2.0 Review of Transit Technologies and Current Research

2.1 Intelligent Transportation Systems (ITS)

Recent problems in surface transportation in the United States have enforced many planners and decision makers to make efforts at improving the safety, efficiency, and environmental friendliness of our transportation system by introducing advanced technologies to transportation operations, facilities, and management. Those efforts had been accelerated by the initiatives of Intelligent Transportation Systems (ITS; IVHS America, 1992, a; ITS America, 1994). ITS is the integrated application of modern computer, communications, surveillance and traffic control techniques to: a) inform the traveler, b) improve the vehicle operation, and c) improve the infrastructure efficiency and environment (IVHS America, 1992, b). Ideally, ITS technologies inform drivers of current network conditions thus promoting more appropriate travel decisions. ITS improves the vehicle operation with devices such as early warning systems, route navigation systems, and improved communication capabilities to make the driving task easier and safer. Other roles of ITS are to improve the efficiency of the infrastructure and to improve the quality of the environment through lower fuel emission. In the other words, the goal of ITS is to make travelers, vehicles and the transportation infrastructure work as efficiently as possible as one integrated system by informing travelers, improve the vehicle performance and reducing negative impacts to the environment (ITS America, 1994).

Some agencies through programs and legislation have created incentives for investing, testing and implementing ITS technologies. Examples of these are the Clean Air Act Amendments of 1990 (CAAA), Defense Advanced Research Projects Agency (DARPA), and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (Papacostas et al, 1993; Hobeika, 1996). The ISTEA clearly annunciates the goals of ITS in its statement of policy: "… *to develop a National Intermodal Transportation System that is economically sound, provides the foundation for the Nation to compete in the global economy, and will move people and goods in an energy efficient manner* (ITS America, 1994)." It is worth mentioning that individual state legislations have also helped ITS technology deployment; the Smart Road in Virginia being a specific case in point.

ITS is an interdisciplinary field that can be defined in terms of technologies, system architecture, user services and function categories (Hobeika, 1996). From a user perspective, ITS offers travelers various services which fall into seven general user service areas shown in Table 2.1.

Table 2.1 ITS User Services.

ITS User Services	AVL[1]	ITS User Services	AVL
Travel and transportation management		Commercial vehicle operations	
• En-Route Driver Information	*	• Commercial Vehicle Electronic Clearance	
• Route Guidance		• Automated Roadside Safety Inspection	
• Traveler Services Information	*	• On-Board Safety Monitoring	
• Traffic Control		• Commercial Vehicle Administrative Process	
• Incident Management		• Hazardous Materials Incident Response	
• Emissions Testing and Mitigation		• Commercial Fleet Management	*
Travel demand management		Emergency management	
• Pre-Trip Travel Information	*	• Emergency Notification & Personal Security	*
• Ride Matching and Reservation		• Emergency Vehicle Management	*
• Demand Management and Operations		Advanced vehicle control & safety systems	
Public transportation operations		• Longitudinal Collision Avoidance	
• Public Transportation Management	*	• Lateral Collision Avoidance	
• En-Route transit Information	*	• Intersection Collision Avoidance	
• Personalized Public Transit		• Vision Enhancement for Crash Avoidance	
• Public Travel Security	*	• Safety Readiness	
Electronic payment		• Pre-Crash Restraint Deployment	
• Electric Payment Services		• Automated Highway Systems	

AVL[1] : The services can be provided by AVL technology
Source : Modified from Hughes aircraft company, 1994

In the functional category, ITS America classifies ITS functions in six well-known basic areas (Walter H. Kraft, 1993) repeated here for completeness:

- Advanced Traffic Management Systems (ATMS)
- Advanced Traveler Information Systems (ATIS)
- Advanced Vehicle Control Systems (AVCS)
- Commercial Vehicle Operations (CVO)
- Advanced Public Transportation Systems (APTS)
- Advanced Rural Transportation Systems (ARTS)

ATMS employ innovative technologies and integrate new and existing traffic management and control systems in order to bring order and efficiency to the dynamically changing movement of highway vehicles. Euler (ITE, 1990) described six primary characteristics of ATMS: 1) collection of real-time traffic data; 2) reaction to changes in traffic flow with timely traffic management strategies; 3) area-wide surveillance and detection systems; 4) integration of various management functions, including transportation information, demand management, freeway ramp metering, and arterial signal control; 5) collaborative action on the part of transportation management agencies and jurisdictions in order to optimize the strategies available to improve traffic flow; and 6) rapid response to incident management strategies.

IVHS America (1992, b) defines ATIS as the function to acquire, analyze, communicate, and present information to assist surface transportation travelers in moving from a starting location to their final destination. This function provides any kind of information (pre-trip, en-route, and electronic ‘yellow’ pages) according to three evolutionary stages; information (near term), advisory (middle term) and coordination (longer term) (IVHS America, 1992, b; Hobeika, 1996).

AVCS add sensors, computers, and control systems into vehicles and the highway infrastructure to help the driving task and establish safer and more efficient highway operations (Euler, 1990; ITS America, 1994). AVCS are perhaps the most strategic area of all the ITS functions. The AVCS research and development plan has been divided into three evolutionary stages: 1) individual vehicle operation (near term), 2) cooperative driver-vehicle-highway operation or combined vehicle motion control operation (middle term), and 3) automated highway operation system (longer term) (Texas Transportation Institute, 1993; ITS America, 1994).

CVO adopt advanced technologies and communication systems to: improve efficiency of operations, increase safety of commercial vehicle/fleet and reduce congestion and air pollution (Hobeika, 1996). The CVO deployment plan recognizes three stages: near term, middle term, and long term stages as shown in Table 2.2.

Table 2.2 The Deployment Plan of CVO Research and Development.

Time schedule	Deployment Issues	Research and development projects
Near term (5-year timeframe)	autonomous and static routing	• Automated weight reporting (WIM) • Automated vehicle identification reporting (AVI) • Electronic toll and traffic management (ETTM) • Automated fleet vehicle location (AVL) systems • Static network routing and scheduling
Middle term (10-year timeframe)	Combined and dynamic routing	• Vehicle safety monitoring systems for driver use • Highway speed toll collection • Automated vehicle and driver credential reporting • Highway safety warning systems • Computerized fleet tracking and dispatching • Automated HAZMAT identification and location • State-line beacon network • Dynamic or combined static/dynamic network routing
Longer term (20-year time frame)	Fully automated and Integrated	• Electronic tax and permit systems • Automated vehicle and driver condition monitoring and reporting

Source: modified from IVHS America, 1992, a

Advanced Public Transportation Systems (APTS) are advanced navigation and communication technologies that are used in all aspects of public transportation. These include the application of advanced electronic technologies to the deployment and operation of high occupancy vehicles, shared-ride vehicles, conventional buses, rail vehicles and the entire range of paratransit vehicles (IVHS America, 1992, b). This ITS subdiscipline encompasses pre-trip travel information, en-route transit information, ride-matching and reservation, electronic payment services, public transportation management, personalized public transit, and public travel security. These systems enable transit agencies to make timely and needed transit information available to passengers, an element that is important to improving the convenience, reliability, and safety of public transportation. Three basic APTS subsystems are available for deployment in support of transit travelers and operations.

- Smart Traveler; the use of traveler information systems to provide real-time, multi-modal travel information to users to help en-route or mode choice.
- Smart vehicle; the use of Automatic Vehicle Location (AVL) to figure out transit vehicle positions in the development of transit fleet management.
- Smart Intermodal Systems, also known as Mobility Manager; strive for coordination and integration of transportation services offered by multiple providers.

APTS will help transit agencies manage a safe and efficient fleet and plan services to satisfy a broad range of consumer needs. When incorporated with a regional transportation system, APTS will also enable a system to manage its roadways with special accommodations for high occupancy vehicles. ARTS applies advanced surveillance and communication technologies to rural area transportation systems with aim to improve safety, increase the efficiency of small community services and provide recreational travelers with location/navigation technologies (Hobeika, 1996).

In terms of technology, ITS covers a multitude of engineering fields including civil, mechanical, electrical and industrial. Each one of these fields contributes in its way to the advancement of transportation as this field has become highly multidisciplinary. To apply various system engineering techniques to analyze specific components of ITS a system architecture is needed. This systems architecture reflects the philosophy, concept, and efficiency of ITS. Important issues related to the system architecture are; a) centralization vs. decentralization of the system structure, b) automation of highway system vs. automation of the vehicle system, c) privacy vs. equity issues, and d) establishing standards (Waller, 1994; Hobeika, 1996). Moreover, a system architecture should have well defined goals to integrate all ITS technologies in a synergistic manner. Judging from recent ITS implementation efforts, perhaps this is an area where ITS has been poorly articulated.

2.2 Automatic Vehicle Location Systems (AVL)

In transit systems the smart vehicle, one of the APTS subsystems, refers to the use of Automatic Vehicle Location systems to estimate transit vehicle positions to optimize transit fleet operations and management. Vehicle locations are determined and transmitted to a central dispatch or control center where information can be used to make real-time adjustments to route planning and scheduling. Automatic Vehicle Location systems (AVL; sometimes referred to as Automatic Vehicle Monitoring or Automatic Vehicle Location and Control Systems; USDOT, 1996, a) are computer-based vehicle tracking systems. These technologies compute and display the location, speed, status, and heading of vehicles (USDOT, 1996, b). The resulting navigation data is transmitted over a radio to the base station (e.g. dispatcher). Several reports provide some detail on the advantages of an AVL system (US DOT, 1996, a; Vaidya, N., et al, 1996);

- Increased dispatching and operating efficiency
- More reliable service, encouraging ridership
- Faster response to service disruption
- Inputs to passenger information system
- Increased driver and passenger safety
- Faster notice of mechanical problems
- Inputs to traffic signal preferential treatment actuators
- Extensive planning information

Most of the AVL technology depends on various well known methods such as dead reckoning (map matching), proximity beacon, signpost and odometer, radio navigation/location, Loran-C, and Global Positioning Systems (GPS) (USDOT, 1996, b). Table 2.3 lists current implementation statistics on AVL systems. Until 1994, the most common technology form of AVL was the signpost and odometer-based system. Primary limitations most often associated with these systems are; decreased flexibility in changing transit route structures; restricted monitoring of transit fleets to only signpost equipped routes; and generally higher costs for signpost installation and maintenance. Today eighty three percent of the agencies installing new systems are choosing GPS-based systems (USDOT, 1996, b). GPS is more robust than other location technologies (e.g., signpost, odometer or dead reckoning) and its cost has decreased substantially over the past several years as GPS receivers are used in many other fields. The main hardware expenditures of GPS are: a) the receivers (typically mounted on the bus roof for better reception); b) a receiver at the control center; and c) appropriate software to integrate signals received from the bus via satellite into a map. For the purpose of this study, the term AVL will be used to represent this hardware and software combination.

Table 2.3 Implementation of North American AVL Systems (1996).

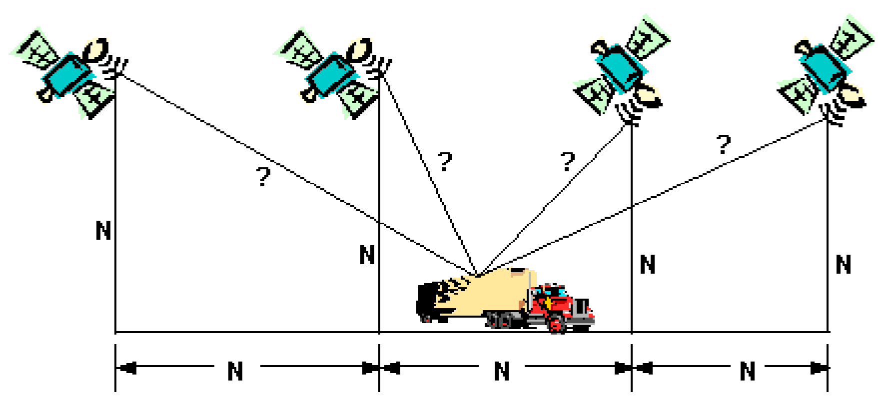
Technology	Operation	Installation/Plan	Total
Signpost and Odometer	14 (50.0)	3 (8.3)	17 (26.6)
Global Positioning System	10 (35.7)	30 (83.3)	40 (62.5)
Other	4 (14.3)	3 (8.3)	7 (10.9)
Total	28 (100.0)	36 (100.0)	64 (100.0)

(Source : USDOT, 1996, b)

AVL systems are just one example of the integration required in ITS where technology offers an apparent opportunity to improve user convenience and perhaps lower costs for service providers. However, the same integration also requires an acquisition cost, extra maintenance actions and personnel know-how that could in principle offset some of the obvious gains of deploying a system. This is the main reason for using a system approach to understand these relationships.

2.2.1 Technologies in AVL

Global Positioning Systems (GPS) technology is one of the most popular in AVL navigation technologies. GPS uses signals transmitted from a network of 24 satellites in orbit. The hardware on a typical bus is located in the roof to maximize the viewing angle from the bus to the satellite. Each satellite transmits a fixed signature pattern at 1.2 GHz.



GPS Location Systems are based upon signals received from 4 or more satellites. In the simplified illustration above, the distances "N" are known distances. The "?" (unknown) distances are calculated by the base CAD/MAP system, and then a lateral location can be arrived at by comparing the timing of the received signals.

Figure 2.1 An Example of GPS Functional Concept.

The receiver on the roof of the vehicle reads the signals from 3 or more satellites and measures the delay in the signal transmission (the transmission carries a time stamp information for this purpose). A position fix of the bus can be obtained by triangulating information from 3 or 4 satellites (See Figure 2.1). Finally, it transmits the calculated location to a dispatch center where this signal is 'fused' with high-resolution software providing surveillance information in real-time. GPS is remotely similar to ground-based triangulation systems, but instead of many transmitters located at points on the ground, GPS instead relies upon a constellation of satellites in high-Earth orbits, which continuously transmit timing and identification data to earth. This constellation of satellites is arranged so that from any location on Earth, it is possible to be within viewing range of at least 4 satellites.

It is generally assumed that the worst-case accuracy of commercial/civilian GPS is within 80 to 100 meters (when selective availability is turned on to degrade the GPS navigation signal). This accuracy is sufficient for most commercial or public transportation systems. However, it is possible to greatly increase the accuracy of commercial GPS systems using differential signals from ground-based stations that reduce the uncertainty of the satellite-based signal. Since the exact location of this fixed receiver is known, the overall system can calculate the intentional 'error' of the signal by comparing the known location with the location using the constellation. This error rate is applied to other vehicles operating around that area and accuracy can be brought to within 10 meters.

GPS works well anywhere in North America except under ground, urban canyons, or foliage. Data collected from GPS systems could also be used to: a) monitor real-time traffic conditions utilizing computer graphics displays; 2) estimate traffic responsive critical intersection control; 3) schedule traffic responsive area-wide control; 4) Develop ad hoc timing plans for nonrecurring situations; 5) automate traffic signal plan processes; and 6) execute transportation planning & system evaluation (Hobeika, 1996).

2.2.2 User Services of AVL

Possible services offered by AVL technology are: a) en-route driver information, b) traveler services information, c) pre-trip travel information, d) public transportation management, e) en-route Transit Information, and f) public travel security so on (Casey, 1994; See Table 2.1). Specific uses of GPS -based AVL technologies are:

- Seamless controlling and monitoring the vehicle operations enhancing on-board's safety, security
- Estimating vehicle positions to assist dispatchers in improving service potential such as on-street schedule adherence, bus timed transfer service
- Obtaining boarding and alighting information in conjunction with automatic passenger counters(APCs)
- Assisting in the development of more realistic schedules
- Facilitating the assignment of individuals to shared ride, demand response services
- Assisting in the preparation of daily driver logs
- Buses as probes for freeway monitoring

2.3 Issues Related to AVL System Implementation Evaluation

Before implementing new technology on transportation system, the precise impact of the technology on the system needs to be considered. One of most widely applied evaluation techniques is cost/benefit analysis. However, the review of APTS applications in the U.S. revealed very few efforts to evaluate these projects using such analysis. In most tests, this analysis is planned as the final step in the project evaluation; after a field test the analysis has been completed and potential benefits have been reported. There are several reports discussing cost/benefit issues related to AVL systems as a part of field test after implementation of the systems(Benjamin, 1997; Galindez, 1997; Spring, 1997).

2.3.1 Benefits of the AVL Systems

The benefit and cost factors of AVL are numerous and varied, whether they can be represented by monetary values or not. Basically, the AVL technology provides up to the minute (or even second) information on exactly where the bus is located. This information can be broadcast an automated dispatch system. This will present bus operational information in real-time to travelers and perhaps affect passenger demand patterns. The improved information improves passengers' acceptance of the system and improves the perceived reliability of the system. For the service provider side, the real-time information allows operators to monitor the vehicle condition and respond in time to problems such as falling behind schedule or incidents. Enhanced control of vehicle operations and management improves service at lower cost. Also, since AVL technology is a major element of ITS, it provides a linkage by which transit can participate in other field of ITS applications. For example, a simple extension the AVL can be applied to, or provide data to such systems as; on-board passenger information, Advanced Vehicle Monitoring & Communication System (AVM/C), Vehicle Management System(VMS), pre-trip scheduling system, and demand responsive dispatching, etc.

Many systems where AVL technology has been implemented experience more efficient and on-time operations as their schedules are improved, they are better able to respond to disruptions, (e.g., a disabled vehicle), and bus operators are aware of their schedule adherence (Casey, 1993). Safety and security typically increase, since the dispatcher knows immediately where to send help. AVL information also provides very useful inputs to passenger information and traffic signal preferential treatment systems (USDOT, 1996, b; Hobeika, 1996). In long term, the compiled historic bus position data can be used for planning route, schedules, fleet and personnel deployment (Morlok, 1991).

For this study, the benefit and cost can be categorized as shown in Table 2.4. The benefit of the APTS can be sub-divided to quantitative and non-quantitative Benefits. The quantitative benefits such as social benefit (social welfare), economic benefit (operator income increase), and environmental benefit can be calculated in the form of times, dollars, and various pollution components. The time saving of total passengers due to the technology yields a kind of social benefit as well as economic benefit. This reduced time yields saved time value of total passengers in the monetary terms referring minimum wage of average persons multiplied by the number of passenger.

Table 2.4 Benefit/Costs of an AVL System.

Benefit		
Categories		Units
Quantitative Benefit	1. Social Benefit (Social Welfare) • Time saving of total passengers	hrs.
	2. Economic Benefit (Operator Income Increase) • Saved time value of total passengers • Increase of Fare Box Revenue (in Dollar) • Reduced Fuel Consumption (in Dollar) • Reduced manpower requirement	 dollar dollar dollar dollar
	3. Environmental Benefit • Reduction of Emission	CO, HC, NOx
Non- Quantitative Benefit	1. Customer Convenience 2. Safety 3. Operational Efficiency Improvement 4. Complaint resolution	
Cost		
	1. AVL Implementation Cost, 2. Maintenance Cost, and 3. Personnel Education Cost, etc	

Increased fare-box revenue can be calculated in dollars if the increased ridership can be estimated. Also changed fuel consumption produces operator money savings. In cost side, on the other hand, AVL implementation cost, maintenance cost, and personnel education cost can be considered as major factors. In this study, to make story simple, quantitative benefit is reviewed mainly on cost savings point of view.

There are some reports about cost savings which is most direct benefit due to the technology. Substantial labor savings and a reduction in some manpower requirements are claimed to be achieved. For example, automated data collection will reduce the labor and cost expended in the collection and analysis of data for scheduling and reporting purposes and manual traffic checkers will no longer be required. The street supervisors also can be more effectively utilized. There are several reports related to the cost savings;

- The Winston-Salem Transit Authority reports that the AVL/CAD paratransit system has decreased operating expense by 8.5 % per vehicle mile and by 2.4 % per passenger trip (See Table 2.5).

Table 2.5 Cost Savings After AVL.

Name of Project	Category	Savings
Winston-Salem Transit Authority's (WSTA) AVL/Computer Aided Dispatch (CAD)	Operating expense	– 8.5 % / veh.-mi.
		– 2.4 % / passenger trip
London (Ontario, Canada) Transit Authority's AVL system	Schedule adherence survey cost	$40,000 ~ $50,000
Kansas City Area Transit Authority's (KCATA) AVL system	Maintenance and operator cost	$400,000/yr.

*: Modified from US DOT, 1996, b

- London Ontario's AVL system will provide schedule adherence on a continuing basis, thus saving the $40,000 to $50,000 previously spent on each schedule adherence survey.
- KCATA used AVL generated data to reduce scheduled running times in conjunction with a systemwide service reduction. It was estimated that the maintenance and operator cost savings from the schedule retiming would be about $400,000 annually. Theoretically, this would result in a fleet reduction of seven buses with an attendant elimination of bus replacement costs of about $225,000 per bus.
- A large transit authority has estimated that AVL generated data would allow them to eliminate 30 schedule adherence checkers and would save approximately $1.5 million per year.
- Rochester-Genesee Regional Transportation Authority's automated transit information system will allow the Authority to eliminate four part-time information agents.
- Although KCATA did not eliminate street supervisory personnel, they did achieve some savings in supervisor labor costs because AVL made it more acceptable to allow short term reductions in the size of the field supervision force resulting from absences or temporary reassignment of supervisors.

- Milwaukee County Transit System plans to reduce the number of street supervisors when the AVL/CAD system is fully operational.
- FARETRANS (Ventura County, CA) estimates that their smart card system will save: $9.5 million per year in reduced fare evasion; $5 million in reduced data collection costs; and $990 thousand by eliminating transfer slips.

On the other hand, several related researches described non-quantitative benefit as followings: 1) customer convenience; 2) safety; 3) operational efficiency improvements; and 4) complaint solution. The following paragraphs describe each of them.

1) Customer Convenience

The schedule improvements and enhanced safety owing to the AVL should increase the quality of service, resulting in greater passenger satisfaction and an increased ridership. There are several reports related to the customer convenience issue;

- San Diego County's interactive voice response system has allowed information agents to increase their productivity in handling calls by over 21 %.
- Over 85 % of Smart Traveler kiosk users in Los Angeles indicated that they would continue to use the kiosks to obtain travel information.
- Rochester-Genesee Regional Transportation Authority has implemented an automated transit information system which answers 70 % of information request calls. Information request calls have increased by 80 %.
- New Jersey Transit's automated voice response telephone information system has reduced caller's waiting time from 85 seconds to 27 seconds and has reduced the caller hang-up rate from 10 % to 3 %. Monthly calls have increased by 40,000 over the previous year.
- Winston-Salem Transit Authority reports that their AVL/CAD system has decreased paratransit passenger waiting time by 50 %.

2) Safety

Better communication and better service provided by AVL system enhance public trust in the system and public perception of security. For example, in Denver, a man who had just robbed a convenience store was observed to have boarded an RTD bus. The police informed the dispatcher, who used the AVL/CAD system to identify which bus the suspect would likely have boarded. The transit control head's message capability was used to confirm the suspect's presence on the bus. The police were then directed to a point where the bus could be intercepted. The suspect was apprehended. There are several reports related to safety issue;

- Also in Denver, a bus passenger had a seizure. RTD was able to notify emergency response personnel of the incident and its location and an ambulance was at the scene within eight minutes.
- There have been several instances in cities with AVL equipped buses where bus operators have observed accidents, crimes, or other situations which warrant quick response by emergency personnel. The AVL system's communication and location capability has allowed the emergency personnel to be quickly notified and directed to the exact location of the trouble (this could have been done using standard two-way radio as well).
- The silent alarm and AVL features permit rapid identification and location of an on-board emergency and a reduction in emergency response time.
- Kansas City Area Transit Authority (KCATA) dispatchers estimate that response times to bus operator calls for assistance have been reduced to three to four minutes with the AVL system from seven to 15 minutes previously.
- Bus operators in transit systems with AVL report a greatly increased feeling of security with the silent alarm, listen-in feature, and rapid response capability that the system provides.

3) Operational Efficiency Improvements

With an AVL onboard dispatchers can use electronic maps to monitor the real-time progress and location of the bus within a city block. Colored icons in monitors identify the status of the bus, indicating whether it is on time, early, or behind schedule. With this system, dispatchers can adjust problematic route schedules quickly, reducing the incidence of bus bunching and improving on-time performance service.

Generally, transit management systems have yielded improvements in on-time performance of 12% ~ 28% while reducing costs to yield a positive return on investment in as little as three years (US DOT, 1996, c). There are several reports related to the Operational Efficiency Improvements;

- The Hamilton (Ontario) Street Railway Company's schedule adherence improved from 82 % to 89 % after AVL installation (See Table 2.6).
- KCATA's on-time performance (from one minute early to three minutes late) improved from 78 % to 95 % after AVL installation.

Table 2.6 Improvement of Operational Efficiency After AVL.

Name of Project	Category	Change of Efficiency		
		Before	After	Change
Hamilton (Ontario, Canada) Street Railway Company's AVL system	Schedule adherence	82%	89%	+ 7 %
Kansas City Area Transit Authority's (KCATA) AVL system	On-time performance	78%	95%	+ 17 %
Maryland Mass Transit Administration's (Maryland MTA) AVL System	On-time performance	.	.	+ 23 %
Milwaukee County Transportation Division's (MCTD) AVL System	On-time performance	90%	94%	+ 4 %
Winston-Salem Transit Authority's (WSTA) AVL/Computer Aided Dispatch (CAD)	Paratransit ridership	.	.	+ 17.5 %
	Passenger waiting time	.	.	– 50 %

*: Modified from US DOT, 1996. a , Federal Highway Administration, 1995.

- The Mass Transit Administration of Maryland reported a 23 % increase in on-time performance of buses in Baltimore in their test of AVL equipped buses on a few routes. AVL will soon be system wide.
- Milwaukee County Transit System claims that on-time performance has improved from 90 % to 94 % after implementing their AVL system, even though the system is not fully operational.
- Since the implementation of an AVL CAD system, the Winston-Salem Transit Authority reports that paratransit ridership has risen by 17.5 % and their client base has increased by 100 %.

Other transit operators also claiming improved schedule adherence after AVL implementation include: County of Lackawanna Transit System (Scranton, PA), Broward County (FL) Division of Mass Transit, and Beaver County (Rochester, PA) Transit Authority. Transit operators reporting improved scheduling include Mass Transit Administration (Baltimore), Dallas Area Rapid Transit, Tidewater Transportation District Commission (Norfolk, VA), and KCATA. In addition to the above, estimated improvements in operational efficiency are as followings;

- Data will be available much sooner for management decision-making.
- More efficient scheduling will result in reduced deadhead and in-route hours.
- Schedule development will be accomplished quicker.
- The automated database will contain daily performance reports from all buses on all routes (compared to the current average of one ride check per route per year). This will provide more accurate running time information and allow scheduling staff to better match schedules to demand, thereby making more efficient use of the buses.
- The new radio system will provide improvements in coverage and channel allocation. It will allow data communications which will reduce the amount of voice communications and make more efficient use of the channels.

4) Complaint Resolution

A more efficient and smoothly running system will elicit fewer passenger complaints, leading to a more pleasant work environment, especially for drivers and telephone operators. There are several reports related to Complaint Resolution issue;

- Denver Regional Transportation District's (RTD) AVL/CAD systems helped to verify a bus operator's claim of being not paid for a one-day work.
- Milwaukee County Transportation Division's (MCTD) AVL System's playback feature was used to verify a bus operator's claim that he did not leave a bus stop too early.
- AVL systems in Beaver County Transit Authority, Tidewater Transportation District, and King County Metro's have many cases in reduced number of customer complaints and permitted easier resolution of complaints.

2.3.2 Cost of the AVL Systems

"Not only can the receiver-antenna unit be purchased for less than $500, but also the signals from the GPS satellites are free to any user" (Westbrook, 1996). Neglecting non-monetary issues of the cost – loss of privacy – the cost of the AVL system can be figured out relatively easily. However, many factors affect the cost of an AVL installation, including in-vehicle hardware, field hardware, control-center hardware, software, training, and support. Although the cost for a GPS system can be as low as $500 for the core equipment, the price can jump to $3,000 if you include a modem and radio for communications. Industry projects, however, put the cost of a combined GPS system – radio, modem, and GPS receiver/antenna – at less than $500 by the end of the decade (Westbrook, 1996). Hall et al. (1997) yielded a simple linear regression to predict cost as a function of fleet size as shown in Equation 2.1

$$\text{GPS AVL System} = \$1.30\text{million} + \$13{,}000 \times (\text{fleet size}) \quad (2.1)$$

The costs of already implemented AVL systems per vehicle vary from $3,846 to $28,000 (average : $11,554/veh., See Table 2.7). This cost is falling drastically as prices for GPS systems are reduced as well. In the past year a few GPS vendors have reduced the price of comparable GPS system by 35% alone. In the particular case of Blacksburg Transit, which is in the middle of AVL deployment, the total cost of AVL implementation on 30 buses has been estimated at $500,000. This figure is typical case of a simple AVL system used in rural areas.

2.4 Review of Current Research on APTS Evaluation

From the advent of the ITS, several evaluation technique have been developed and applied on the assessment of ITS impact on given transportation environments. Recent researches classified those efforts into four parts according to methodological approaches; Technical Evaluation, Empirical Evaluation, Model-Based (or Prospective) Evaluation, and Subjective Evaluation methodologies (Underwood et al, 1992; Hill, 193).

2.4.1 Technical Evaluation

This methodology assesses system performance at operational test stage and attempts to find answer to the questions such as; ‘Was the system built properly?’, ‘Is it functioning to specifications?’. It is the evaluation for not only the functionality of the system but also the user responses to the system (e.g., via survey of passengers using the system). An example of this methodology is presented in the HELP/Crescent project. In this test the adaptability of AVL on highway environment to collect data was evaluated. Component, software, database, system, and cost evaluations are covered under this heading. Vaidya (Vaidya, N., et al, 1996) developed such evaluation method to test the accuracy of AVL systems.

Table 2.7 Sample AVL Cost of Transit Systems in U.S.A.

#	City	System	vehicles	Cost*	Cost/veh.	Comment
1	Tucson, AZ	PTS	200	3.5	17,500	
2	Los Angeles, CA	LAMTA	2,085	12	5,755	Location accuracy "very good" in early test; minor software glitches
3	Napa, CA	The Vine	18	0.13	7,222	
4	Denver, CO	RTD	900	11	12,222	Some software difficulties early in the installation process
5	Miami, FL	BCT	610	14.5	23,770	
6	Palatka, FL	Arc Transit	20	0.44	22,000	
7	Atlanta, GA	MARTA	250	7	28,000	Linked to state-wide multi-modal, multi-jurisdictional ATMS
8	Gary, IN	GPTC	32	0.14	4,375	
9	Louisville, KY	TARC	257	2.5	9,728	Insufficient accuracy in sched. Database, had contractor problems
10	Baltimore, MD	MTA	935	8.9	9,519	Former successful test of Westinghouse Loran-C system on 50 buses
11	Detroit, MI	SMART	250	2.7	10,800	Buses used as probes for MDOT freeway monitoring
12	Buffalo, NY	CDTA	415	9.6	23,133	
13	Portland, OR	Tri-Met	770	5.2	6,753	Engine probes gave false alarms
14	Rochester, PA	Beaver County TA	13	0.05	3,846	"valuable tool", on -time performance up, complaints are down
15	Scranton, PA	COLTS	32	0.3	9,375	Great record-keeping tool; "buses on time;" easier ADA compliance
16	Dallas, TX	DART	1200	16.4	1,3667	Reliability problems in 1994, worked out
17	San Antonio, TX	VIA	531	3.7	6,968	
18	Norfolk, VA	PRTC	151	2	13,245	Allows tighter scheduling, functioning very well, reduced pass, complaints
19	Bremerton, WA	Kitsap Transit	155	0.6	3,871	Phased project: II - outlying area buses; III - paratransit veh.; IV - ferries
20	Seattle, WA	KC Metro	1250	15	12,000	Operators rely on increased security
21	Milwaukee, WI	MCTS	600	7.8	13,000	
22	Sheboygen, WI	STS	20	0.1	5,000	
	Average		486.1	5.6	11,554	

*: in million dollars, when purchased
source : modified from USDOT, 1996, a

Table 2.8 Strengths and Weaknesses of Technical Evaluation.

Strengths	• Can also measure passengers responses as a part of the on-site observation • Support control or monitoring feature to system operator and this enables to resolve some negative user responses • Empirical evaluation reflects the minimum values of benefit compared with the full implementation later
Weaknesses	• Can be labor intensive, and may cause significant expenses to be incurred; automated evaluation technique can reduce costs that are associated with this effort and increase the reliability of this approach. • Limited data acquisition at primitive stage of operation may yield biased or underestimated results to compare with the fully implemented stage.

2.4.2 Empirical Evaluation

Empirical Evaluation uses data collected on selected MOEs during the operational test. Underwood (IVHS America, Dec. 1992, b) divided this empirical evaluation methodologies into 6 areas. These are; 1) user operation and interface design (human factors research); 2) user perception and preferences; 3) user behavior and individual impacts; 4) direct traffic impacts; 5) higher order impacts; and 6) institutional factors.

1) User operation and interface design approach: This approach measures user-friendliness of the system and seeks the improvements in the design of the system. Typical MOEs in this approach could be travel time and speed variance, response time, and usability. An example of this approach is TravTek (Fleischman, et al, 1991).

2) User perception and preferences: This evaluation approach provides an assessment of the potential market for the system, whether the people will accept it and support it with public resources. The standard method involves stated preference surveys. Benjamin(1997) researched cause of ridership change after AVL implementation through the study of consumer questionnaire.

3) User behavior and individual impacts: This method is designed to measure the improvements in a transit systems performance and operation that result from APTS. The basic design of this method is generally a comparison of data collected on selected MOEs, such as user acceptance, equipment performance and reliability, safety and security, cost and revenue effectiveness. Baseline data are collected before the test and are then compared with data from the operation test. Two main types of comparison are used: before versus after and experimental versus control.

4) Direct traffic impacts: This impact evaluation approach assesses the contributions of APTS in improvements in traffic measures. MOEs for the measurement is number of single occupant vehicles during peak hours, traffic smoothing, accidents, transit/auto ridership, etc.

5) Higher order impacts : Higher order impacts such as air quality, noise, and fuel consumption are result from APTS but are largely unintended, uncontrolled or indirect (Underwood at al, 1992). These are given consideration in evaluations of operational tests.

6) Institutional factors: This approach specifically observes the institutional environment. This includes assessing the impact that ITS will have on the transit agency personnel, community goals, system architecture, and jurisdictional relationships. Spring et al (1997) conducted the empirical evaluation to assess the impact of winston-salem paratransit via before-and-after data sets. Benjamin (1997) researched cause of ridership change after AVL deployment through the analysis of consumer questionnaire.

Table 2.9 Strengths and Weaknesses of Empirical Evaluation.

Strengths	• The data collection from the empirical evaluation approach helps to calibrate and validate traffic models for other ITS operational tests, as well as the potential risk check-up. • The approach is useful in collecting data as a standardized measurement for additional improvements to the system. • Careful analysis from collected data enables planners to estimate variables.
Weaknesses	• The approach requires costly and tedious data collection procedure. • High quality of data analysis is required to reflect error term such as time span and environmental change during data collection procedure. • In the case of before versus after type comparison, the data may fail to show how the system affected any significant change in MOEs. Similarly, the data collected in experimental versus control evaluation may not provide an indication of the amount of change attributable to the system. • As data accuracy decides test results, additional quality control for the data processing procedure is needed.

2.4.3 Model-Based Evaluation

Model-Based Evaluations simulate the potential benefits and impacts of APTS. Models are used primarily in prospective evaluations to assess the future benefits of an APTS, considering trends in trip demand and market penetration of the system. Chang, G., et al., (1995) produced and tested models for adaptive bus-preemption control in the absence and presence of AVL systems. Researchers in California Polytechnic State University developed transportation management center simulation model with which they provided controlled environment and evaluated traffic management and operation alternatives (Hockaday, S., et al, 1997).

Table 2.10 Strengths and Weaknesses of Model-Based Evaluation.

Strengths	• Models provide flexibility in evaluating various APTS strategies without the added cost and risk associated with full deployment of a system
Weaknesses	• Using models to evaluate the effects of an APTS system requires travel demand(i.e., origin-destination) data that implies a massive data collection effort. • Simulation of APTS applications needs to include mechanisms for representing various types of systems and their capabilities. For example, ageographic update mechanism where a vehicle provided information to passengers on the next scheduled stop when passed a specific point in the simulated network would represent an AVL system. • Owners of the technology (i.e., software) may be reluctant to release their property to a model-based evaluation effort. For example, if the model uses parameters that do not represent the real world accurately enough then the results will not reflect the true potential of the system. • Public transportation is not a closed loop control system. Decisions by user of the system can neither be simulated, nor can the decisions by non-users of the system be expected to remain in static equilibrium • Models can not account for changes in travel demands resulting from other impacts on public transportation(i.e., land-use policies)

2.4.4 Subjective Evaluation

Concerning the benefits of the APTS application compared to the cost of the system, a subjective evaluation of the project should be made at some point in an operational test with information from the other evaluation techniques. Cost/benefit analysis (CBA) is commonly used to aid decisionmakers in assessing the feasibility of proposed projects. CBA involves the quantification of the time stream of costs and benefits as determined through technical, empirical, and model-based approaches. Morlok (1991) presented the benefit and cost evaluation tool for Advanced Vehicle Monitoring & Communication systems (AVM/C) for bus transit before the deploy of the transit system.

Table 2.11 Strengths and Weaknesses of Subjective Evaluation.

Strengths	• The information assembled in a cost-benefit analysis can provide decisionmakers with a summary net present value of a project • In cases where benefits are difficult to qualify, or if alternative projects are considered, a uniform level of benefits can be assigned and then projects can be evaluated based on cost.
Weaknesses	• Inherent to this approach is the difficulty in qualifying certain benefits and costs, such as the value of a life and the need to conduct a qualitative or social impact analysis • Cost/benefit analysis provides decisionmakers with one dimension of the investment, or investments being considered. This approach omits certain qualitative benefits in its analysis. • The benefits in a cost-benefit analysis are represented in dollar values rather than quantitative utilities such as, time savings in seconds or fuel consumption in gallons