Part of the “Evaluation of the Benefits of Automated Vehicle Location Systems” Project

Conducted for:
Wisconsin Department of Transportation

Center for Urban Transportation Studies
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EVALUATION OF THE BENEFITS OF AUTOMATED VEHICLE LOCATION SYSTEMS

A project conducted for the Wisconsin Department of Transportation
Executive Summary

Automatic Vehicle Location Systems give an agency the ability to track, record, and analyze how vehicles are performing in real time. These features lead to improvements in public service through better on-time performance and quicker response time to emergencies. The increase in the number of AVL systems in operation, from seven in 1985 to 46 in 1995, shows that there is a growing interest in the capabilities and the benefits of these systems. Even though the amount of information currently available on the different types of AVL systems is limited many new systems are planned for installation in the near future. From looking into what the current state of the art is for Automatic Vehicle Location systems, it was apparent that much of the information is quickly changing much faster than the literature available. In addition to this many documents also tend to overlap the basic information, such as how these systems work, but are unable to agree on particulars such as accuracy or cost information. An effort has been made to establish what the current state of AVL is and the following is a list of some of the report’s major findings:

1. Currently there are four types of AVL systems in service that have been utilized for locating vehicles. They are:
   - Global Positioning Satellites
   - Signpost technology
   - Ground based radio
   - Dead-reckoning

2. The most popular Automatic Vehicle Location system, based on data supplied by the Federal Transit Administration, is Global Positioning Systems. As of 1995 there were 10 systems installed with another 30 planned. These numbers significantly surpass the same figures for any other AVL systems during that time period.

3. Automatic vehicle location systems are comprised of three elements. The first element is locating hardware, which is the component necessary to identify the position of a vehicle on the earth’s surface. The next is the communication package, which takes the positional data and relays it back to the central office. And the final element is the computer display system, which reveals the location of the vehicle as it travels in real time.

4. Communication packages used in AVL systems consist of one of the following classifications:
   - Analog Radio
   - Digital Radio
   - Analog Cellular
   - Digital Cellular
   - Satellite technology
   The most commonly used of these communication systems is trunk analog radio. Although it is more cost effective when compared to the other types of communication packages it currently requires longer transmission times and additional hardware when used in an AVL system.

5. Computer display systems assist in the transformation of raw data from the field to a graphical representation in the office. Many of these systems perform additional features that further improve the reliability and usefulness of an AVL package. These include the best route or shortest path features, turn by turn route guidance instruction, and interpolating field data to match mapped streets. The last feature takes a vehicle’s position and matches it to the closest street. This eliminates the errors that normally might place a vehicle in the middle of a block and not on the roadway.
6. Automatic vehicle location systems are also part of a group of technologies called Advanced Public Transportation Systems or APTS. These are components that when used alone or with an AVL system provide additional services to riders and the agency. The following is a list of the individual categories that these technologies fall under, including:

- Fleet management and operation systems
- Traveler information systems
- Electronic fare collection systems
- Traffic management systems

As new information is made available, there will be a greater understanding as to what the best AVL system is. Currently the data shows individual agencies choosing GPS as their first choice for an AVL system and in some cases with other agencies even replacing existing AVL packages, for it. As new advances in technology occur the availability of GPS and other AVL products should increase as the price of basic systems decline.
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Transit agencies for years have faced a dilemma. Ridership is down, funding is becoming scarce, and the need to satisfy the customer and their expectations without raising fares is difficult. Reacting to the rider’s needs for on-time pickup and arrivals, matched with the need to assure safety at the same time is forcing many agencies to look in new directions for ways to offer better service while cutting costs.

Until recently many agencies were forced to consider decreasing service as a way to deal with fiscal problems. Much of this was in the form of cutting routes, decreasing operational hours, or increasing fares. Some of this thinking has changed however. With the introduction of new advances in technology, strides have been made in finding better ways to locate, manage, and plan the movement of transit vehicles. Using this technology has given agencies the tools needed to better manage existing resources.

Much of this new technology has been labeled as “Advanced Public Transportation Systems” or APTS. Under APTS there are four categories, which are used to identify the purpose of new hardware and software, being made available to agencies these are:

1. Fleet management/operations systems
2. Traveler information systems
3. Electronic fare collection systems
4. Traffic signal systems

All of the categories above are discussed more in Chapter V. With each of these areas under APTS comes a range of different products that can be utilized to improve transit service, planning, or management. However, when talking about APTS one technology is usually mentioned as the first step toward implementation of APTS. This technology is Automatic Vehicle Location or AVL.

Like the name indicates AVL is the ability to identify a vehicle’s location in real time. AVL works by tracking a vehicle, as it maneuvers on a fixed route or travels to a preset destination. To do this AVL uses a variety of hardware and software products currently available on the market. Eliminating the need for on the street inspections or for drivers calling out their location, AVL automates this process and offers additional benefits not available with traditional methods of locating.

**Basic Benefits of AVL Technology**

Many of AVL’s benefits come from being used to locate, manage, and plan for the most effective use of an agency’s vehicles. Using AVL to locate vehicles, in real time, is beneficial, not only for everyday operation but also when it’s critical. There are applications where it is essential that an agency know the precise location of a vehicle. These include the need to deal with criminal activity, medical emergencies, or mechanical breakdowns. Locating a vehicle while it travels is also helpful when there is a need to document its location. This can arise as in the cases of verifying legal claims, rider complaints, and driver performance. And one of the most important features is the ability to monitor on time performance.

AVL’s use as a management tool can be demonstrated through its ability to monitor and relay information back to the office as it is occurring out on the streets. Monitoring a vehicle, management can observe relations between bus performance for different times of the day and with different drivers. Using this data is beneficial for adjusting service schedules and managing staff. All of these are applications where AVL can help management make decisions about their operations.

In planning, AVL is a tool that allows an agency to evaluate and pursue new ways of adjusting their service. This includes examining how a bus performs on a new route through trial runs and adjusting headways of current routes based on the data collected. Using AVL, in planning will help an agency find areas that need to be improved on, so service is preserved, efficiency is increased, and operating costs are cut.
One of the primary reasons AVL is appealing to agencies is its application in cutting costs. Reducing the personal needed to manually locate vehicles on the streets along with the ability to monitor how a vehicle is performing on a given route are significant cost savings features. However, even though there are significant benefits to agencies to have an AVL system, the decision to purchase one is not without some drawbacks and risks.

**Basic Drawbacks of AVL Technology**

There are issues to consider when making a decision to install an AVL system. Some of these include evaluating potential benefits and risks to the agency. Questions like how reliable is an AVL system and how it will be accepted by employees need to be answered to avoid the risk of delays and setbacks. Its not having sufficient information to questions like these that will make installing AVL risky, especially when looking at the cost of a system.

AVL systems can be expensive. There is the cost of purchasing the AVL system package and then training personnel to use it. There is also the costs incurred for annual equipment updates and necessary replacement of broken hardware. Adding all of this together with the knowledge that fiscal budgets are tight, and that a new system doesn’t instantly start saving money, might leave an agency exposed to financial risk.

Along with the costs of a system there is the chance that personnel will object to it. Some people have strong feelings on being “watched”. Because of this a system like AVL is viewed as a threat or a tool that the agency will use to discharge unwanted employees. Fears by other personnel arise from having to deal with and learn new technology. Even today there are individuals that resist new ideas because they don’t want to change from a routine they have become accustomed to. Communication with everyone that is impacted by using AVL helps to set aside fears, and reduce the chance of delays due to employee objections.

Finally, even if costs and people are not an issue, there is a risk that an AVL system may not perform to an agency’s expectations. Under certain conditions AVL may not be very reliable. Locating vehicles in severe weather, in valleys, and in areas surrounded by high rises can lead to poor performance by certain types of AVL systems. In other cases the hardware supplied by one vendor may not be compatible with another. This would mean that as upgrades to a system become necessary, an agency losses the ability to choose among competing suppliers. However despite the potential drawbacks more agencies use AVL and have shown it to be beneficial and worth consideration.

**Objectives of This Report**

This report’s objective is to offer the reader an easy to understand yet useful guide to AVL technology. The report will not focus heavily on technical jargon but instead expose the reader to the basic components that make up the different AVL systems and present it in an easy to understand manner. Much of the report identifies the different AVL systems and their individual components, as well as advantages and disadvantages of each system. Furthermore, the various advanced public transportation systems (APTS) that are used in conjunction with an AVL package are also introduced.
CHAPTER 1: BASIC AVL COMPONENTS
OVERVIEW

Current AVL systems are broken down into three basic components: the hardware, a communication system, and some computer mapping or location identification system. Each component depends on the others to acquire and display the position of a vehicle. Working alongside these components are additional software and hardware devices that enhance AVL benefits and capabilities. Examples of the most frequently used add-on systems are Computer Aided Dispatch software and on-board emergency alert systems.

Location Hardware Components

Location components are the mechanical devices needed to identify a vehicle’s position in a given area. These mechanical elements consist of transmitting devices, which produce a data signal and receivers that identify that signal. The data signals are generated from orbiting satellites, local land-based radio, and from short-range transmitters built into pavement or other infrastructures. The receivers getting the signals are devices that scan the spectrum of available frequencies and respond to only the appropriate pulses. Once the signal is received it is relayed to a location where it will be processed. This happens on the vehicle or at the agency’s control room.

It is more difficult trying to locate a dynamic object, such as a moving vehicle. Problems occur when vehicles travel into areas where the location is concealed by vegetation, man made objects, or intense electromagnetic interference. These areas tend to mask the vehicle rendering it temporarily invisible. In addition to blind spots there are other drawbacks associated with each type of location hardware. Satellites, land-based radio, and other devices have different limitations that will be discussed later in this report. In the majority of cases the extent of these problems and their real impact on the system’s effectiveness does not become apparent until after it’s operational.

Communication Components

Vehicle communication components link the locating hardware to the mapping system. This is done using conventional radio, cellular, or another form of communication that is capable of transmitting data. It is not uncommon for the agency to use the same communication system package that it had originally used to communicate with its drivers before installing AVL. However, data transmissions take place on regular intervals, such as every few minutes or every few seconds. If an agency elects to use its current communication system, it will have to make sure that it can handle data and verbal transmissions that are taking place simultaneously.

Communication with a fixed location that has stationary components is simple compared to what is needed for a moving vehicle. When communicating to a fixed site from a fixed site, the medium that the data travels is in a solid state. This solid state communication is very reliable because of the consistence of the element it’s traveling through. A typical example of this is voice or data transmissions over telephone lines, which use a pulse traveling through a line. This is not the case in moving carriers. The state...
of the medium in which the data signal travels is in a gaseous state (the air) and the environment is in flux. This negatively impacts the reliability of the communication system. Many cellular phone users experience loss of communication or interference on a regular basis, due to changes in the weather, or their geographical location. It’s data that is lost during transmission that impacts the dependability of communication and ultimately the AVL system. Strides in technology continue to improve the reliability of communication systems. Increased frequency of the vehicle’s position will improve the dependability of an AVL system.

**Computer Display Components**

To display the location of a vehicle a mapping technology must be used. Current mapping systems are not only graphical representations of a city grid, but also intelligent software programs that are capable of understanding how each roadway in a street network relates to the others. After taking the data generated by a location device the mapping software must place the location of this vehicle on the street network. In some cases, it must also identify errors in transmitted data and make corrections to it. For example if a vehicle’s location is identified just off to the right or left of a street, the software system can correct this and move the vehicle’s location, on the screen, to the closest roadway segment. In doing this the map will show the vehicles on the streets and not in the middle of a block.

Obtaining these digital maps and computer software is not a complicated task. Digital maps of most cities are available from software vendors or can be constructed by digitizing. The TIGER files supplied by the U.S. Census Bureau are a good source for this data. In either case the software and map must have intelligence and the ability to take data from a locating device and display it’s position on a digital map. The firm supplying the location technology to the agency programs this intelligence, in many cases.

**Advanced Components**

When the hardware, communication, and software systems are working AVL can become the backbone for a list of other useful systems. Many of these additional devices are used to supply information to an agency about their customers or supply useful information to the riders. A few of these include

- Traffic Priority
- Automatic Fare Collection
- Traveler Information Systems
- Automatic Passenger Counters
- Emergency Alarms
- Engine Monitoring

Most of these components, like AVL, fall into the category of APTS or Advanced Public Transportation Systems and are used to provide better customer services and to help transit agencies make more informative decisions.
In 1996 the Federal Transit Administration (FTA) listed 58 AVL systems as currently in operation or planned for installation throughout the United States. Of these systems the four primary vehicle location systems were Global Positioning Systems (GPS), Signpost, Radio Navigation, and Dead-reckoning. These AVL systems are being used in combinations or as a stand-alone. Among the examples of systems operating in combination would be the Chicago Transit Authority who utilizes not only GPS but also Dead-reckoning to locate its vehicles. While in other systems like the Milwaukee County Transit System the only method of vehicle location is the deferential GPS.

GLOBAL POSITIONING SYSTEMS:

Description of Infrastructure

Global Positioning Satellites are the property of the US Department of Defense. Although originally created to serve the military’s need to locate vehicles on the battlefield and ships at sea, this technology has now moved into use by the private sector. The system utilizes a total of 24 high earth orbit satellites (11,000 miles), traveling in a spherical constellation, that broadcast two signals L1 and L2 every second. The two signals supply similar data except at different frequencies. The data consist of location identifiers and the precise time at which the signal was sent from the satellite. The time variable is essential to the success and accuracy of the system. Each clock on the satellite is capable of measuring time to better than a 10^-9 seconds. The clock in each satellite (each satellite has four, of which three are backups) is synchronized to the clock in a receiver on the earth’s surface. Thus by utilizing the signals generated by at least 4 satellites a receiver on the earth’s surface can calculate the pseudo-range and pseudo-velocity of the satellite by using the difference between clocks. This allows the receiver on the earth to calculate its position in relation to the satellites on a Datum. A datum is used because the earth is not a perfect sphere so the irregular shape of the earth must also be factored in and calculated to reduce the error. The most commonly used datum is the World Geodetic Survey Datum and the North American Datum (NAD). Both data are numerical equations used to “mathematically” represent the earth’s shape. The shape of the earth is complex, however, and neither datum is completely accurate for all locations on the earth’s surface. The one that best represents the curvature of the earth surface for North America is the NAD and therefore the most commonly used.

GPS Accuracy

GPS has proven to be very accurate, with a few exceptions. As mentioned before GPS is still owned by the United States Department of Defense (DOD) under the NAVSTAR Joint Office, and therefore is subject to shared use policies. Within any 48-hour period the DOD can choose to cut off and encrypt the signals coming from the satellites rendering them useless to the private sector. Although this could be expected during times of National Security, the DOD currently during times of peace also chooses to degrade the signals. This action is referred to as “selective availability” and accounts for the majority of error in the GPS signal.

Besides selective availability there are other errors that effect the accuracy of GPS. The most common error has to do with the receivers. The
synchronized clocks have to be precise. Errors in the clocks of more than $10^{-2}$ second could result in an error of almost 1,000 miles off in any direction. Most commercial clocks however are good to the $10^{-9}$ second. Other sources of error can come from the atmosphere and electromagnetic interference. However much of that is corrected by the use of two separate signals (L1 and L2). Other corrections to positional data can be achieved by the use of DGPS or “Differential”-GPS. In DGPS the position of a single point on the earth’s surface is known with a high degree of accuracy. A location difference can be calculated by comparing the actual location and GPS-determined location of the same known reference point. This difference between the actual and GPS position of this location can be used to generate a correction factor, which is then applied to all positions located by the GPS system until the correction factor is calculated again. In many instances this “known point” is generated by the agency that is using the GPS for tracking their vehicles. However in some states such as Minnesota, there exists radio transmission towers that have been erected by the state transportation agency for use as “known points” for purpose of transmitting correction factors in DGPS applications.

Cost of the System

The costs of the GPS components can vary widely depending on the degree of accuracy needed. For most small consumer needs the degree of accuracy is low typically within a few hundred feet and the price is fairly inexpensive, with less than $200 per unit. But for applications where the degree of accuracy is needed to be within a few meters the cost can vary between $1,000 to $5,000 per unit. Cost might also depend on other factors such as service agreements, purchasing of specialized versus interchangeable components, or service life of the equipment (how long the agency wishes to use a unit before purchasing the next generation of technology). When looking at these additional factors the final price per unit could climb to as much as $10,000.

Advantages and Disadvantages of GPS

There are several benefits to selecting GPS as a location technology. The largest advantage is that the most expensive part of the system, the satellites, is free. There is no charge to use the satellites and Department of Defense is currently in the process of launching new satellites, to keep the system in operation. Along with this, the satellite coverage is 98% over North America. This assures that there are at least four satellites available at all times. The only GPS hardware that an agency needs to acquire is the receivers.

The disadvantages of GPS come in the form of signal interference. The first form interference comes from the Department of Defense and their ability to introduce selective availability (SA) into the signal. At no time is there any guarantee that the signal will not be degraded to a point that an agency using the technology can no longer depend on the system. Nor is there any guarantee that the service will remain “free” to users. Another concern occurs when vehicles travel through “blind spots”, which are areas where the signal from a satellite can not reach a receiver. In these areas such as spaces between high rises and streets with dense tree coverage GPS will not work.

**GLOBAL POSITIONING SYSTEMS SUMMARY**

<table>
<thead>
<tr>
<th>Accuracy:</th>
<th>Within 100 ft. for most applications, could be within a few feet</th>
</tr>
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<tbody>
<tr>
<td>Advantages:</td>
<td>• Flexible not fixed to a single route • Satellites usage is free • Currently 98% coverage of North America is covered by satellites</td>
</tr>
<tr>
<td>Disadvantages:</td>
<td>• Signal interference in urban canyons and dense foliage • Satellites controlled by the Department of Defense</td>
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**SIGNPOST:**
Description of Infrastructure

For many years the most utilized method of vehicle location was signpost. This technology tracks vehicles as they pass specific points using a variety of methods, including utilizing short-range communication technology between the vehicle and the signpost. There are several types of signpost systems that can be used by an agency. Current varieties of signposts included optical scanners, magnetic strips, short-range radio, and beam emission. Each type of beacon has different power consumption rates and varying effectiveness under a variety of conditions.

Currently there are two methods for utilizing signpost technology. The first method is referred to as a “traditional signpost” system. This method uses the signpost as the short-range transmitter. When a vehicle passes by a signpost it acquires the signpost device’s ID through a short-range signal broadcasted by the device. Along with the signpost’s ID the vehicle also records the odometer reader at the same time. Later when that vehicle is contacted by the agency to give its position, the signpost’s ID, old odometer reading, and current odometer reading will be needed. The ID will indicate the last location of the vehicle and the differences between the odometers will indicate how far the vehicle has traveled since then. A current location of the vehicle can then be determined along the route. In the other method referred to as the “neo-traditional signpost” system the location device acts as the receiver. As a vehicle passes each signpost the vehicle’s ID is transmitted to the signpost and then relayed through to the agency. By knowing the site of each signpost and each vehicle’s ID the location of every vehicle can be monitored as they pass by a signpost. This method does not require additional information such as the odometer reading.

Signpost Accuracy

Signpost systems have a high degree of accuracy. When properly maintained the degree of accuracy for a signpost system can be within a few meters. Errors in the system typically occur due to mechanical failure, and lack of continuous maintenance.

Cost of the System

The manufacturers of signpost technology offer their products in packages. The average package includes the beacon, the receivers, installation fees, protective cases, and a power source. In most cases the common power source is a battery. The complete package for the location hardware varies in price depending on several factors. The most common factor is the number of receivers and beacons along with if the system is going to be a traditional or neo-traditional setup. Even once a system is purchased there is the additional long-term investment of maintaining the system. The average life span of a signpost battery is approximately 180 days. The current list price for a battery is $450 to $500 per unit.

Advantages and Disadvantages of Signpost

Signpost locating technology has many benefits over other newer technologies. One of the most significant is the system’s ability to eliminate “blind spots”. Since a vehicle needs to travel close in proximity to a beacon there leaves little in the way of physical obstructions that can mask it. This means that it can operate in areas of dense foliage and high-rise development. Also signpost technology has been operated in several major US and Canadian cities since the early 1980’s. Current signpost technology is not a “first generation” product but has been applied and continues to be improved.

Drawbacks of this technology have to do with how it is deployed. The beacons that make up a system do not allow the vehicle to be tracked if it should leave its fixed route. A vehicle that leaves a route outside the monitoring range makes it hard to locate and monitor. An
additional disadvantage is the need for continuous maintenance of the system to guarantee its accuracy, which leads to higher long-term costs. Without this maintenance the system will not perform to desired expectations.

**SIGNPOST SYSTEMS SUMMARY**

**Accuracy:**
Within 1-20 meters

**Advantages:**
- Proven Technology
- Has been in use for several years
- Good accuracy, little interference

**Disadvantages:**
- Continuous maintenance required
- Limited to a fixed route

**GROUND BASED RADIO:**

**Description of Infrastructure**

GBR or Ground Based Radio technology uses radio triangulation to locate vehicles. The system can operate with one or more antennas that broadcast a signal, in most cases broad spectrum to improve signal quality, which is then acquired by the vehicle. The low frequency waves along with an associated timing are used to calculate the vehicle’s position. One of the most common uses of GBR technology for location is Loran C. Loran C uses a low frequency wave that is generated by several towers that are synchronized to each other. Each station will transmit in an order and at an exact time in relation to the others, forming a pattern. A receiver that picks up the signal knows what the pattern is and can calculate its position based on the deviation from that pattern.

Loran C, which is maintained by the United States Government, under the direction of the Coast Guard, will be scraped by the turn of the century. Currently there are only three agencies that utilize Loran C technology. No additional new systems are planned.

**GBR Accuracy**

Under perfect conditions the best accuracy of a Loran C system is within 100 feet. However due to interference from other radio transmissions, atmospheric phenomena, and even overhead power lines, the real accuracy of a system, could be as much as a quarter of a mile off in any direction.

**Cost of the System**

There currently is no information available that adequately depicts the cost involved with purchasing or maintaining a GBR system. This could be due to the fact that few agencies actually use such a system and therefore little has actually been published.

**Advantages and Disadvantages of GBR**

The only advantage of a GBR system is that under good conditions it does work. However due to the number of potential factors that could cause interference, there is only a small chance that the system will give continuously reliable data.

**GROUND BASED RADIO SYSTEMS SUMMARY**

**Accuracy:**
From less than 100 feet to over 0.25 miles

**Advantages:**
- Proven Technology
- Not limited to a fixed route

**Disadvantages:**
- No continuously reliable accuracy
**DEAD-RECKONING:**

Description of Infrastructure

Dead-reckoning employs the use of simple mathematics principals for locating vehicles as they travel. In theory, if a vehicle’s starting point is known and its speed and direction are acquired, the location of the vehicle can be calculated in respect to the starting location. Early mariners first used this system of navigation as they traveled at sea. By using maps that located known land masses as starting points along with information on the wind and current speeds they could plot courses and arrive at a set destination. Today the electronic land navigation of dead-reckoning is done with wheel rotation monitors (for speed) and internal compasses (for direction). Although the principals are the same the paths are electronically monitored continuously by use of computers and data inputs for accuracy.

A Dead-reckoning system needs two different types of data, direction and distance traveled, to locate a vehicle from a given starting point. The first data type, distance, can be acquired by counting wheel rotations. Wheel rotation data can be acquired through three separate methods. The first method uses a system of tags placed on the wheel and a reader on the stationary inner wheel hub. As the wheel turns the reader counts the number of times it senses the tags. These data are then used to compute speed and distance traveled. The next method utilizes a chain mechanism. A chain or belt device is directly linked from the vehicle wheel to a smaller wheel on the reader. The reader acquires the distance traveled and speeds of the vehicle by counting the rotation of the reader’s wheel. In the last method a reader is linked directly to the vehicle’s odometer. In this way the wheel revolutions have already been counted so the distance traveled is known. Data on the vehicle’s direction can be acquired by using an internal compass. The on board compass observes the direction the vehicle is positioned. Both data components are needed to estimate the location of a vehicle with some degree of accuracy.

Dead-reckoning Accuracy

In the early mariner days of navigation and world exploration, where the concepts of dead-reckoning were originally developed, the need to constantly correct the course of the ship was needed to keep it on course. Similarly with today’s modern mechanically driven dead-reckoning systems there is a need to “correct the course” to retain the system’s accuracy. Although in theory dead-reckoning can be an accurate method for navigation, 3% linear error and 10% directional error for every 5 miles traveled can occur. These numbers can be improved by increasing the frequency of new starting points. By resetting a new starting point, at given locations, a more accurate position of the vehicle can be acquired. The longer the vehicle goes without being checked the larger the errors will be.

Inaccuracies in the system occur due to several factors. Among the most influential of those is the terrain in which the vehicle is driven. Steep or hilly terrain could lead to inaccurate distances traveled. Distance data acquired as a vehicle travels on an incline will be different than a horizontal map distance. Also loss of wheel traction, resulting in the tire slipping, as well as vibrations from roadway surface defects can contribute to additional error that must be corrected by checking the system or to set a new starting point.

Cost of the System

Currently there is not much information available as to what a dead-reckoning system costs. Although there are a large number of vehicles that use this technology they are primarily in military service. In other circumstances this technology is not utilized as a stand-alone system but rather as a supplemental system. In the case of the Chicago Transit Authority GPS is the primary system used to locate vehicles in real time. Dead-reckoning is used primarily to locate their vehicles in the urban canyons of downtown Chicago. With the dead-reckoning system in place even in the shadows of Chicago’s tall buildings the transit
agency can follow and track its vehicle movements.

Advantages and Disadvantages of Dead-reckoning

Dead-reckoning has several advantages over other methods of AVL. The first advantage being that it does not have to rely on location hardware outside of the vehicle. Since the components that track the transport are all on the vehicle the system doesn’t have to rely on outside mechanisms such as satellite or radio transmissions to give it a location. The only time dead-reckoning needs assistance to locate the vehicle is when it is verifying its location. If a vehicle’s location is verified frequently the accuracy can be comparable to other AVL systems.

However there are also disadvantages that degrade the usefulness of the system. The first of these include the fact the errors will accumulate with the amount of distance traveled if left unchecked. Next the system proves more difficult to track vehicles if they move off fixed routes. When a vehicle is on a specified route the exact position can be known, however if it should leave that route the best a dead-reckoning system will be able to do is to indicate an area that the vehicle is in.

**DEAD-RECKONING SYSTEMS SUMMARY**

**Accuracy:**
Within 200 to 250 feet

**Advantages:**
- Self contained on vehicle
- Very accurate over short distances

**Disadvantages:**
- Errors grow exponential without correction
- More difficult to locate vehicles of fixed routes
- Components difficult to transplant into another vehicle

**Current Trend in AVL Systems**

The current trend in AVL systems shows growing interest in utilizing GPS technology. According to the Federal Transit Association there are 10 systems currently using GPS and additional 30 new systems planned. These numbers show GPS will become the most widely used of the AVL systems in the coming years. The next most utilized system is Signpost. Signpost systems, as of 1996, had 14 systems in operation, (more than GPS at the time) but only three new systems planned. The other systems such as Dead-reckoning and Radio Navigation together only had four in operation with another three planned. This would appear to make the use of GPS and Signpost technology the primary means of vehicle location.
CHAPTER 3: COMMUNICATION SYSTEMS

Good communications between the components in the field and at the office is critical to the successful operation of the total AVL package. There are currently many types of communications packages. Some of these include traditional radio, analog cellular telephone, and advanced digital telephone technology. Each of these systems undergoes improvements as advances in technology continue.

The Need To Use Communication Systems

Most AVL location technologies use computers on the vehicle to receive, analyze, and then calculate the position of a vehicle. This process happens on a continuous basis so that a vehicle’s real time location is known. Positional data once computed needs to be relayed back to the agency where the vehicle’s location will be displayed on a computer generated map. The communication between the on board computer and the agency requires a fast rate of data exchange, since the on board computers are generating continuous streams of data on multiple vehicles.

Types of Communication Systems

The major communication systems available for utilization in AVL applications consist of Radio, Cellular, and Satellite technologies. These systems currently use transmission towers or orbiting satellites to link vehicles and agency centers. Each of these technologies is explained in greater detail below.

RADIO TECHNOLOGY

Currently conventional radio is the primary means of communication in use by many agencies. The typical radio frequency is in the range of UHF 400-500 MHz and VHF 25175 MHz. Some systems utilize shared airtime with other commercial users in the same geographical area.

There are two types of radio transmissions analog and digital. Both are in use in the United States by different agencies. But each has a different method for dealing with the requirement of data transmissions.

Analog systems are typically what are in use at most agencies. In analog systems the voice of the dispatcher and the driver is transmitted over the air. This system is good for verbal communication but is insufficient, by itself for data transmissions. The current way that data is transmitted over these systems is similar to that applied by most office fax machines. Such transmissions are characterized by high-pitched ringing and squealing. The data is converted from digital form to a sound, which is transmitted over the air, and then translated back to the digital form at the receiving end. This method leads to slow transfer rates due to the extra time needed to convert and translate data. Another problem exists in “switching” between data transmission and voice on the same channel since only one (voice or data) can use the channel at any given time. In a larger agency a trunked radio system may be used to deal with this problem. In trunked radio system several channels are used instead of one. A central control station receives a call and assigns an open channel. Once the call is done the channel is again open to be reassigned to the next call. Each call that comes in receives its own secure and private line for any length of time needed. A variety of tasks including both voice and data transmissions can be accomplished simultaneously.

To accommodate the need to transmit voice and data communication between an agency and their vehicles a switch or data conversion is employed. This can be expensive, and may be more practical to evaluate if a separate line can be installed for data streams instead of interweaving data and voice.

A Digital radio system is more adapt at handling data transmissions although more expensive than analog. In digital radio a method of Time Division Multiple Access or TDMA is applied. The data is sent in its digital form (no converting) in time bursts usually milliseconds, leaving the remaining time to be utilized for
voice communications over the same channel. Since data and voice are digital the radio can split time between the two different signals, transmit the pulse, and then recombine them in a useable form at the receiving end. This means less airtime required since both voice and data can use the same channel at the same time.

Radio transmissions exist in three distinct forms. These transmission forms are spread spectrum, shared spectrum, and FM/AM subcarrier. In spread spectrum systems the radio transmission is issued at a low power, over many frequencies, and relies on an intelligent receiver to decipher the information. Due to its low power it does not currently need Federal Communication Commission licensing. In shared spectrum the transmission is shared among a group of users. This takes advantage of the fact that airtime is not utilized 100% by most agencies. This allows for an agency to share the same spectrum and the cost with additional commercial interests. In FM/AM subcarrier systems the agency does not secure its own frequency but rather it rides or “piggy backs” on an already existing radio signal, such as a local radio station. All these methods have varying degree of usefulness depending on what is being transmitted, how often, and what degree of reliability the agency requires.

**Cellular Technology**

Approximately 60% of the geographical areas in the United States have available cellular technology, which has lead to interest in using this as a communication system in AVL packages. Current cellular technology operates by bouncing a signal off transmission towers that form a sort of “honeycomb” network in a service area. The signal is received and relayed to specific “cells”.

Much like radio, there currently exist two types of cellular communications, analog and digital. Many of the same problems explained before are also encountered with this technology. However there are different solutions to solve the problem of transmitting data and voice at the same time over an analog system. The first solution is to utilize cellular sidebands called “sidebanding”. There presently exists between cellular frequencies a 3-kHz separation that is not allocated. This would allow the use of voice on one frequency and data transmission simultaneously on an only slightly different frequency, which a smart receiver could read.

Also there is the possibility of using a “blank and burst” method. In this way voice is blanked out for only a few milliseconds while a data burst is transmitted. This allows voice and data to use the same frequency. Where the previous two methods have tried to find ways to transmit data over the same or very close frequencies the final method operates outside of a secured frequency. Cellular Digital Packet Data uses idle or inactive channel space on a cellular transmission system. This allows CDPD to transmit on a range of frequencies, utilizing any one that is available. To do this it also requires a receiver that can scan those frequencies to capture the signal. Digital cellular, in contrast to the methods applied to analog above, does not need any of these special techniques. All transmissions are translated into data bits. This allows any data or voice message to be encoded, broken down, transmitted, and reconstructed on the receiving end without the need of special techniques.

Cellular technology is an expensive technology to use in an AVL package. Typical cellular expenses are generated based on the amount of airtime used. In AVL packages that relay positional data on a continuous basis, the charge for airtime will be excessive. In other AVL packages where the need to locate a vehicle is only a few times per day, the air time expenses are likely to be more reasonable, and comparable to a radio system that transmits continuously.

**Satellite Technology**

Satellite communication systems are a technology that will be the next step in telecommunication. This technology moves away from the need to install an increasing number of transmission towers and instead invest in only a few satellites that orbit the earth giving much better coverage.

Satellites currently are categorized as two types. The first is a GEO satellite. In this type of earth orbiter the satellite is placed in a path and with a velocity that is in sync with the rotation of the earth. This maintains the satellite’s position over a specific area at all times. GEO systems are capable of handling both data and voice communications. However since the altitude of these space vehicles is approximately 36,000 kilometers the only way of communicating with them is through high powered antenna. The second type is called LEO. In this type the satellite is at a lower orbit, approximately 800 kilometers which would allow it to communicate...
with hand held devices. This type of satellite is used to relay data only and is low power.

**Communication Systems Summary**

In transit agencies today, the most common method of communication is still analog radio. This system remains one of the most economical form of direct communications available, when compared to the other options mentioned earlier. However, analog systems are not considered by many to be efficient or reliable enough for use in AVL systems. This is because of the need to translate data from digital to sound. This process of translation requires additional time to process (the data) and additional airtime to send it. In the future it is more likely that digital radios with their ability to take data in its digital form and transfer it faster will eventually replace analog.
The final component in an AVL system is a computer display system. Once the vehicle has been located using location hardware, its position calculated, and then communicated to the agency it must be located on a map. Computer maps are responsible for taking the information being supplied by the vehicle and displaying it on a digital roadway database. Many of these digital maps are sold as part of the total AVL package.

Digital Map Databases
The digital map database, needed to display the vehicle locations, can be obtained by an agency in several ways. The easiest way is to purchase the map information. Currently there are several vendors that sell digital maps throughout the United States. The maps can vary in price depending on what information or the amount of information that is being required. The coverage of these maps is good but also limited. Updating city grid information, when new street are constructed, will require additional personnel training, unless a service agreement is made with the map supplier. Additionally, most map suppliers are limited to larger metropolitan areas. For smaller, less urban areas there may not exist ready-made large-scale digital maps. Agencies in smaller urban areas may have to create their own map databases. This can be done in two different ways. The first is by digitizing current street patterns from local maps and creating the database from scratch. This is a time consuming process that requires commitment and a capital investment. The other way to create a map database is by purchasing it from the Federal Government. The Federal Bureau of the Census compiles digital map data into TIGER files. These files contain roadway information that can be used to create a crude local route map database. Local agencies will need to clean and enhance the TIGER file for AVL use.

Once the initial database is available there are a range of functions that digital maps can perform. Some of these can be grouped into the following:
- Geocoding Street Addresses
- Best Route Information
- Route Instruction

Each of these is used to increase the accuracy and usefulness of the overall AVL system.

Geocoding Street Addresses
This basic function of digital map is to allow a vehicle to be located as it travels along a given path. To do this, streets in a digital map are stored not as graphical lines but rather as a series of address ranges with directional orientations. In this manner a street’s address ranges can be converted into longitude and latitude, with the location of the vehicle linearly interpolated along that line. This allows the vehicle’s location to be shown between address ranges.

Geocoding using the linear interpolation mentioned also allows a digital map to perform “snap to” calculating. Because the AVL locating hardware is not completely reliable, many times the location of a vehicle does not fall within the address ranges of the digital database. Rather than displaying the location of the vehicle in the middle of a city block a digital map can use its geocoding function to “snap to” the nearest street location that matches the position of the vehicle. This allows for a better graphical presentation of the vehicle’s location. Without this feature, it might appear that a vehicle traveled near to, around, but never always on the street it was intended to.

Best Route Information
Because information on each street in a network is stored as numeric data with an orientation it is possible for a computer to use this to derive directional information about one street in relation to another. This is seen in the computer’s ability to take a digital map and perform a best route or shortest path calculation between two points. In the event an agency’s vehicle needs to travel to a destination in the shortest period of time possible, this function would be beneficial. The digital map not only has stored information about how a street is orientated in the real world but also how that street is orientated to other roads as well. This allows the computer to derive the best path for a vehicle to take given that the destination and the street network are known.

Routing Guidance
Route guidance is the function by which the agency uses the digital map to guide a vehicle to its destination. By using this the digital map tracks a vehicle as it proceeds along a path toward a preset destination. As the vehicle is traveling the map will send out directional information such as when to turn and how far the vehicle needs to travel until the next turn. Using this function the vehicle is not just being tracked by the digital map but are directed to their destinations.

**Computer Display Systems Summary**

Current computer display systems utilize digital maps. These maps are purchased or created and can perform different functions to contribute additional benefits to an AVL system. These benefits might be “snap to” location for vehicles, best route information, or route guidance. Together with the location hardware and the communication system the computer display is the last component necessary to have a working AVL system
CHAPTER 5: ADVANCED PUBLIC TRANSPORTATION SYSTEMS

Automatic vehicle location systems are only one of the new advanced technologies that are being utilized by agencies. These recent technologies known as Advanced Public Transportation Systems or APTS center around the need to gather information and promote more effective public service. Many of these new systems can operate as stand alone or in conjunction with an AVL package. In this chapter the use of these systems in combination with an AVL system is explored.

Advanced public transportation systems can be categorized into the following:
1. Fleet Management and Operation Systems
2. Traveler Information Systems
3. Electronic Fare Collection Systems
4. Traffic Management Systems

I. FLEET MANAGEMENT AND OPERATION SYSTEMS

This category of systems focus on the agency’s need to monitor its vehicles in the field. This includes the need to observe events on the vehicle as it travels and pinpoint the vehicle’s location, when needed. The following is list of the current technology that can be found in this category.

Silent alarms: These are alarms placed near the driver, which can be activated to alert officials when an emergency has occurred. Primarily a safety feature used to alert the agency if criminal activity, medical emergencies, or a vehicle accident has happened, it becomes a more powerful system when used in combination with an AVL package. In this form when activated not only will the agency know in which vehicle an incident has occurred on but also where it is located, without having to contact or compromise the driver’s safety.

Audio and visual equipment: This is equipment used to monitor the activities that are happening on the vehicle. They are used as a legal tool to record criminal activity. They also prove beneficial in monitoring the individuals on the vehicle during an accident to identify individuals that were actually on the vehicle. Again when used in combination with AVL package the system can not only record the events that are happening on the vehicle but also the location of the vehicle when the incident happened.

Computer Aided Dispatch Software: A computer aided dispatch system is used in conjunction with AVL to monitor and dispatch vehicles on demand. In addition to fixed route service it is also used by taxi and para-transit services. AVL allows an agency to locate where a vehicle is in location to pick up or drop off points so that quicker and more efficient service can be offered.

Geographical Information Systems: Also know as GIS these systems are used by municipalities to track and analyze a variety of information. GIS is widely used to analyze existing services and its associated demographic conditions. Similar information in turn can also be used to locate and plan new routes. By locating the regions of a city with the highest volume of population and greatest potential for ridership new routes can be planned or existing routes adjusted. AVL systems can take advantage of GIS as well. New programs are available that allow AVL systems to use a GIS package as the computer display system. This allows the agency greater capabilities to display and interpolate information that is not available with most standard digital maps.

Automatic Passenger Counters: Counting the number of passengers getting on or off the vehicle at a given location and at what time can assist the agency in modifying its services. This can be done by two methods. The first uses infrared beams that when broken can detect and record the movement of a passenger on or off the vehicle. The other method is activated by pressure generated by the movement of a passenger’s foot moving over an area. The direction of the movement also gives an effective way of counting the number of passengers arriving at or getting on at a given stop. AVL systems that are
joined with automatic passenger counters allow the agency to retrieve information on how many individuals get on or off on any given stop.

II. TRAVELER INFORMATION SYSTEMS

This category of systems is used primarily to inform the current passengers, or potential passengers of information they will need to get to their destination. “Information” could include when a vehicle is scheduled to arrive at a certain stop, if a vehicle is running behind schedule, or what the next is. The following are a list of systems that can be found in this category.

On Board Visual Display Panels: Current forms of this technology involve on board panels that scroll through information for the benefit of the passengers. These displays can be a mono- or multi-color arrangement and utilize a matrix of small light emitters that when signaled together can form pictures, words, or animation. One use of these panels is the “next stop” display. This provides a visual announcement of what the next scheduled stop is. AVL can improve the accuracy of this function. When the location of a vehicle is known the next stop can be calculated and displayed. The current system uses a clock to guess at where the vehicle should be along its path.

On Board Announcers Systems: These systems use prerecorded announcement to verbally indicate important information to passengers, such as next stop and time to arrival. Advantages of such a system over the visual display boards is that they can be utilized by the vision impaired. One disadvantage is that they can become annoying to riders if the announcements are set on a short repeat cycle.

Smart Kiosks Systems: These devices are located at pickup/drop-off locations and offer a variety of information to the traveler. Information can include when the next vehicle will arrive, what other modes of transportation are available at the traveler’s destination, and what are the connecting routes and times. These devices are usually connected to the agency by a communication link so that up to the minute information can be made available to the traveler.

Automated Telephone Information Systems: This system takes advantage of a caller’s touch-tone phone to direct the individual to the information that they request. These systems utilize prerecorded announcements for each step, which are stored on a digital medium. This digital storage allows the same recordings to be played simultaneously on different phone lines if necessary. This system is also refereed to as an electronic operator.

Internet Information System: As the growth of the Internet continues individual access to it will also grow. This will allow more people to check the schedule of a vehicle, routes, transfers, and even see it traveling in real time, to help them make more informed travel plans.

III. ELECTRONIC FARE COLLECTION SYSTEMS

One perception of the average passenger is that a vehicle trip costs too much. This is primarily because the rider is asked to pay each time that they use the service. This can also lead to frustration on the part of the rider since they may not possess the exact fare needed to ride. The advantage of electronic fare collection systems is that they do not require the rider to have the exact fare but to only have available an identifier (ID) card that can identify and bill them at a more convenient time, instead of at the fare box. There are two types of methods that can be found in this category.

Contact-less Smart Cards: This card utilizes a system similar to the anti-theft tags used by major department stores. In each card, registered to a specific passenger, is a small “tag” with a unique identifying code. When this tag comes into close proximity with the reader (located at the fare box) its code is scanned, read, and recorded. At the agency the tag codes are linked to the individual that it was released to and after a period of time, a bill is sent to that individual. The advantages of this system are that the agency doesn’t have to deal with money as often and that people don’t need to carry money.

Contact Smart Cards: The primary difference between this method and the one above is that here the card requires the rider to swipe it through a reader. The smart cards in this method primarily use a magnetic strip in the
back of the card that contains the id code. The code is recorded and handled very similarly to the method mentioned above.

IV. **Traffic Management Systems**

This category of systems concentrates on how to move a vehicle more efficient through traffic. This is done in a variety of ways. Currently the most utilized method is through geometric design, which guarantees designated space on a road to high occupancy vehicles. But there is another method that is starting to be used to move a vehicle more effectively on streets that do not have special lanes. This method is Signal Preemption.

**Signal Preemption Systems:**

These systems use a communication link between a vehicle and existing traffic signals to give priority to the vehicle as it approaches a set of lights. In this way if a vehicle is running behind schedule, the traffic signal activated by the vehicle and can adjust the traffic lights to offer more green time. Thus the vehicle will be given a priority and allowed to pass without stopping.
CONCLUSION

The current state of the art for automatic vehicle location systems combines positioning hardware, a communication package, and a computer display system to monitor and track a vehicle’s movements in real time. The advantages to the agency that uses AVL is the ability to observe, collect, and analyze information about a fleet’s performance as it travels in real time. This data give an agency the ability to make better and more informed decisions while also providing quicker response to emergencies. The benefits to the rider mean better on time performance and less waiting. The exact extent of how beneficial AVL is, depends on how an agency chooses to apply this technology, so results will vary between agencies.

Currently of all the available AVL systems the one that is drawing the greatest attention is Global Positioning Systems or GPS. With nearly double the number of new installations planned over all other types of AVL packages, it appears to be the preferred location technology. GPS allows an agency the ability to track its vehicles on or outside of fixed routes with nearly 98% satellite coverage of North America. The disadvantages of GPS come when the line of sight between the satellite and the vehicle is broken. GPS can not operate in areas of dense foliage or extremely tall structures.

Before GPS was available, signpost technology was the most widely used location product. This technology still requires a heavy investment due to the expense involved with equipping not only the fleet but also modifying the existing infrastructure. Signposts are activated by the close proximity of a vehicle mounted with a receiver or transmitter. This allows signpost technology an advantage over other packages. The fact that the line of sight between a signpost and the vehicle is small decreases the chance of interference by large structures. However the need to monitor the system and continuously maintain it requires more personnel than other comparable systems.

One of the first forms of AVL technology being used by agencies to track vehicle movements was the Loran C or ground based radio system (GBR). This system applied radio triangulation to acquire a vehicle’s position. GBR utilized a very simple technology. However the accuracy of this system is not consistent. There are a variety of factors that interfere with radio transmissions and these also degrade the usefulness of GBR. In the near future the current system of radio towers originally maintained by the US Coast Guard will be scrapped. This explains the reason for way there are no additional system planned.

The last type of AVL system is the only one that relies on components all stored on the vehicle. In a dead-reckoning system there is no need for outside radio, satellite, or short-range transmissions. The entire system resides on the vehicle. In this type of system an internal compass, gyro, and wheel rotation information is used to calculate a vehicle’s position from a known starting point. The mathematics that is utilized to calculate the vehicle’s position is very precise. However due to the limitation of hardware the actual result is less than precise for long distances.

In the market today there are several types and versions of AVL available to chose from. Each has its own advantages and limitations. Agencies need to evaluate what systems are right for them and budget for installation and maintenance costs. Through planning, evaluation, and reasonable choices does the full benefit of this type of technology pay off, not only for the agency but also for the rider.
REFERENCES


