not surprisingly), the AVL positional accuracy claimed by vendors is higher than that reported by the transit agencies (the users).

Technology Application Dimensions. Within the transit agency survey, the objective of one section was to determine the factors influencing AVL/CAD installation decisions. These factors were classified into the categories listed below. Each agency was asked to indicate the degree to which each of the following factors influenced system selection:

- opportunity-based conditions, i.e., based on unique opportunities;
- need-based conditions, i.e., based on existing and/or pressing agency needs;
- operating the system, i.e., the capabilities and impacts of the technology; and
- maintaining the system, i.e., the capabilities of the agency to maintain the technology.

A five-point Likert scale ranging from “strongly agree” to “strongly disagree” was used to seek responses. The salient opportunity-based conditions promoting AVL/CAD implementation were, first, that a member in the organization pushed for adoption, and second, that financial assistance was easy to secure. The need to replace (or upgrade) the existing radio/dispatching system and the need to expand the agency’s services and capabilities were reported to be the critical need-based considerations leading to AVL/CAD system adoption. In operating the system, key requirements in procuring AVL/CAD were whether the system effectively identifies vehicles and monitors schedule adherence. Other important considerations included the requirements that the AVL/CAD system effectively monitored drivers’ performance, monitored vehicle location, effectively supported dispatching decisions, allowed employees to adjust easily to the new operating procedures, and gave consistently accurate information. Relatively less important considerations were effectively monitoring vehicle conditions, monitoring in-vehicle security, directing en-route operations, and monitoring passenger loads. The important maintenance considerations were whether the suppliers are in business and whether they continue to provide system components and technical support.

AVL/CAD Impacts. Agencies reported their perceived benefits and experiences with the AVL/CAD systems (or expected benefits, if the system was planned/under installation). The survey also contained questions about actual performance before and after AVL/CAD implementation. Most agencies did not have or did not provide quantitative measures of system performance, both before and after implementing an AVL/CAD system. (The questions included criteria such as operating costs, revenue, percentage of vehicles adhering to schedules, and response times to breakdowns and crimes.) Therefore, the responses to questions about “before and after” impacts are not reported.

In response to the question, “Has the AVL/CAD system been a valuable investment?”, 17 out of 28 agencies said yes, 5 said that they did not know, 1 was uncertain, and the rest did not respond (none said no). These responses should be interpreted with caution because, to some extent, the positive responses might represent justification bias, i.e., having committed to the AVL/CAD system, respondents may find justification for their agencies’ decisions.

AVL/CAD intra-organizational impacts are summarized in Table 2. Within this table, overall benefits of the AVL/CAD system are ranked based on the average scores, which were computed as follows: Strongly Agree = 3, Agree = 2, Disagree = 1, Strongly Disagree = 0. (Note that this scale is ordinal, and the truly permissible statistic for central tendency is the mode.) The “don’t knows” were not included in the calculation. The survey inquired about how various individuals in the agency had responded to the implementation of AVL/CAD. Our *a-priori* expectations were that the more technology-literate members of the agency would respond favorably to the new technology, while those less familiar with computers, electronics, and technology would be less receptive to the AVL/CAD system. Largely true to these expectations, those who responded positively included general managers, boards of directors, planners, schedulers and analysts, dispatchers, phone operators/customer service agents, on-street supervisors, ride or trip checkers, maintenance staff, information system managers, and drivers (in that order).

Table 3 indicates the general agreement reported by implementers in certain classes of benefits to the transit agency who responded to the question,

Table 2
Level of Agreement of Transit Agency Staff Experiencing
a Positive Reaction to AVL/CAD Implementation

<i>Group</i>	<i>Number of Agencies</i>					<i>Avg. Score</i>
	<i>Strongly Agree</i>	<i>Agree</i>	<i>Disagree</i>	<i>Strongly Disagree</i>	<i>Don't Know</i>	
General Managers	13	8	-	-	2	2.62
Boards of Directors	9	5	1	-	6	2.53
Planners/Schedulers/Analysts	11	10	1	-	1	2.45
Dispatchers	7	11	-	-	4	2.39
Phone Operators/ Customer Svc Agents	4	14	-	-	4	2.22
On-Street Supervisors	7	6	4	-	6	2.18
Ride or Trip Checkers	3	4	2	-	9	2.11
Maintenance Staff	4	11	3	-	3	2.06
Information System Managers	5	9	2	1	2	2.06
Drivers of Transit Vehicles	4	11	4	-	4	2.00

“Describe the benefits you expect from your AVL/CAD system.” As noted in the table, most respondents believe that the AVL/CAD improves their ability to monitor vehicle location; improves schedule adherence; enhances security for bus drivers and passengers; improves the ability to respond to breakdowns, accidents and schedule adjustments; improves the ability to monitor driver performance; improves ability to respond to crimes or other security incidents; and, improves the ability to direct en-route vehicles. Much less confidence was placed in AVL/

Table 3
Expected Benefits from AVL

<i>Benefit</i>	<i>Number of Agencies</i>					<i>Avg. Score</i>
	<i>Strongly Agree</i>	<i>Agree</i>	<i>Disagree</i>	<i>Strongly Disagree</i>	<i>Don't Know</i>	
Improve ability to monitor vehicle location	23	2	-	-	1	2.92
Improve schedule adherence	20	5	-	-	1	2.8
Enhance security for bus drivers and passengers	17	8	-	-	1	2.68
Improve ability to respond to breakdown, accidents, schedule adjustment, etc.	17	8	-	-	1	2.68
Improve ability to monitor driver's performance	13	10	-	-	2	2.57
Improve ability to respond to crimes or other security incidents	13	11	-	-	1	2.54
Improve ability to direct en-route vehicles	12	11	1	-	2	2.46
Improve coordination with other transportation modes	5	13	2	-	5	2.15
Reduce labor hours (e.g. on-street supervisor)	9	8	5	1	3	2.09
Reduce number of vehicles as a result of better planning	7	8	6	1	3	1.95

CAD technologies in improving coordination with other travel modes, reducing labor hours (e.g., on-street supervision), and reducing the number of vehicles as a result of better planning.

APTS Integration. As their AVL/CAD systems are currently installed, 24 agencies indicated that they also have silent alarms; 22 indicated that they have

on-board computers; and 14 indicated that they have mobile data terminals. A cross tabulation of these systems by AVL tracking system type is presented in Table 4. This indicates that integration of APTS technologies is taking place at several transit agencies. However, when combined with the results of the vendor survey, it appears that much of the responsibility for integration falls directly on the transit operator. That is, they either integrate these systems themselves and/or contract out with system integrators. This finding is in contract to AVL/CAD technologies coming as part of an integrated bundle of APTS technologies from a single vendor.

Table 4
Other APTS Technologies That Can Be Integrated with
Vendors' Current Tracking System

<i>Tracking System</i>	<i>Number of Agencies</i>		
	<i>Silent Alarms</i>	<i>On-Board Computers</i>	<i>Mobile Data Terminals</i>
Dead Reckoning	-	-	-
Proximity Beacon/Signpost	5	5	1
Radio	1	-	-
Satellite-Based GPS	11	11	9
Other (Signpost and Odometer)	1	1	1

With respect to the possibility of upgrading their existing system (adding a system), 6 agencies indicated that they can upgrade their system with on-board computers or with silent alarms, and 5 agencies indicated that they can upgrade their system with mobile data terminals. Moreover, a majority of the transit agencies indicated that they have integrated Automatic Vehicle Identification systems and on-board computers with their current AVL/CAD system. Of the systems currently not installed, automatic passenger counters were chosen most

often by transit agencies as the system they would like to add to their existing system.

Transit agencies were asked to report which of the following APTS technologies are currently integrated with their AVL/CAD system: pre-trip information to travelers, in-terminal information, in-vehicle real-time information, on-board computers, vehicle performance, traffic signal priority, automatic passenger counters, and automated fare payment systems. Respondents were then asked to "Describe the total benefits of these combinations in terms of those accruing to the operator and those accruing to the traveler." Tables 5 and 6 present a summary of perceived total operator and traveler benefits from integrating AVL/CAD systems with other APTS technologies. The perceived benefits of such integration, in order of highest to lowest benefit, are:

- improved ability to monitor vehicle location;
- enhanced security for drivers;
- improved schedule adherence;
- improved ability to respond to crimes and security concerns;
- improved ability to monitor driver's performance;
- improved ability to respond to breakdowns and accidents;
- improved ability to direct en route vehicles;
- reduced labor hours;
- improved coordination with other transportation modes; and
- reduced number of vehicles as a result of better planning.

The ranking of expected benefits from integration largely mirror those reported for AVL systems alone. However, in comparing the results from Table 3 (AVL systems alone) and Table 5 (AVL systems integrated with other APTS technologies), it appears that transit operators perceive higher incremental benefits from AVL implementation alone than they do from system integration. This result, while perhaps not surprising, suggests that, at this early stage of AVL/CAD deployment, operators do not perceive a significantly higher value of system integration in the AVL/CAD context.

Table 5
Level of Agreement Regarding Transit Agency's Benefits from
AVL/CAD Integration with Other APTS Technologies

<i>Benefit</i>	<i>Number of Agencies</i>					<i>Avg. Score</i>
	<i>Strongly Agree</i>	<i>Agree</i>	<i>Disagree</i>	<i>Strongly Disagree</i>	<i>Don't Know</i>	
Improved ability to monitor location	16	6	-	-	1	2.73
Enhanced security for drivers	14	9	-	-	1	2.61
Improved schedule adherence	12	11	-	-	1	2.52
Improved ability to respond to crimes and other security incidents	11	12	-	-	1	2.48
Improved ability to monitor driver's performance	7	14	1	-	2	2.27
Improved ability to respond to breakdown, accidents, etc.	7	15	1	-	1	2.26
Improved ability to direct en-route vehicles	6	15	1	-	2	2.23
Reduced labor hours	2	16	3	-	3	1.95
Improved coordination with other transportation modes	2	15	3	-	4	1.95
Reduced number of vehicles as a result of better planning	5	8	7	1	3	1.81

Table 6 shows that the important traveler benefits as perceived by the transit agencies implementing AVL/CAD systems include enhanced security for passengers, improved ability to make connecting services, and, to a lesser extent, reduced wait times. It is generally not true that transit agencies expect to be able to reduce walking distances to stops and stations through use of AVL/CAD systems. Overall, a majority of the agencies expressed that AVL/CAD technologies

Table 6
Level of Agreement Regarding Traveler Benefits from
AVL/CAD Integration with other APTS Technologies

<i>Benefit</i>	<i>Number of Agencies</i>					<i>Avg. Score</i>
	<i>Strongly Agree</i>	<i>Agree</i>	<i>Disagree</i>	<i>Strongly Disagree</i>	<i>Don't Know</i>	
Enhanced security for passengers	9	13	1	-	1	2.35
Improved ability to make connecting services	4	16	2	-	2	2.09
Reduced wait times	3	15	4	-	2	1.95
Reduced walk distance to stops / stations	-	3	13	3	4	1.00

were performing their main functions and that it was a valuable investment. There is higher uncertainty about whether the AVL/CAD was providing quantifiable benefits to both the agency and travelers. Respondents' lack of response to questions about quantitative "before and after" benefits underscores the need for better tools to characterize and quantify the impacts and benefits of AVL/CAD systems.

Summary and Conclusions

In this research, a conceptual structure for analyzing AVL/CAD technologies was proposed. The structure was used to explore the design and technical application dimensions of technologies; the structure also identifies the impacts/benefits of these technologies in specific contexts.

AVL/CAD technologies can be defined by their design and application dimensions. The design dimensions are technology features, functions and performance. The technology application dimensions include the conditions of implementation, integration with other technologies, and the spatial, temporal, and

user attributes, indicating where, when, and for whom the technology is implemented.

Technology deployment takes place in an implementation context. For example, the service network structure and density, number of vehicles, duration of peak flows and types of travelers served can influence AVL/CAD impacts. The operator impacts can be measured in terms of efficiency and costs, while the traveler impacts are measured in terms of transit service improvements. These impacts also have "distribution" dimensions; that is, the impacts of the AVL/CAD system can depend on the scope of technology implementation.

The structure developed in the study was used to explore the AVL/CAD commercial availability (supply) and deployment (demand). A survey of vendors showed that satellite-based GPS and proximity beacon/signpost AVL/CAD technologies are popular with both the vendors and transit agencies; GPS technology is being widely deployed in transit agencies. Moreover, transit agencies reported a substantial number of APTS technologies that can be integrated with AVL/CAD.

The AVL/CAD survey of potential and current transit implementers indicated that those who responded positively to the implementation included general managers, boards of directors, planners, schedulers and analysts, dispatchers, phone operators/customer service agents, on-street supervisors, ride or trip checkers, maintenance staff, information system managers, and drivers (in that order). The perceived benefits were the improved ability to monitor vehicle location, improved schedule adherence, and enhanced security for bus drivers and passengers. It is not clear whether many transit agencies believe that AVL/CAD systems reduce costs (i.e., by reducing labor hours or vehicle hours). Furthermore, there was evidence that AVL/CAD implementation decisions are made as longer-term upgrades and/or investments. There is a need for more quantitative evidence about AVL/CAD impacts on transit operators and travelers. This research indicates that there may be considerable questions raised about the overall cost-effectiveness of such systems from the perspective of transit implementers. It is also telling that the AVL/CAD systems are liked most by the white-collar

workers and relatively less by the people who are working day-to-day with the system and with the public (i.e., people on the “front line”).

Although limited insight was gained in this paper from studying potential traveler impacts from the transit implementer’s perspective, there is a strong need to evaluate traveler benefits. Research should be directed at:

- evaluating objectively-measured benefits to transit users in terms of travel-time reliability, reduced uncertainty, information on waiting and transfer times, and reduced travel time;
- user-perceived benefits measured in terms of the above criteria and reduced stress;
- changes in ridership (if any) due to improved level-of-service; and
- marketing of the benefits (if any) to attract non-users to transit.

While AVL/CAD suppliers and implementers perceive significant benefits, there is a need to synthesize the experiences of transit agencies (see Casey and Collura 1994). Importantly, there is a need to identify APTS technologies that can be mixed to provide the correct balance between operator effectiveness and customer satisfaction. The correct mix will also depend on transit agency objectives and operating environment. In future research, it will be interesting to evaluate how the perceived impacts of APTS technologies depend on the design dimensions, application dimensions, and the implementation context.

Individually, APTS technologies may be of limited value, but, collectively, they may significantly enhance transit system performance and attract travelers. While operators perceived significant benefits from AVL/CAD implementation, they did not perceive significant additional benefits from system integration. However, the issue of APTS integration may be critical to the long-term success of these new technologies. More research is needed to explore the benefits of system integration. ♦

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