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COST-BENEFIT ASSESSMENT OF IMPLEMENTING AUTOMATIC VEHICLE LOCATION (AVL) IN KANSAS DEPARTMENT OF TRANSPORTATION'S MAINTENANCE VEHICLES

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OCTOBER 2002

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KANSAS STATE UNIVERSITY
THE UNIVERSITY OF KANSAS

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16 **Abstract**

Technological advances in computing, communications, and locating systems have been applied to a broad spectrum of the responsibilities shouldered by KDOT, including maintenance activities. However, even though one specific technology—Automatic Vehicle Location (AVL)—has been thought to have significant benefit for maintenance operations, investing in the technology has been difficult to justify because the benefits are not easily quantifiable and little hard data exists related to the benefits of applying AVL to highway maintenance. This report describes the technologies associated with AVL, discusses a national survey of transportation agencies conducted as part of this work, and presents an analysis of the costs and benefits of implementing AVL for use in KDOT maintenance vehicles and striper trucks.

The survey included all state DOTs, Canadian provinces, and municipalities thought to have implemented AVL. Of those surveyed, 15 had implemented or were in the process of implementing AVL for maintenance activities, 12 of those citing snow removal as their primary application. Chapter 4 discusses some of the specifics of each implementation. All implementations were considered beneficial, but none of the implementations included a quantitative study of the benefits.

In the absence of any before and after data related to AVL implementation in highway maintenance activities, the benefit/cost analysis was based on conservative assumptions relating to the types of benefits identified (qualitatively) through the survey. Conservative estimates of snowfall, accident rates, and the effect of AVL on snow clearance times were used, along with some averages of estimates provided by survey respondents, such as time savings from reduced paperwork. These conservative assumptions resulted in B/C ratios ranging from 2.6 to 3.0 over 20 years, depending on the implementation schedule. Moderate assumptions were also applied to better represent the results that can be reasonably expected (though still leaning to the conservative side). The resulting B/C ratios ranged from 24.3 to 28.4. Most likely, the savings in operational efficiencies alone would more than offset the cost of system implementation and maintenance. While the initial capital costs are substantial, the results of this study show that AVL for highway maintenance operations is a worthwhile investment.

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Final Report

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A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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CHAPTER 1: INTRODUCTION

Automatic Vehicle Location (AVL) systems are a fleet management tool that integrates several technologies to allow a fleet manager or dispatcher to see the location of their vehicles at any given time. Many systems can also indicate the status of each vehicle. For example, a law enforcement dispatcher can be informed whether a vehicle is in service, on break, or in hot pursuit. A snowplow can automatically report whether the plow is up or down, and when it is spreading sand or salt. Putting this kind of information at the hands of managers enables them to make more efficient use of their resources. Both public and private agencies are taking advantage of AVL to enhance both the efficiency and the effectiveness of their operations. AVL has been widely used in the trucking industry for several years. Many transit and emergency service agencies have also implemented AVL. Use among highway departments has been sparse, possibly because the benefits in that context are less obvious, but several state Departments of Transportation (DOTs) and municipal Public Works departments have implemented AVL and found it to be a valuable tool for maintenance and operations activities.

Many AVL applications incorporate Mobile Data Terminals (MDTs) to allow users to wirelessly send and receive textual messages, much like Email. Most AVL systems allow a limited number of predefined messages—or, perhaps more accurately, status codes—to be sent from the vehicle to the control center. The combination of AVL and MDTs can provide a central control system with immediate contact to the vehicles, help reduce voice communications between drivers and the control center, reduce communication errors, and automate some record-keeping functions formerly performed by hand.

The improvements in mobile data systems over the last decade have been tremendous, and, driven by the ever-accelerating pace of technology, they are continuing to improve with respect to both hardware and software. Their advent in the highway maintenance industry is opening new doors to increased productivity and more cost-effective operations.

1.1 Historical Perspective

The AVL services industry was born when Qualcomm launched its OmniTRACS service in 1988. Providing vehicle tracking and data messaging, the service primarily targeted the long-haul trucking industry. Although OmniTRACS continues to hold a commanding share of the AVL market, especially in the trucking industry, a number of rivals emerged, including Highway Master, InTouch Communication, American Mobile Satellite Corporation (AMSC) and Orbcomm. (Beckert, 1999)

Most of these companies rely on the same technology, Global Positioning System (GPS), for their geolocation function. In contrast, a variety of wireless technologies are used for communications. OmniTRACS, for example, leases capacity on geo-stationary satellites. HighwayMaster and InTouch use analog cellular telecommunications. AMSC relies on a hybrid system that operates over both its geo-stationary satellite and the ARDIS terrestrial data network. In November 1998, Orbcomm began offering commercial vehicle tracking services that use its constellation of 28 Low-Earth Orbit (LEO) satellites for communications. Teletrac uses a dedicated radiolocation network. (Beckert, 1999)

Since Car Trace Inc., of Irvine, California, was issued a patent in 1996 for its vehicle monitoring technology, several other companies have developed similar systems that automatically notify emergency response agencies when the vehicles they are monitoring have been stolen or involved in an accident. (ITS America, July 1999)

1.2 Highway Maintenance Application of AVL/MDT

In 1998, the Virginia Department of Transportation (VDOT) implemented an AVL system that allowed snowplow managers to better manage snow removal in four counties. (Castle Rock, et al, 1998) The Smart Plows utilize ITS technologies to monitor vehicle location, road surface condition, and apply the appropriate amount of chemicals or sand to treat the roadway. The goal of the system was to facilitate the following functions.

1) Continuous location of snowplow fleet operations
2) Ability to identify vehicles with abnormal behavior
3) Increase safety for the vehicle operator
4) Ability to detect and minimize waste and fraud
5) Ability to capture statistical data
6) Improved communications efficiency.

These benefits are typical of those expected by other highway departments who have deployed AVL. In general, the consensus seems to be that AVL can deliver all of these benefits, although quantitative data is not yet available.

1.2.1 Benefits of AVL Implementation

The benefits of implementing AVL for the purposes of highway maintenance are not well documented. Several implementations have conducted informal evaluations, but the goals and contexts of the implementations have differed enough to make any hard conclusions regarding the magnitudes of the benefits impossible. For example, the results of an implementation to aid with street sweeping in a metropolitan area has little implication on the benefits of an implementation to aid in regional snow removal. Likewise, the benefits of using AVL in winter operations in Minnesota are not necessarily indicative of the benefits that might be realized in Virginia or Utah. Even so, it is possible to identify the nature of some likely benefits and perhaps make some assumptions regarding their magnitudes based on the responses to the survey of maintenance departments, conducted as part of this study. Chapter 4 discusses implementations of AVL by transportation agencies, and Chapter 5 presents a cost assessment based on the results of other implementations, tailored to reflect likely benefits for an implementation in Kansas.

1.2.2 Benefits of Mobile Data Terminal Integration

Even less information is available regarding the incremental benefits of integrating MDTs with AVL than is available for AVL itself. Again, the survey of maintenance departments across the country (Chapter 4) provided some insight. Likely benefits would include:

- Messages can be delivered even if the receiver is not in the vehicle. (i.e., messages can be stored and later retrieved by the recipient upon returning to the vehicle.)

- Communications can be reviewed at any time. (Particularly helpful for messages that involves numbers, distances, names, or locations.)
- For certain types of data, messaging is more efficient than verbal communications. Using MDT over a dedicated data channel reduces the load on the voice channels.
- Data can be entered in the field, allowing many processes to be automated.
- Data can be retrieved over the system without involving the dispatcher.

Nearly all contemporary deployments of AVL include integrated MDTs.

1.3 Forecasted Use of AVL/MDTs

The market for AVL systems is growing rapidly. AVL is being used by both public and private agencies. Trucking companies, transit agencies, emergency response agencies, and others are investing in AVL to get the safety, cost efficiency, and productivity benefits it offers. Competitors in both the AVL market and the telematics industries will need to overcome significant technological and marketing challenges in the years ahead, but regardless of how individual companies fare, the long term prospects for AVL are very good. (ITS America, July 1999)

Beckert (1999) cited a survey that indicated that the demand for AVL services and equipment was likely to remain strong in the ensuing five years. As shown in Figure 1, it was projected that the number of AVL devices used in the United States would increase from 430,000 in 1998 to nearly 2.2 million in 2003, with more than $1 billion in revenues. The survey also revealed that the level of market penetration among long-haul shippers was approximately 20 percent, limiting new growth opportunities in this market segment. Demand from private fleets and companies that have more localized operations, such as utilities, couriers, and local soda bottling companies, would likely drive future growth.

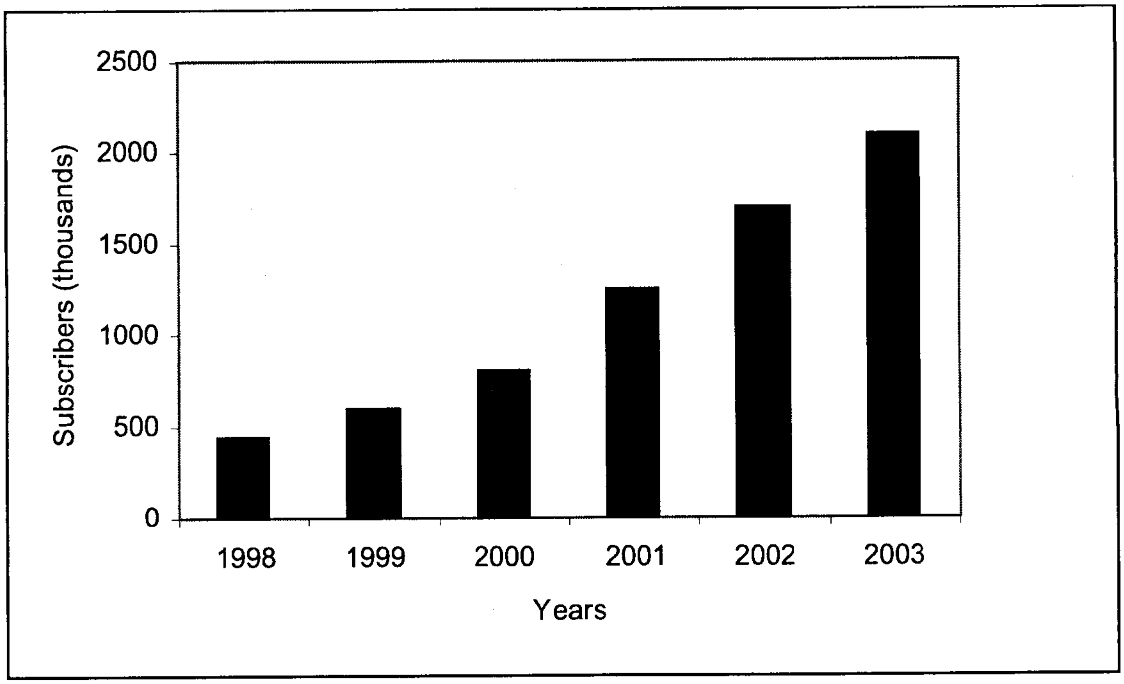


Figure 1. Projected Use of AVL (Beckert, 1999)

As shown in Figure 2, AVL is expected to play a huge role in the wireless data service industry. AVL revenues for commercial vehicle fleets and trailer tracking are expected to grow from $367 million in 1998 to over $1 billion by 2003. (TechnoCom Corporation, 1999)

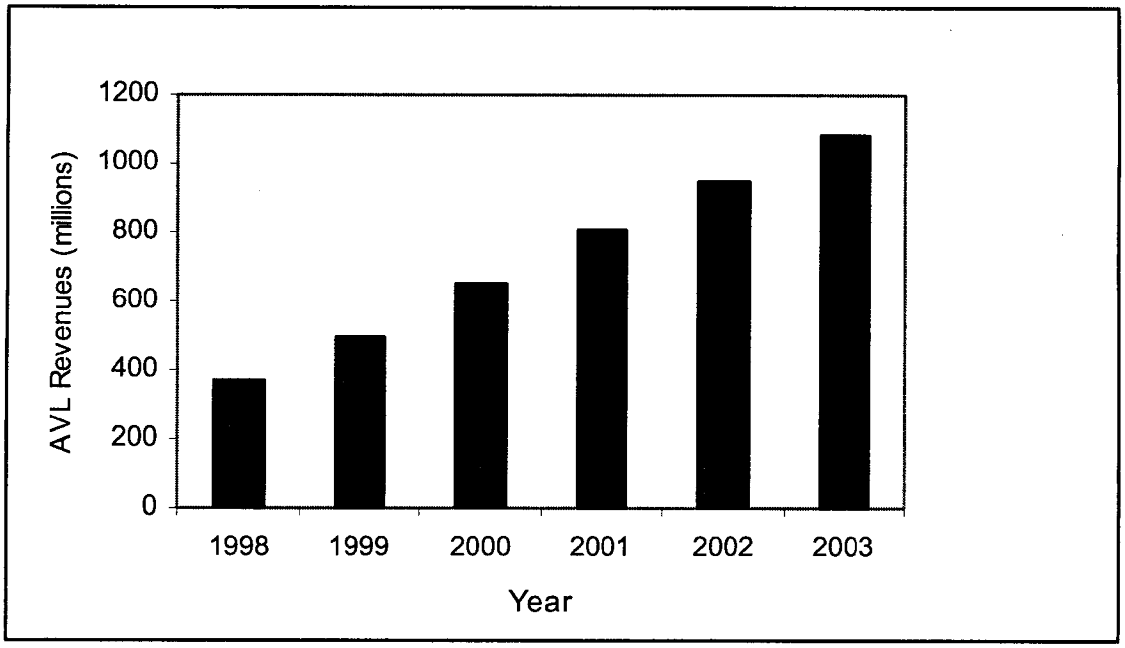


Figure 2. Projected AVL Revenues (TechnoCom Corporation, 1999)

While revenues and subscriber base increases and projected increases do not necessarily guarantee that AVL is a sound investment for highway maintenance agencies, it does confirm that the benefits are broad in scope and the associated technologies are likely to be well supported in the future.

1.4 AVL/MDT Cost-Benefit Analyses

As alluded to previously, the benefits of AVL are obvious in many cases, but the extent of the benefits is not easily defined. It is difficult to judge whether or not the benefits outweigh the costs of implementation and operation for a given application unless formal evaluation studies have been conducted in a similar context as that under consideration. AVL and MDT technologies have been deployed around the world by various types of agencies, but predominantly by transit agencies and commercial trucking companies. All too frequently, once an agency obtains approval to implement AVL, justifying the costs becomes a low priority. Evaluation plans are often sacrificed at the first signs of a budget shortfall. While that is understandable, it is often the result of a near-sighted perspective and is very unfortunate for the transportation community at large, particularly in the longer term as agencies have difficulty justifying investments in AVL because of the lack of documentation of benefits.

Many transit operators experience strong pressure to upgrade their fleet management systems with the latest AVL technologies. The many benefits of such systems have been very well publicized in numerous U. S. Department of Transportation (USDOT) publications. With a 45% annual return on investment reported as the cost effectiveness, these systems quickly end up paying for themselves. In that light, it is not surprising that there is a strong push for system procurement (MITRE, 1996). But it is noteworthy that this return of investment is for fleet management systems and not for highway maintenance operation purposes.

There are, however, some general principles that are worth considering in developing a strategy for assessing the potential benefits of AVL in a highway maintenance context. Schweiger C. L., and Marks J. B. (1999) have considered four critical parameters that must be determined for a cost-benefit analysis. Their particular concern was the use of AVL in public transit, but the principles have broad application across contexts.

1.4.1 Determination of Life-Cycle Costs

Determining the life cycle of a technology is difficult. For example, the National Architecture uses horizons for various transit ITS components that are longer than the traditional 12-year replacement cycle for a transit vehicle. Additionally, it has been suggested that electronic components on-board transit vehicles do not last more than seven years. Another factor in determining the life cycle of a particular technology is the stability of the standards that were used in its development and manufacturing. Moreover, translating the experience of the transit industry in AVL implementation to values appropriate for highway maintenance applications would be almost purely speculative in some areas because of the relatively limited experience of the maintenance community with AVL.

1.4.2 Methodological Approach to Cost/Benefit Analysis

Selecting the appropriate method of cost/benefit analysis is a challenge. Each method has strengths and weaknesses, depending on the following factors: confidence level of the cost and benefits data; the magnitude of the costs and benefits; and the importance of determining the marginal benefit of each technology over all the other technologies being considered.

1.4.3 Quantification of Risks

It is often difficult to quantify risks, but they can be quantified. There are several ways to incorporate them into an analysis. For example, if a particular risk, such as technological capability, could result in lower benefits, the analysis may be performed using a range of benefits. The benefits of the technology can be examined as "best case," or low or no risk; "medium case," which contains a medium level of risk; and "worst case", which contains the maximum risk. The best-case benefit would simply be the calculated benefit; the medium case benefit would be multiplied by some factor less than

1.0 to reflect some level of risk; and the worst-case benefit would be multiplied by a factor less than the medium case factor.

1.4.4 Assignment of Dollar Values to Intangible Benefits

It is a challenge to account for benefits that cannot be monetarily quantified. For example, it is presumed (although not yet proven) that there will be a benefit resulting from the collection of AVL data for planning and scheduling functions within an agency. Quantifying such a benefit in fiscal terms would be difficult even if it had been measured in some manner. It becomes completely infeasible when no data is available at all.

1.5 Computer Aided Dispatching and AVL

The use of Computer Aided Dispatching (CAD) using MDTs has allowed more contact between operators and supervisors and allowed dispatchers to attend to more calls. In Denver, the Regional Transportation District (RTD) implemented an AVL/CAD system, and found that the system resulted in an increase of 108% on the number of contacts between bus operators and supervisors because the system permitted the supervisors to contact operators directly instead of going through a dispatcher. (Stearns, 1999)

In Clark County, Nevada, where an Advanced Public Transportation System was implemented, including CAD/AVL, officials were pleasantly surprised by the financial benefits. With an annual rate of return of 21.6% on the 15-year service life of the system, the payback period was 5 years. Clearly the system has the ability to not only pay for itself, but to produce significant net cost savings for the transit agency over the lifetime of the system. (Ohene, 1998)

1.6 Background

In 1999, KDOT joined ENTERPRISE, a consortium of state DOTs that funds projects that promote the deployment of Intelligent Transportation System (ITS) applications in the rural context. In May of that year, KDOT proposed to the consortium a pilot project in which AVL would be deployed in a highway maintenance fleet for the purpose of evaluating the benefits in rural highway maintenance activities. ENTERPRISE did not approve funding for the project on the basis that deployments were ongoing. However, each of the ongoing deployments either were in a context substantially different from Kansas such that the benefits could not be reliably mapped to benefits likely to be realized from a deployment in Kansas, or else the evaluation was informal and would not be able to provide quantified benefits data.

Because of the shortcoming of ongoing deployments and the need to provide justification for capital investment in AVL technology, a proposal was submitted to the K-TRAN program in November of 1999 to conduct a cost-benefit analysis of the application of AVL to KDOT maintenance activities (i.e., this study). The project was approved, and work began in the Fall of 2000.

1.7 Approach

No source was available for identifying AVL deployments among highway agencies other than the agencies themselves. So, a survey was conducted to determine the level of involvement of highway agencies in AVL deployment. Those agencies identified by the survey as having deployed an AVL system were contacted with a more extensive survey related to their experiences. Both surveys and their respective results are discussed in Chapter 4.

The costs of AVL implementation could be drawn from the survey data, but information pertaining to the benefits of applying AVL to highway maintenance activities was either anecdotal or speculative. Without quantitative benefits data from previous deployments, no rigorous cost-benefit analysis could be performed. Two risk perspectives (low risk and very low risk) were examined to provide insight into the likely magnitude of the benefits. Costs were constant across scenarios. Benefits in the *very low risk perspective* were calculated using conservative assumptions. The results of this analysis provide the minimum benefits that can reasonably be expected. In other words, the actual benefits are highly likely to be equal to or greater than the calculated benefits, and likely to be much greater.

Benefits in the *low risk perspective* were calculated using more moderate (though still somewhat conservative) assumptions. The resulting figures more closely approximate what can be expected. The actual benefits are likely to be close to but slightly greater than the calculated benefits.

For both perspectives, the results are used to calculate a cost-benefit ration based on three different implementation scenarios, conservative, moderate, and aggressive, with the full implementation occurring in 20, 10, and 6 years, respectively. The process and the results are detailed in Chapter 5.

Chapters 2 and 3 provide information about the technologies associated with AVL system as a backdrop for the subsequent discussion of the deployments identified in the surveys. The two principle component functions of AVL are geolocation and wireless telecommunications. The most common approaches to serving these two functions are briefly explained, and characteristics that are particularly relevant to the applicability of each technology to AVL implementation are highlighted.

CHAPTER 2: GEOLOCATION OF VEHICLES

Geolocation, one of the two primary component functions in AVL systems, is the process of determining and describing a given location in some coordinate system, often latitude and longitude. Several means of geolocation exist, and extensive research in this area is rapidly advancing the state of the practice.

2.1 Cellular Geolocation

Currently, no standard exists for determining the location of the origin of a cellular phone call. In order to promote enhanced 911 (E-911) service, the Federal Communication Commission (FCC) mandated that, by October 2001, cellular service providers must be able to provide the location of a cellular caller to within 120 meters 67% of the time. (Skalski, 1997) Although cellular providers were not able to meet this mandate and the FCC eventually pushed the deadline back, it has been purely because of technical issues. Cellular providers are interested in providing location-oriented services to their customers, an application with tremendous market potential, and so will continue to push until the FCC's intents are realized. With the improvement of the cellular geolocation technology, cellular phones can be used for tracking vehicles, as well. There are two primary means of using the cellular signal itself and the network of cellular towers to determine the origin location of the call, Time Difference of Arrival (TDOA) and Angle of Arrival (AOA). Both technologies utilize information collected at the cell sites (towers) to compute the caller's location using basic principles of geometry. The benefit of using cellular geolocation is that no special hardware or software is needed in the handsets, meaning that the system works with the current market base. However, the location error increases as the caller moves farther from the cell sites. And, because it takes at least two cell sites to compute the caller's location, in rural areas where cell sites are relatively far apart, pinpointing a location using one of these methods can be difficult.

Some proprietary technologies are being marketed that claim to accomplish the location task by other means, which only require one receiving site. However, these technologies have not been proven to be market viable.

2.1.1 Time Difference of Arrival (TDOA)

TDOA uses trilateration to determine the location of a wireless call's origin. As a phone communicates with a tower, or base station, the radio waves travel at a constant speed of about 1000 feet per microsecond. (TruePosition, Inc., 1997) When the signal first reaches a tower, a time stamp is associated with the call. The distance from the handset to the tower can be calculated if the time it took the signal to reach the tower is known. Figure 3 shows a signal reaching tower B, in time t_1, over a corresponding distance d_1.

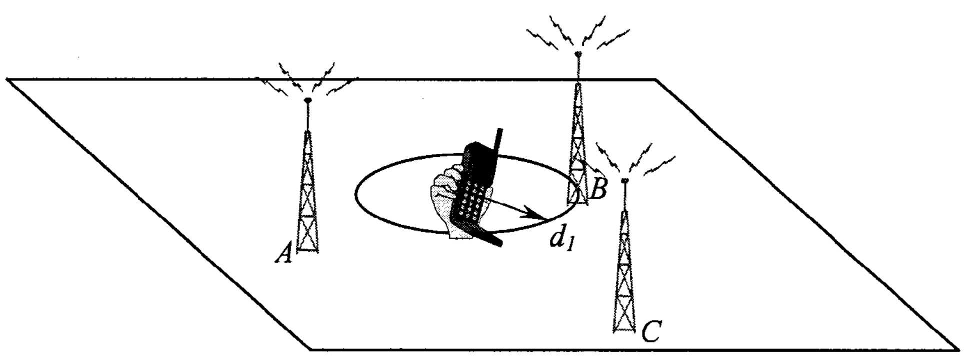


Figure 3. Distance (d_1) from the handset to tower B.

As the signal continues to travel away from the handset, it will next reach tower A, in time t_2, over a corresponding distance d_2, as shown in Figure 4.

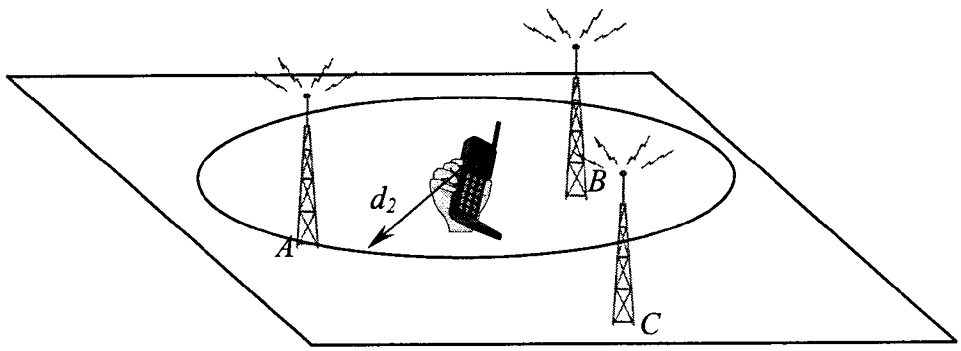


Figure 4. Distance (d_2) from the handset to tower *A*.

If t_1 and t_2 (and thus d_1 and d_2) were known, the circles in Figure 3 and Figure 4, if centered on the receiving towers instead of the handset, would intersect at two possible locations of the caller. A third receiving tower would pinpoint the location. However, t_1 and t_2 are not known, because the time the signal left the handset is not known. With synchronized clocks in the towers, only the *difference* between t_1 and t_2 is known. There are many possible locations for the handset where the *difference* between t_1 and t_2 would be the same, but all of these locations fall on a particular hyperbola, defined by the location of the towers and the time differential. By using the time differential between towers *A* and *B* and the differential between towers *A* and *C*, two hyperbolae can be defined which intersect at the location of the handset, as shown in Figure 5.

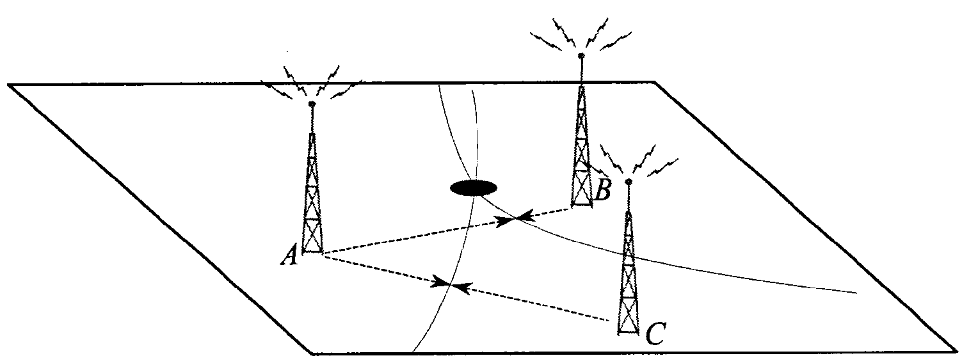


Figure 5. Location determined by time distance of arrival.

While this technology has the advantage of being able to work with existing phones, it is very expensive. With more than 18,000 cell sites nationwide (TruePosition, Inc., 1997), the cost of providing TDOA functionality would total about $10 billion. (Friend, 1997) The calculations require a minimum of three base station time stamps to be able to determine a location. This is often an unlikely scenario in rural areas. Moreover, while three time stamps is the theoretical minimum, various sources of error in the calculations may require that more than three time stamps be used.

2.1.2 Angle of Arrival (AOA)

Some antennae are capable of determining the horizontal angle at which the cellular signal arrives at the tower. This angle identifies a line of travel on which the call's origin lies. Theoretically, the lines of travel identified by two or more cell sites will intersect at the location of the caller.

The antenna consists of several elements, each of which receives the signal separately at angles θ_1, θ_2, and θ_3, as shown in Figure 6. Because the distance, d, between the elements of the antenna is very small compared to the distance, D, from the handset to the nearest antenna element, it can be assumed that $\theta_1 = \theta_2 = \theta_3 = \theta$, without introducing any significant error.

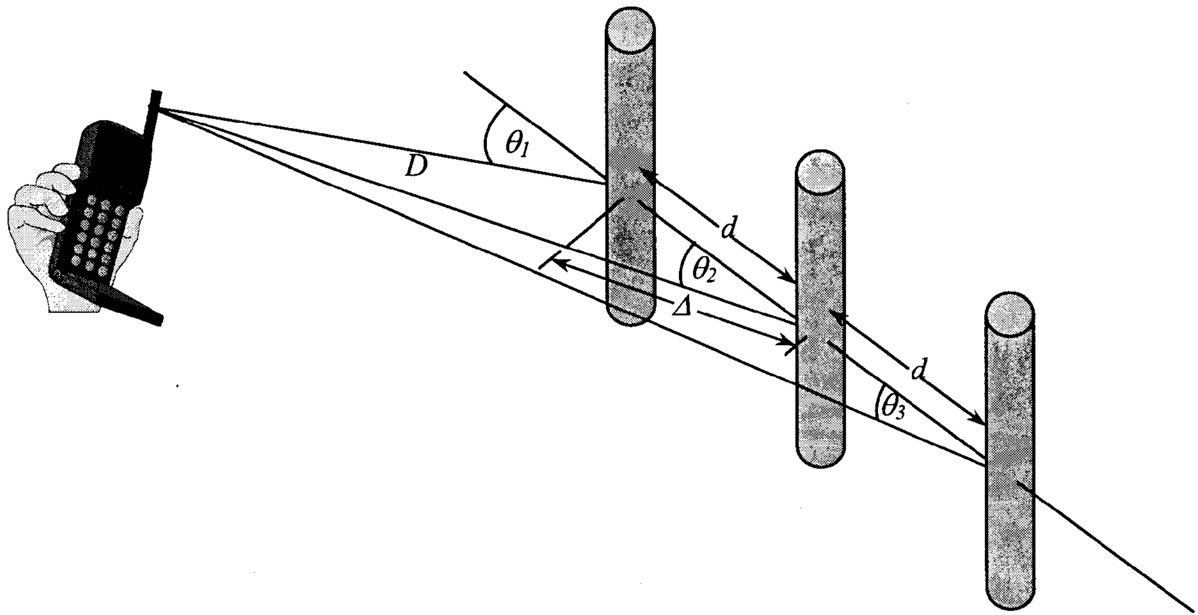


Figure 6. Signal reception by multiple antenna elements.

After reaching the nearest antenna element, the signal must travel an additional distance, Δ, to reach the second element. This distance can be calculated from the time differential between the first element's reception of the signal and the second element's reception of the signal. The angle θ can then be calculated from the properties of a right triangle, as shown in Equation 3.1.

$$\theta = \cos^{-1}\left(\frac{\Delta}{d}\right) \qquad \text{Eq. 3.1}$$

The orientation of the antenna is combined with the relative angle to the handset, θ, to derive a bearing, ϕ_1, from the antenna to the handset. The bearings from two antennae intersect at the location of the handset, as shown in Figure 7.

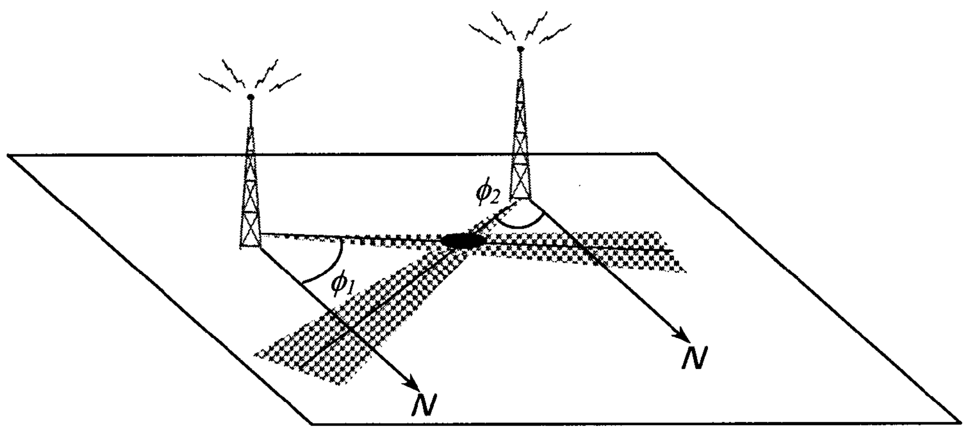


Figure 7. Location determined by angle of arrival.

Because the angles are used to determine the location to the handset, the error in the calculations can be visualized as a wedge shaped area. As a result, the absolute location error increases as the distance from the handset to the antennae increases.

The angles of arrival techniques are very sensitive to *multipath* errors. Multipath error results from the signal reflecting off natural and manmade objects, as illustrated in Figure 8. This phenomenon causes several duplicate signals to be received by the antennae, each at a different time (a reflected path is a longer distance than a direct path), and from a different angle.

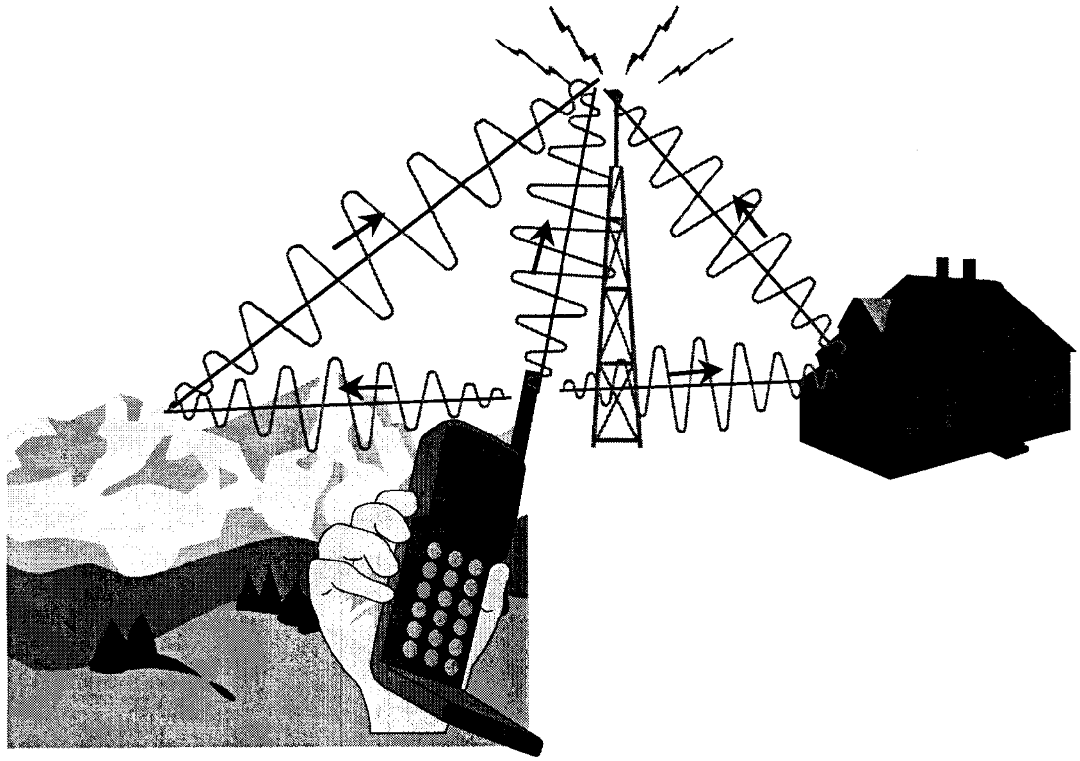


Figure 8. Reflected signals causing multipath error.

Deployment of this technology for locating highway maintenance vehicles is typically prohibitively expensive.

2.1.3 Other Proprietary Technologies

In direct response to the FCC's mandate regarding wireless Automatic Location Identification (ALI), numerous proprietary technologies have been developed to determine the originating location of a wireless call. For example, US Wireless has developed a technology called *radio camera locating*. While the specifics of the algorithm for determining location are proprietary, the conceptual basis of the technology is that a wireless call from a particular location received by a particular tower possesses a unique signal pattern, or fingerprint, comprised of various characteristics of the multipath signal. A database of these radio wave fingerprints can be developed such that the fingerprint of an incoming call can be compared with those in the database. Through this comparison, an approximate location of the origin of the incoming call can be determined.

An advantage of this type of technology is that it only requires data from a single tower (triangulation-based methodologies require that the signal be received by at least two towers simultaneously, and sometimes three—a rarity in remote areas). However, the methodology works only in areas for which a database of radio wave fingerprints has been developed.

Some companies are considering the integration of a single-chip GPS receiver into their phones. This has significant potential for several reasons. First, it is relatively inexpensive and can be accomplished as users purchase new phones. Little or no tower modifications are necessary. With Selective Availability turned off, GPS precision is better than nearly any competing technology. However, GPS signals are blocked by metal, so an external antenna would be needed for the receiver to work from inside an automobile. This is a significant drawback because most estimates indicate that about half of the cellular calls made are from a moving vehicle. For some applications, AVL included, the problem could be easily circumvented by using an external GPS antenna (separate from a cellular antenna).

2.2 FM Position Location

FM position location uses commercial FM radio stations to compute the location of the receiver. Every stereo FM broadcast includes an inaudible *pilot tone*, a 19 KHz sinewave signal. The phase of the pilot tone changes as the receiver moves relative to the broadcast antenna. By tracking the changes occurring in the pilot tones of several stations simultaneously, the position of the receiver can be triangulated. FM position location systems work better in estimating relatively short ranges. In urban or mountainous areas, where obstructions such as buildings and mountains are present, the accuracy of FM position location systems decreases due to multipath error. Table 1 is a comparison of two FM position location systems.

Table 1. Selected Radiolocation Systems

Company	Terrapin Corporation	Galaxy Microsystems
Positioning Technology	Position Information Navigation Subsystem (PINS)	NA
Working Principle	PINS measures the phase of the signal and then derives the range to the transmitter, the location of which is defined.	Use spread-spectrum CDMA transmission to compute the user's position.
Accuracy	10-20 meters	10 meters or better

Source: Driscoll, 1994.

2.3 Satellite Position Location System

Satellite position location systems use Low Earth Orbit (LEO) satellites to facilitate communications and determine the location of the transmitting unit. The location is determined by triangulation, based on TDOA principles. Multiple satellites receive the signal simultaneously. The time of receipt is transmitted to a ground station where the calculations are performed and the location determined. Because LEO satellites are close to earth, low power transmitters can be used, which makes the technology appropriate for mobile applications. However, when LEO satellites are not available (they orbit the earth once every 90 minutes), data delay and loss will occur. Table 2 is a list of selected satellite position services.

These systems are widely used in the commercial vehicle operations (CVO) community. However, because of the expense, they may be impractical for the implementation of highway maintenance vehicle tracking purposes.

Table 2. Selected Satellite Position Technologies.

Positioning Technology	OmniTRACS	ORBCOMM	STARSYS
Working Principle	Computes the range to each satellite and derives the third measurement needed for position from a topographic model of the earth	Computes position by integrating Doppler measurements with radio ranging	Compute position by integrating Doppler measurements with radio ranging
Accuracy	Typically one-quarter mile	100 to 1,000 feet	100 meters
Other Features	Provides two-way data communications between fleet vehicles and dispatch	Provide two-way data messaging and location capability for trucking applications.	NA
Terminal Price	$3,500-4,000	$400	NA
Monthly Fee	$70/vehicle	NA	NA

Source: Driscoll, 1994.

2.4 Signpost Navigation

Signpost navigation is a type of system for locating vehicles along a predetermined set of routes. There are two general categories of signpost navigation systems. In the first category, the signposts are simply low-power beacons that transmit unique signpost identification tags. When a vehicle passes a signpost, a receiver in the vehicle reads the ID, then forwards it to the location where the vehicle is being tracked.

In the second category, the vehicle contains a beacon that transmits a vehicle identification tag. When a signpost receives an ID, the ID is passed to the tracking center, along with the ID of the signpost. A related type of system exists in which the signal broadcast from the vehicle is received at 3 or more antenna sites, and a TDOA method of locating the vehicle is used.

In all signpost navigation systems, the location is tracked at a central location and only for specially equipped vehicles. Consequently, such systems are useful for vehicle fleets, but not for general navigation. Because the systems are limited to routes on which signpost sites have been established, they are particularly appropriate for fixed route purposes, such as with urban transit fleets. But this type of technology is not suitable for statewide tracking of maintenance vehicles where there are numerous routes.

2.5 Location Monitoring Service (LMS)

The operational principle of LMS is basically the same as that of signpost navigation systems, discussed in section 2.4. These systems are effective for certain applications, but coverage is predominately limited to metropolitan areas, and thus an ineffective technology for use on rural highways. Another drawback is that LMS shares frequency bandwidth with many other devices such as cordless phones, amateur radio operators, and federal government radiolocation systems. (Rappaport, Reed & Woerner, 1996) As a result, interference can significantly degrade performance.

2.6 Long Range Area Navigation (Loran)

LORAN is a radionavigation technology in which signals from two or more land-based transmitters are used to locate the receiver. The low frequency and high signal level used allows the transmitters to be spaced hundreds of miles apart and their signals to be received thousands of miles away, at times.

LORAN was originally designed for naval use because its extremely long ranges make it well suited for guiding ships. More recently, LORAN has become a useful tool for land navigation as well as naval use. LORAN-C, the most recent generation of the LORAN system, has shown accuracy in the range of 19 to 90 meters. (Rappaport, Reed & Wormer, 1996) Low-power LORAN-C receivers can be purchased for less than $1,000 in large quantities. (Lachapelle & Townsend, 1990)

2.7 Global Positioning System (GPS)

The Global Positioning System (GPS) is the most common technology used for locating vehicles in an AVL system. It allows a GPS receiver to determine its location nearly anywhere on earth. Developed by the US Department of Defense (DOD) for military purposes, a portion of the system's capabilities are accessible to the general public. Most of the agencies that have deployed AVL technology are using GPS for locating the vehicles.

GPS uses a very sophisticated type of a triangulation to determine location. Signals are continuously broadcast from satellites orbiting the earth. The signal contains information about the broadcasting satellite and the precise time at which the signal was broadcast. When a GPS receiver receives one of these signals, the broadcast time contained in the signal is compared with the receiver's internal clock to determine the range (distance), r_1, to the satellite. This places the receiver somewhere on a sphere of radius r_1 centered on the satellite. Determining the range to a second satellite, r_2, places the receiver somewhere on a circle representing the intersection of the two spheres, as shown in Figure 9. Similarly, tracking a third satellite will narrow the location of the receiver to two points. Using a sphere approximating the surface of the Earth is generally sufficient to eliminate one of the two points, leaving the remaining point as the location of the receiver, as shown in Figure 10. While some very sophisticated calculations (and at least one additional satellite) are necessary to help compensate for the motion of the satellites and the rotation of the earth, for minute errors in the receiver's clock, for atmospheric interference, and for various other sources of error, the fundamental principle remains the same.

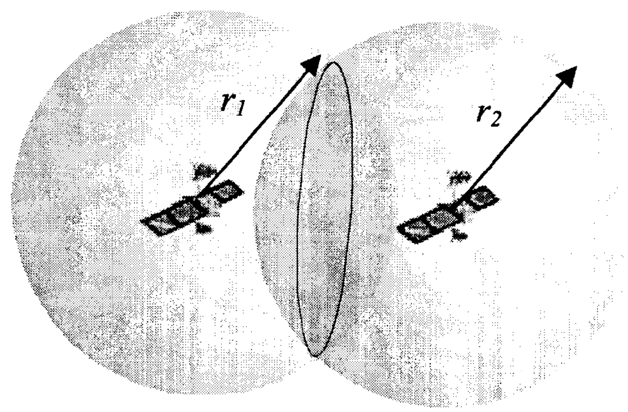


Figure 9. Circle representing the intersection of two satellite ranges.

In order to get a reliable fix on a receiver's location, several satellites (at least four) must be tracked simultaneously. Currently, the constellation of 24 satellites provides nearly complete and continual coverage of the US. Because the system requires a direct line of sight between the receiver and the satellites, extremely mountainous terrain can block enough satellites that the receiver cannot obtain a location fix. In metropolitan areas, tall buildings can create an *urban canyon*, which can also prevent the receiver from determining a location.

The DOD can introduce deliberate random errors into the information broadcast by the satellites to prevent its effective use by other countries in military action against the US. This policy is known as *Selective Availability*, or *S/A*. Including S/A, errors vary up to 100 m. (The US military uses a special encrypted signal from the satellites that has no deliberate error.) S/A was recently turned off, reducing the typical error to 10 m or less.

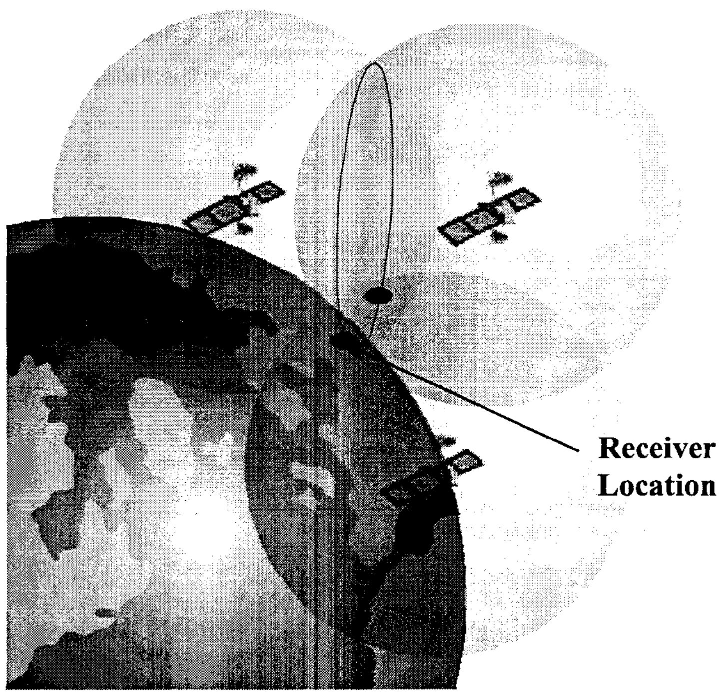


Figure 10. Three satellite ranges and the Earth's surface locate a receiver.

GPS is relatively inexpensive, with some GPS receivers retailing for under $100. Navigation systems (in vehicle or handheld) with integrated GPS receivers retail for as little as $300 to $500.

For those applications that demand extremely high accuracy (e.g., less than 1 m error), a technique known as Differential GPS (DGPS) can be used. DGPS utilizes a base station with a very precisely known location. The base station compares its known location with the location indicated by a GPS receiver to calculate the GPS errors. These errors are then communicated to a field receiver, allowing it to filter out the error before determining its position. The cost of the communications link (as well as more sophisticated equipment) makes DGPS significantly more expensive than stand-alone GPS. While S/A was still on, AVL systems have demonstrated accuracy of 15 m without and 5 m with the application of differential corrections. Differential corrections are no longer needed for typical AVL applications.

2.8 Global Navigation Satellite System (GLONASS)

Global Navigation Satellite System (GLONASS) is the Russian equivalent of GPS. GLONASS only takes 1/3 as much time as GPS to synchronize the clock in the receiver with the clocks in the satellites. (Rappaport, Reed & Woerner, 1996) It also does not incorporate into its operation any deliberate errors such as the GPS errors incurred through S/A. However, GLONASS requires receivers to have a wider bandwidth than a GPS-only receiver in order to decipher the satellite signal. Moreover, the GLONASS reliability remains uncertain since Russia does not have the resources for maintaining their satellites. (Daly, 1993) As of October of 1998, only 14 of the constellation of 24 satellites were operational. (Holmes, 1998) In addition, net loss of accuracy may actually occur as the result of including the GLONASS code measurements in differential mode. (Hall, Burke, Pratt & Misra, 1998) Ultimately, the solo use of GLONASS in position location does not guarantee its performance even though it has many promising characteristics.

2.9 Integrated Use Of GPS And GLONASS

The impetus for integrating GPS and GLONASS is to provide a larger quantity of satellites that will result in higher accuracy. Misra points out, "GPS contributes a larger satellite constellation, and GLONASS contributes measurements of better quality." (Misra, 1998) The integration of the two systems has the potential to substantially reduce position errors. (Rappaport, Reed & Woerner, 1996) The GPS and GLONASS combination also offers additional reliability through redundancy. Even if one of the systems is not working properly, 99.9% of the time users will still be able to estimate the position location within error of 200 meters. (Misra, 1998) GPS and GLONASS use different transmitted frequencies, suggesting that the integration of the two systems will provide a greater immunity to RF interference, and the immunity is enhanced by the frequency diversity of the GLONASS signal. (Hall, Burke, Pratt & Misra, 1998) Table 3 compares the position accuracy of GPS, GLONASS, and a combined system that utilized both GPS and GLONASS. From Table 3, the integrated system decreases the position error compared to either GPS (with SA on) or GLONASS operated alone.

Table 3. The Projected Position Accuracy of GPS and GLONASS.

	Horizontal Error (m)		Vertical Error (m)
Percent of readings with error <= X	**(50%)**	**(95%)**	**(95%)**
GPS (SA off)	7	18	34
GPS (SA on)	27	72	135
GLONASS	10	26	45
GPS+GLONASS	9	20	38

Source: Misra, 1998

Despite the apparent accuracy potential of integrated GPS/GLONASS receivers, by simple attrition the GLONASS constellation is expected to be entirely depleted by the end of 2001 if new resources are not expended to launch new satellites.

2.10 Integrated Use Of GPS And LORAN-C

Some research suggests the integration of GPS and LORAN-C position location systems can also improve data accuracy. For instance, the hybrid GPS/LORAN-C signal availability is improved over 90% in mountainous terrain when compared with signal availability of 60% for GPS and 75% for LORAN-C. (Lachapelle & Townsend, 1993) Unfortunately, the relatively high cost of this type of integrated systems is likely to prevent their widespread use in land vehicle navigation.

2.11 Wide Area Augmentation System

The Wide Area Augmentation System (WAAS) is a system being developed by the Federal Aviation Administration (FAA) to help improve the accuracy of GPS, using a technique similar to DGPS, only less geographically limited and without the need for an expensive communications link. While the system is technically still under development and should not be used for flight-critical functions, the system is nonetheless available for other applications, and WAAS enabled receivers are commercially available. The FAA offers this explanation of the system's function.

> "The WAAS is based on a network of approximately 25 ground reference stations that covers a very large service area. Signals from GPS satellites are received by wide area ground reference stations (WRSs). Each of these precisely surveyed reference stations receives GPS signals and determines if any errors exist. These WRSs are linked to form the U.S. WAAS network. Each WRS in the network relays the data to the wide

area master station (WMS) where correction information is computed. The WMS calculates correction algorithms and assesses the integrity of the system. A correction message is prepared and uplinked to a GEO[1] via a ground uplink system (GUS). The message is then broadcast on the same frequency as GPS (L1, 1575.42MHz) to receivers on board aircraft which are flying within the broadcast coverage area of the WAAS." (FAA, 2001)

While the FAA cites an accuracy of 7 meters vertically and horizontally, typical accuracy is less than 3 meters. (Garmin, 2002) Though the FAA warns against its use for navigational purposes until the testing period is formally completed, WAAS-enabled receivers are already commercially available.

[1] geostationary communications satellite

CHAPTER 3: COMMUNICATION SYSTEMS

In an AVL/MDT system, it is essential to maintain communication between the vehicle and the central control system. An appropriate communication technology has to be selected based on the coverage area, costs involved and the importance and the purpose of the communication. Several communication systems are discussed below,

3.1 Cellular Communication

Cellular communications is the most commonly used form of wireless communications. Cellular phones provide a wireless connection to the Public Switched Telephone Network (PSTN), the phone network that connects phones used in homes and businesses across the country. Jurisdictional issues related to the routing of emergency (911) calls from cellular phones continues to be a problem. (Blaschka, 1994) 911 calls are often routed to the PSAP whose jurisdiction includes the tower that received the call. This is mandated by statute in Kansas. However, in some cases, multiple repeater sites are involved, and the "receiving tower" is the site where the call is transferred to the PSTN, sometimes more than 100 miles from the location of the caller. Some improvement in this area should result from the FCC's mandate that by October of 2001 (now postponed) wireless providers deliver the caller's location with at least 67% of 911 calls. However, in many cases a 67% rate could be achieved by addressing only the urban areas, since the density of calls is much higher than in rural areas. If the location is determined by a technical solution that requires modifications to the cellular towers, many rural areas may not see the benefits of wireless E-911. In order to reduce the costs associated with complying with the FCC mandate, cellular providers will address the urban areas first, moving toward the rural areas only far enough to achieve the mandated rate of 67% delivery of location information.

3.1.1 Analog Cellular Communications

Analog cellular communications is the most common type of cellular communications. The coverage of analog cellular phones includes most metropolitan areas and inter-city travel routes, and it continues to improve in more remote areas. In the Fall of 2001, the University of Kansas completed a study for KDOT in which the coverage of analog cellular communications with respect to the state highway network was measured and analyzed. For emergency purposes (i.e., combining the coverage of all carriers), coverage of the state highway system is better than 95% for 3-watt car phones and only slightly less for 0.6-watt handheld units. Coverage of county and local roads that are not on the state system is presumably less, though testing in Jefferson and Cloud Counties indicates coverage may be 90% or better for both 3-watt and 0.6-watt phones. (Meyer, 2001) These figures are consistent with estimates from other rural states for all but the most remote areas.

3.1.2 Cellular Digital Packet Data (CDPD)

Cellular digital packet data (CDPD) communication systems represent another standard that can be used to communicate data over cellular connections. While CDPD is more efficient for transmitting data, its use is largely limited to urban areas, and consequently may not be adequate for rural communications. (Asawa & Stark, 1995) Though this technology is being used by a number of agencies for maintaining communication between the maintenance vehicle and the control center, unfortunately, it is not available in Kansas.

3.1.3 Personal Communication System (PCS)

The Personal Communication System (PCS) industry has grown out of the analog cellular industry, but some of the operational principles are different. The primary difference is that PCS is an entirely digital transmission medium. Digital transmission allows more efficient use of the available frequencies, and more efficient transmission of computer data. While these characteristics are indeed better suited to the task of communicating binary data (as opposed to analog voice), the coverage of PCS is still far sparser than that of analog cellular systems. However, the wireless industry is pushing the digital technology very heavily, offering substantial incentives to subscribers to choose digital, and the market is rapidly increasing. The available coverage may soon approach that of analog cellular, and may eventually surpass it. At present, PCS service is only available in and around metropolitan areas in Kansas. Consequently, it is not an applicable communications media for statewide AVL.

3.2 Advanced Radio Data Information Service (ARDIS)

ARDIS is an example of a type of communications medium called Packet Data Networks. In Packet Data Networks, data is exchanged in small amounts, or packets, over a radio frequency connection. Transmitting data in small packets allows multiple users to exchange data over a single frequency. Additionally, users can be charged by packet usage, rather than time usage. This means that users can be "logged on" continuously, but only pay for the data they transmit. "ARDIS is a private carrier and charges on a per-packet basis, therefore, it is not subject to price regulation by state public utility commissions." (Brodsky, 1990) However, because the data must be transmitted in packets, these networks are not very suitable for continuous real-time communications, such as voice. Moreover, the coverage areas of these networks are rather limited, concentrated in urban areas. Table 4 is a comparison of ARDIS with other radio frequency communications companies. Service in Kansas is currently limited to the following metropolitan areas: Hutchinson, Wichita, Salina, Manhattan, Topeka, Lawrence, St. Joseph, and Kansas City.

Table 4. Nationwide Data Radio Services Features/Capabilities

Provider	Ardis	Mobitex	Coverage PLUS
Area Served	400 cities, all 50 states	50 major cities by mid-1992	Midwest, East & West coasts, Florida, E. Texas, Oklahoma, Missouri, and Arkansas
Coverage Type	In-building & On-the-street	Mobile & Fixed	Interstate Highways
Voice	No	No	Yes
RF Data Rate	4800 bps (19.2 kbps planned)	8000 bps	4800 bps
Usage Cost	$0.8/packet	Fixed monthly + per packet	$35/vehicle/mo. + $0.05/packet
Hardware Cost	$3300	Unknown	$2000-3700
Channels per Market	1	10-30	20
Open Architecture	No	Yes	No
Automatic Vehicle Locating	No	Optional	Loran

Source: Brodsky, 1990.

3.3 Satellite Communications

Satellite communications is a broad category that includes any two-way communications media that utilizes satellites to communicate between the stationary base units and the mobile field units (as opposed to cellular communications, which use terrestrial towers). Typically, satellite communications systems provide nearly complete geographical coverage. Additionally, most systems can also track the location of the caller. However, both the hardware and the service tend to be significantly more expensive than terrestrial based systems, though their competitiveness with the cellular industry is improving somewhat.

Geosynchronous (GEO) satellites are a special class of LEO satellites, so named because their orbit is such that the speed of the satellite is synchronized with the rotation of the earth, allowing the satellite to remain stationary relative to the earth's surface.

A few selected satellite communication vendors and their prices are listed in Table 5.

Table 5. Selected Satellite Communication Technologies

	GEO		LEO		
Company	American Mobile Satellite Corp.	Qualcomm's Globalstar	ORBCOMM	Motorola's Iridium	TRW's Odyssey
Satellites	NA	48	36	66	12
Handset Price (est.)	$3,500	$700	NA	$3,000	$550
Price Per Minute (est.)	$1.49	$0.3	NA	$3	$0.65

Source: Corporate Promotional Materials

3.4 Dedicated Land-based Mobile Radio (LMR)

Dedicated land-based mobile radio (LMR) is another broad category of communication media. LMR is particularly important in the discussion of using AVL for highway maintenance because many DOTs already own and maintain a LMR system.

While various characteristics of any given system would have to be considered before assessing the systems applicability to AVL, if it is plausible, the cost savings are significant.

LMR operates in frequency bands that must be licensed from the FCC, including ranges at 220 MHz, 440 MHz, and 800-1000 MHz. Allowable transmitter power varies up to 100W, but generally is less than 50W. Typical transmission ranges are 8 km (5 mi) to 16 km (10 mi).

The Kansas DOT operates an 800Mhz LMR system for communications between area and sub-area offices and their maintenance vehicles. The system is currently voice only, but there is interest in implementing a dedicated data channel if an appropriate source of funding can be obtained.

CHAPTER 4: DATA COLLECTION

4.1 Surveys

The literature discusses a number of AVL/MDT deployments among highway maintenance agencies, but no formal cost-benefit assessment is available. Costs vary widely from implementation to implementation, and benefits are largely anecdotal and undocumented. To exacerbate the problem, most deployments in the highway maintenance arena are so recent that even the anecdotal reports of benefits are speculative. It is very likely that some agencies have implemented AVL without having published information about the systems, though it is unlikely that such an implementation would include a formal evaluation.

Based on results of the literature review, a survey was developed to help identify agencies that have had experience with AVL. The preliminary survey is provided in Appendix A. Initially, all 50 state DOTs, Canadian provinces, and 6 municipal public works departments were contacted regarding their deployment of AVL/MDT technologies for tracking maintenance vehicles. Several of the municipal applications were identified by contacting technology integrators (i.e., consultants) that are prominent in the field. The survey was also made available over the Internet and various organizations were asked to bring it to the attention of their constituents. Organizations contacted included ITS America, ITS Australia, ERTICO, and VERTIS. Regretfully, no responses were received as a result of involving the ITS organizations.

Approximately 60 percent of the surveyed agencies replied to the post card surveys within two months of mailing them. Remaining agencies were contacted by telephone and the correct contact addresses verified. The preliminary survey was administered by phone in a few cases, and additional surveys were mailed when more appropriate contacts were discovered. Eventually, all the initially surveyed agencies were contacted. The implementation status of AVL/MDT for locating highway maintenance vehicles in the surveyed agencies is summarized in Figure 11.

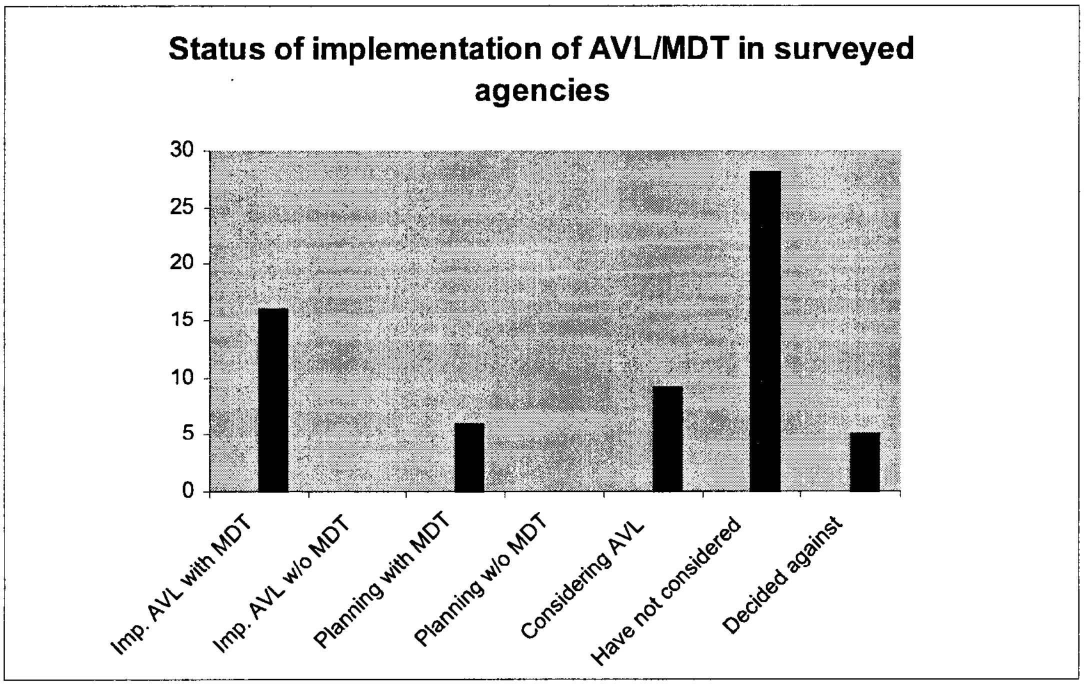


Figure 11. Implementation status of AVL/MDT for tracking maintenance vehicles.

The preliminary survey revealed that fifteen agencies had already deployed AVL/MDT technologies for tracking their highway maintenance vehicles. A detailed questionnaire was developed to further explore the experiences of these agencies. This questionnaire included questions regarding the technology being used, costs and benefits experienced, and obstacles encountered. The detailed questionnaire is provided in Appendix B. The questionnaire was initially sent via Email, and then followed up as necessary by telephone. All the systems used GPS for determining the location of the vehicles. Other details are discussed in the following sections.

4.1.1 Results Summary

The earliest deployments began in 1998, the most recent in 2001. Figure 12 shows a time line of the AVL deployments that were identified in the preliminary survey.

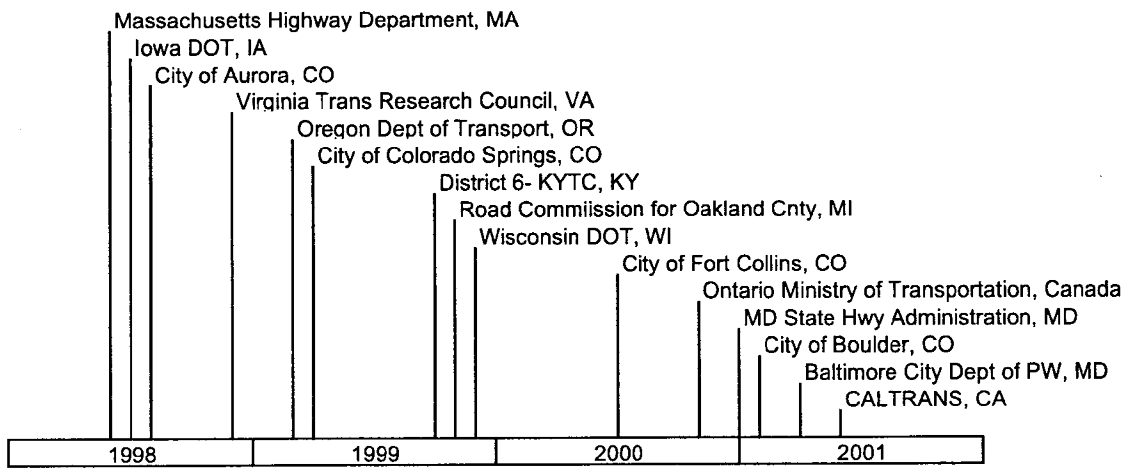


Figure 12. Time Line of AVL Deployments.

Among the deployments, the number of vehicles outfitted with *in-vehicle units* (IVUs) ranged from 4 to 150 with an average of 36. Half of the deployments involved 20 vehicles or more. 12 of the 15 agencies cited snow removal as their primary application. Table 6 shows present applications cited by at least one agency surveyed. Also shown are applications cited as future applications by at least one agency that were not cited as a present application by any respondents. The most frequently cited benefit was improved snow removal. Each benefit sited at least once is listed in Table 7.

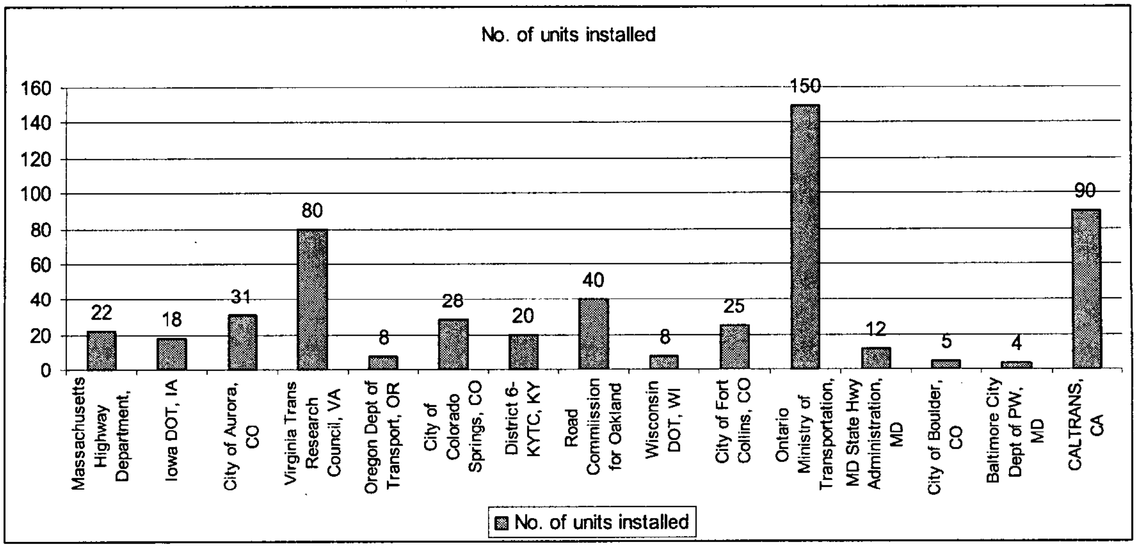


Figure 13. Mobile units installed.

Table 6. Present and Future Applications of AVL.

Present Aplication	Future Application
Snow Removal	Cleaning storm drains
Grader applications	Control quantity of materials
Incidence Management	Dead animal removal
Patching	Dispute claims
Right of way/Pavement maintenance	Grader
Striping	Herbicide Application
Sweeping	Locating Right of Way fences
	Safety Patrol Service
	Spreader control data
	Traffic Signs installation

Table 7. Perceived Benefits of AVL Deployments.

Major Benefits
Activity tracking
Cutback material use
Determination of completed section
Helps to follow EPA regulations in snow plowing
Improve response times
Increased productivity
Keep more records
Locating emergency vehicles
Maintenance information
More efficient snow removal
Post service analysis facilities
Real time info.
Reduced liability
Reduced paperwork
Routing Sweepers
Saving manpower-saved 2 supervisor position
Sharing information about vehicle location between two dispatch centers
Temp. and other data

The agencies were asked to cite the most significant obstacle encountered during the deployment process. The most common issue seemed to be funding, although several other obstacles were mentioned. Table 8 shows the obstacles cited by all 15 agencies.

Table 8. Major Obstacles to Implementation.

Major Obstacles Faced
Disfunctioning of the operating system software
Poor communication system between dispatch and 135 maintenance garages
Installing the units
CDPD should be replaced by radio frequency, Mostly trucks are hired, Cigarette lighter power problem
Some modems in the MDTs had to be replaced
CDPD line is costly, Hooking up the sensors in the vehicles
Fragile piece of antenna
Contract negotiation
Some drivers resisted new technology
IVU repair
Monetary
Installation of IVU
Monetary
No Response
Software adaptation

The costs of deployment are difficult to characterize because they are reported in a variety of ways. In most cases, if not all, work done in house was not included in the costs cited. Table 9 shows the responses related to cost.

Table 9. Costs of Deployment and Operation.

Intial Costs	Intial costs includes hardware?	Includes softwares in stations?	Software of Station costs	Cost of Additional Unit	Operational costs for Communication
$ 1 million for 2 base units	Y	Y	N/A	$2,200/unit	$3,000 per month over all
not exactly known	N	N	Not known	$3,500	almost zero
$ 85,000 for 15 IVUs and others	Y	Y		$3,500	$ 65 per vehcicle per month
$675,000 for 80 units and 3 stations+Adding sensors-$40,000, Consultant $25,000	Y	Y	N/A	$3,000-4,000	$120/unit/mpnth CDPD cost
$60,000/5 vehicles (initially)	Y	N	$ 3,000/station	Not known	$50 per vehicle per month
$100,000 including ten units	Y	Y	N/A	$3,500	$ 50 /vehicle/month
$269,000	Y	Y	N/A	$3,000-4,000	$60/vehicle/month
not sure	Y	Y	N/A	Not known	Negligible
$ 15,000-20,000 per truck X 8 Trucks = $120,000 - $160,000	Y	Y	included	Not known	yet to be calculated
$80,000	Y	Y		$4,000	$ 50 per vehicle per month
Ca$ 1,400 for IVU (per vehicle) in Cellular area and Ca$ 1,750 for IVU (per vehicle) in Sattelite coverage area, Communication- for Cellular $ 33/month/vehicle and for Sattelite $ 100/month/vehcile	N	N		Not known	Cellular Ca $33 per month per vehicle + Ca $ 40 per month for service and website per vehicle
$145,000	Y	Y		$3,000-4,000	$ 50 per vehicle per month
Not known	N/A	N/A			
Hardware at the control/dispatch center $ 1,000, Software $ 1,000, Installation cost $ 1,400 per vehicle	Y	Y	$ 1,000 per station	Not known	Cellular cost approximately $ 16 per month + long distance fees

The majority of the deployments (10) utilized CDPD for transmitting data. Two used satellite, two used analog cellular (one of these two also used satellite), and two used LMR.

When asked whether they thought the system was cost-beneficial overall, two agencies said their systems were cost-beneficial, and the rest indicated in some way that they could not yet tell. These responses were not surprising given that, at the time of the survey, one of the systems been in operation for more than three years, and most even less time. The actual responses to this question are listed in Table 10.

Table 10. Perceptions of the Cost-Effectiveness of the Systems.

Do you think the system is cost-beneficial?
Not yet known
Not known
Yes
Not experienced sufficiently
To be assesed
To be considered
Not known
Can be known after the second phase is over
Not known
Yes
Not sure
We have consulted the University of Wisconsin about this
Not yet experienced
(No response)
(No response)

The following sections provide specific details about each of the deployments represented in the survey. First, regional or statewide deployments are discussed, following by municipal deployments.

4.2 Regional Applications

4.2.1 CALTRANS

CALTRANS began using an analog-cellular based system in the summer 2001. Digital cellular and the next generation radio product were expected to become available in Fall 2001. IVUs have been installed in 90 vehicles and are expected to be installed in all 120 vehicles by 2002. This equipment is being used for snow removal, right of way maintenance, and striping operations. Greystone Group Inc. and Logistic Fleet Sales have supplied and installed the equipment. The hardware cost per vehicle was $1000 for the IVU and $400 for installation. Operational costs include $16 per month per vehicle plus additional long distance charges. The deployment of the technology allowed more efficient snow plowing and helped with record keeping. The convenience of knowing the location of their vehicles at any given time was considered to be the most significant benefit. The response of the employees to the new system was mixed. About 80% of the employees saw it as a management tool to benefit the department, and the remaining 20% think of it as "big brother." Software adaptation was considered as the major obstacle to the deployment of the system.

4.2.2 Kentucky Transport Cabinet (KYTC)

The Kentucky Transport Cabinet (KYTC) has implemented an AVL system for tracking their maintenance vehicles using CDPD for the communications link. Twenty snowplows have been installed with IVUs since October 1999. It is being used primarily to improve the efficiency of snow removal. In the future, it will also be used for road sweeping and traffic sign installation purposes. Eight highway safety patrol vehicles have also been outfitted with IVUs. Mentor Engineering supplied the equipment and SRF Consultants (MN) served as the integrator. The software, base station equipment, and 20 IVUs cost $269,000. Each additional IVU costs about $3,000. The operation of the system incurs CDPD costs of $60 per vehicle per month. A limited number of pre-fixed messages can be sent from the vehicle to the dispatch center. The equipment operators have been trained, and the technology has been generally well accepted. A fragile component of the antenna has caused some initial difficulty.

4.2.3 Massachusetts Highway Department

The Massachusetts Highway Department has implemented AVL as a pilot project begun in 1998. They currently track 18 of their combo-plow-spreaders and 4 supervisors' vehicles. The combo-plow-spreaders are being used for snow plowing and salt spreading. Science Application International Corp. (SAIC) and Kinetics Corp. have worked as the integrators. The initial cost of two base stations, including software and IVUs was about $1 million. The system provides location data only. In the future, it is expected to collect road temperature and air temperature data as well. Early in the project, drivers resisted the system, though dispatch found it to be very helpful. Employees have since come to accept the system. The software presented the greatest obstacle to implementation. The DOS-based control software was not very user friendly, and software malfunctions were difficult to overcome.

4.2.4 Virginia Department of Transportation

The Virginia Department of Transportation also implemented an AVL system in 1998, integrating GPS and CDPD technologies. They have three base stations for tracking the vehicles. The first terminal was placed in the headquarters, the second in the residency office, and the third in the public information office. IVUs have been installed in 80 snowplows. One vehicle is also being used to collect money from the tollbooths. In the future, it is expected that IVUs will also be installed in safety service patrols. Orbital TMS has worked as the supplier of the equipment and Stuart International has assisted in installation. The eighty IVUs and 3 remote monitors cost about $675,000. Adding sensors cost about $40,000. Stuart International charged from $25,000-$30,000 for the consultation. Each additional unit costs about $3,000. The operational cost of CDPD is $120 per unit per month. The major benefit obtained from the system has been the sharing information between centers. The project occurred in an urban setting, and so far there has not been sufficient snowfall to accurately judge the magnitude of the benefits of the system with respect to snow removal. Early in the implementation, worker privacy was a significant obstacle (i.e., the "big brother" syndrome). New drivers had to be trained. The cigarette lighter connection, the power source of the data terminal, was not available in all of the trucks. It was recommended that IVUs have their own power source. CDPD has been insufficient at times.

4.2.5 Road Commission for Oakland County, Michigan

Oakland County, Michigan, has deployed AVL using GPS and 900MHz radio. Their initial demonstration used CDPD for the communications system in 10 vehicles. In Phase I, 40 trucks were installed with IVUs using a 900MHz radio system, and it is expected that 290 vehicles will be installed with IVUs by 2002. The vehicles that already have IVUs are dump trucks and winter maintenance vehicles. Orbital TMS and Veridian Engineering have worked as the integrators and providers. The total hardware and software cost for Phase I was about $1 million. The operational cost for the radio communication is negligible. The main objective of Phase I was to find out how durable the system is. The objective of the Phase II is to increase the number of vehicles installed with IVUs. The response of the workers has been mixed. Some resistance to a new system has been observed. The major obstacle during implementation was the negotiation of the contract.

4.2.6 Oregon Department of Transportation

The Oregon Department of Transportation has deployed an AVL/MDT system for tracking their eight COMET incidence response vehicles. The system used CDPD for the communications component. The project was initiated in 1999. In the future, the system is expected to be used for highway maintenance activities, as well as the service patrol. Orbital TMS has been involved in supplying the equipment, and the CDPD connection is provided by AT&T. The initial cost was about $60,000 for 5 vehicles, including $3,000 for each dispatch station. The operational cost of CDPD is $50 per month per vehicle. The main advantage of the system is the ability to update vehicle location every two seconds. Employees were generally accepting of the new system. Orbital TMS has provided training for the employees. The main obstacle has been the need to replace the modems of the IVUs. The supplier did eventually complete the necessary replacements.

4.2.7 Wisconsin Department of Transportation

Wisconsin deployed an AVL system using CDPD in November 1999. The present application of the system is snow removal. Monroe Truck Equipment Company has worked as the private agency to supply the equipment. The overall cost of deployment was $15,000-$20,000 per truck. This cost includes base station hardware and software as well as IVU costs. The major benefit of the system has been the improved efficiency in the salt spreading and snow removal process. The workers have responded well to the new technology, overall, though some were not ready to accept the new technology.

4.2.8 Iowa Department of Transportation

The Iowa Department of Transportation, in 1998, implemented the first 18 snowplows with IVUs as the first phase of their Tracking Resources with Automated Capabilities (TRAC) project. Their existing 800MHz digital radio system was used for communication. Expected future uses of the system include herbicide application, paint striping, cleaning ditches, and mowing. The supplier of the equipment was Orbital TMS. They installed one IVU and the remaining IVUs were installed by the department mechanics. The operational cost of the system is very small because an agency-owned radio system is being used for communications. An additional unit costs about $3,500. Other initial costs were not available. Formal analysis of the system's performance has not been conducted, though the data archive now contains 3 years of data, which should be sufficient for such an analysis.

The existing radio system was data-capable and had enough capacity to accommodate the minimal additional load imposed by the pilot project. There are some concerns that system capacity may be have to be expanded before the system can accommodate the intended 1,000 IVUs in the full deployment.

During the pilot project, the system collected pavement and air temperatures, plow position, wing position, application rates of dry and liquid materials, and the typical

GPS-related information (location, speed, etc.). Periodic updates were sent from the vehicles to the headquarters server. The information was then sent back to the garage over the Department's computer network.

Following a storm, the system could provide the amount of material used on each roadway by milepost, pavement temperature profiles, average speed of operations, deadhead miles, how often the plow was down or up, and how much winging was done. IDOT used reporting software to determine costs for labor, materials, and equipment for each storm event.

The main benefit of the system is more efficient snow removal. It is also expected to reduce paperwork by allowing some forms to be filled out electronically, some to be completely automated, and some to be eliminated altogether. Finally, IDOT believes they can save materials by allowing spreading rates to be monitored at the dispatch center. Workers responded positively. The main obstacle to the system was the inadequate system for communication between the dispatch center and the 135 maintenance garages statewide. Some software difficulties were experienced at the dispatch center, but were solved by updating Motorola's software.

The initial deployment was considered successful. However, budget reductions precluded the renewal of the maintenance agreement with Orbital Sciences to keep the system running optimally. Consequently, the IVUs were removed from the vehicles until a project report and expansion plan is completed and additional funding is obtained.

4.2.9 Ontario Ministry of Transportation

Ontario, Canada, has deployed a radio-based AVL system for tracking their maintenance vehicles. They have installed this system in 50 vehicles, including 7 pickup trucks, 5 snowplows, 9 spreaders and in other combo trucks. The system is being used for snow removal, patrolling, spreading, etc. They are also investigating the value of the system in striping operations. Grey Island of Canada has assisted in the deployment of the technology. The system provides real-time vehicle location, plows status (i.e., up or down), tracks the application of materials, and monitors current temperatures. The project was implemented November 2000 after a two-year trial. The response of the workers to the new system was positive. Monetary constraints were the main obstacle to system implementation.

4.3 Municipal applications:

4.3.1 City of Colorado Springs Department of Public Works

The City of Colorado Springs, Colorado, in April of 1999, deployed AVL using CDPD. They have already installed IVUs in 18 of the sweepers and 10 tandem trucks. They are also planning to install them in other trucks in the future. These technologies are being used for snow removal, right of way maintenance, and pavement maintenance. Planned uses include tracking storm drains that have been cleared and the removal of dead animals. The equipment has been purchased from CompassCom and installed by the radio shop in the Department of Public Works. The total cost for the hardware, software, and 10 units was about $100,000. Each additional IVU costs about $3,500. The primary operational cost is $50 per month per vehicle for CDPD service. The system allows more efficient snow removal and helps to reduce liability and paperwork. It has also helped monitor compliance with EPA regulations in sweeping operations. Savings have been observed in reduced material use in maintenance activities. The most significant benefit is that in the case of an emergency involving a maintenance vehicle, the dispatch center can be quickly notified of the vehicle's status and location. In the beginning of the deployment the workers did not respond well, but its is expected that with time the early objections will dissipate. The main obstacle to the project is the costly CDPD service and the difficulty integrating the vehicle sensors with the system.

4.3.2 City of Aurora, Colorado

Aurora has installed IVUs in 31 of their maintenance vehicles (20 snowplows and 11 sweepers). The project was initiated in August 1998 using CDPD for data transmission. These vehicles are being used for snow removal and street sweeping. The system is eventually expected to be used for grader applications. IVUs will eventually be installed in front-end loaders, paving equipment and spot-patchers. Both Orbital TMS and CompassCom have been involved in the deployment. The total initial investment for computers, 15 IVUs, training, hardware, and software was about $85,000 plus $3,500 for each additional IVU. For sharing the information, one central control station is connected to four workstations. The operational cost of CDPD is about $65 per month per vehicle. It is estimated that a 12-15 percent increase in productivity has been achieved since the beginning of the project. It has been reported that using the AVL/MDT system could eliminate two supervisor positions. Drivers were slow to accept the system, but over time were won over. The main obstacle to the deployment of the technology was the installation of the IVUs. The IT department worked with Orbital and AT&T to solve the problems.

4.3.3 City of Boulder, Colorado

Boulder has deployed a CDPD-based AVL system. In January 2001, 5 trucks were installed with the IVUs, with a total of 18 trucks scheduled for installation by September 2001. These vehicles are being used for snow removal and pavement patching. CompassCom has worked as the system integrator and the IVUs were installed in-house. The total initial cost was $145,000, which included the cost of 2 computers, software, 18 IVUs, and sensors (temperature and application rate). The primary operational cost is the CDPD service at $50 per month per vehicle. The system helps provide more efficient snow removal, reduced liability, and reduced paperwork. The system will be able to send information about how much material was applied and the current air and pavement temperatures. Workers had some concerns about the system at the outset. The monetary constraint was the major obstacle to the deployment. The installation of the equipment took longer than expected.

4.3.4 Fort Collins, Colorado

Fort Collins has deployed the similar technology as that being used in Aurora and in Boulder. CompassCom worked as the system integrator. The project was initiated in 2000. Eighteen dump trucks and seven sweepers were installed with the IVUs. They expect to add 6 more vehicles by the end of 2001. These vehicles are being used for snow removal, sweeper routing, and to help resolve claims of property damage related to maintenance vehicles. This system is providing more efficient snow removal, reduced liability, and more efficient routing of street sweepers. As a result, it was possible to eliminate one sweeper and one truck from the fleet (each of them cost about $140,000). The initial cost of software, hardware, and 13 IVUs was about $125,000. The operational cost of CDPD service is $50 per month per vehicle. An additional IVU costs about $4,000. The response of the workers to the new system has been positive. The main problem has been the maintenance of the IVUs. Repair times have been longer than anticipated.

4.3.5 City of Baltimore, Maryland

The Baltimore Department of Public Works was in an initial stage of deployment in the summer 2001. Only 4 of their vehicles were installed with the AVL/MDT system at the time of the survey. In Phase I, 75 plows will be outfitted with IVUs, with an expected rollout of 500 vehicles over the next couple of years. Orbital TMS served as the provider and system integrator. The system can monitor plow status (up or down) and track the roadway segments that have been serviced. Motorola Private Mobile Radio system was selected as the communication link.

4.3.6 ARTIC, Minnesota

The Minnesota Guidestar project, Advanced Rural Transportation Information Coordination (ARTIC), has been a model for many aspects of AVL implementation. While its goal is to develop a centralized communications center that serves multiple agencies, highway maintenance has been one of the considerations in the planning and implementation of the system. Although the system initially met with significant resistance from dispatchers, once the center became operational, the benefits were obvious. (MnDOT, 2000) Other areas of Minnesota requested similar centers, and MnDOT is planning to implement centers across the state.

Most of the benefits of the system have not been quantified, although they are evident. They include the following, as cited in a project summary. (Deeter, et al, 2001)

- Reductions in response time for accident and road condition emergencies through combining DOT and public safety dispatching;
- Better removal of snow resulting in faster incident response and reduction in delays;
- Improved safety on roadways during inclement weather;
- Ability to monitor agency vehicles in real-time;
- Optimize the dispatching of agency vehicles for numerous operations.

In addition to highway maintenance, rural transit, law enforcement, and emergency medical services were also involved in the project. Several lessons were learned in the planning and implementation processes that would also pertain to an exclusively highway maintenance implementation. Budgets and time frames were found to be quite optimistic. Personnel resources were also found to be a key to successful implementation. "A committed project champion (empowered to make key decisions) at the local level is necessary to keep the project moving...Implementing an AVL system will require at least one full-time agency person dedicated to the project as the system is designed and integrated." (Deeter, et al, 2001) It was also recommended that several vendors and products should be examined to ensure that the technology is appropriate, the geographical coverage is adequate, and the most cost-effective solution is identified. The total cost of the project was $1,542,000. (MnDOT, 2002)

CHAPTER 5: COST ASSESMENT

5.1 Investment Costs

It is assumed that KDOT's existing 800 MHz radio system will be used, and a dedicated channel will be added for data transmissions. The implementation cost for the dedicated data channel is approximately $750,000 for the pilot project and $6,000,000 for a statewide deployment. These estimates were provided by KDOT's Bureau of Construction and Maintenance, based on current equipment costs. Consistent with other deployments, the communications costs are by far the most significant portion of the total system cost. Cost estimates for other components of the pilot test and subsequent statewide implementation were drawn from the data collected through the survey of transportation departments, conducted as part of this study. Various considerations were used to determine each number, including the consistency of the costs for that component across implementations, how recent the costs were (i.e., when the implementation began), and the similarities and differences between the characteristics of the implementations described in the survey and the expected characteristics of an application to KDOT needs. The scope of the pilot project and the statewide deployment in terms of administrative areas and vehicle counts is shown in Table 11.

Table 11. Pilot Project and Statewide Deployment Scope

	Pilot	Statewide
Areas	1	26
Subareas	6	112
Maintenance Vehicles	23	585
Paint Trucks	1	6

In the vehicle, three different types of expenditures are considered. An In-Vehicle Unit (IVU), comprising a GPS receiver, a data modem, and a Mobile Data Terminal (MDT), is estimated to cost approximately $3,500, including installation. A total of 24 units are considered for the pilot project—23 maintenance vehicles and one paint truck. Road and air temperature sensors are estimated to cost $600 per vehicle. However, it is assumed in this analysis that the existing sensors can be used. The software licensing includes mapping software, reporting software, and database software for the client server. It is assumed that a single computer will be used to store the information and act as a server. A single three-day training session has been included in the pilot project. The duration of the pilot project is assumed to be two years. The cost for evaluation assumes that the system can log the data needed for analysis. The expected costs for the pilot test are shown in Table 12. Because the radio system will be brand new at the outset of the pilot project, and the duration of the project is relatively short, it is assumed that no maintenance will be required on the radio system during the pilot project.

Table 12. Pilot Test Initial Costs

Items	Unit Rate ($)	No. of units	Amount ($)
Base station hardware	7,000	1 base station	7,000
Software (licensing)	25,000 for the first computer	1 computer	25,000
Sensors and software integration	$15,000 (software)		15,000
In Vehicle Units	3,500/unit	24 units	84,000
Training (3 days on site)			3,000
Repair and Maintenance	4,000/year	2 yrs[1]	8,000
System integration			15,000
Evaluation			50,000
Add data channel to radio system	$150,000/tower	5 towers	750,000
Total initial expenditure			957,000

[1] Project will encompass one year of planning and two years of data collection. Maintenance costs are only incurred during data collection.

If the results of the pilot project support a recommendation to move forward with statewide implementation, costs could be expected to be proportional to those of the pilot project with the exception of software integration and system evaluation. Software integration would occur once, whereas other implementation costs would occur at the individual area level. System evaluation should be mainstreamed into the standard departmental operating procedures. Evaluation parameters established during the pilot test should continue to be monitored during and following the statewide implementation. This will help to verify the cost-effectiveness of the system and serve as a means for evaluating future policy decisions and operational strategies. The costs associated with a statewide deployment are shown in Table 13.

Table 13. Statewide Implementation Costs

Items	Unit Rate ($)	No. of units	Amount ($)
Base station hardware	7,000	26 (1/area)	184,000
Software (licensing)	25,000 for the first computer 5,000 per additional	26 (1/area)	150,000
Sensors and software integration	$15,000 (software)		15,000
In Vehicle Units	3,500/unit	585 units	2,047,500
Training (3 days on site)	3,000/area	26 areas	78,000
Repair and Maintenance	4,000/year/area	26 areas	104,000
System integration	15,000/area	26 areas	390,000
Add data channel to radio system[1]			6,000,000
Total initial expenditure			8,968,500

[1] Includes $750,000 expended during pilot project.

5.2 Operation and Maintenance Costs

The operating cost generally involves the monthly fees for the CDPD connection if a CDPD based communication system is used. For a KDOT implementation of AVL, operation and maintenance costs are comprised primarily of maintenance and repair for the radio system's dedicated data channel, the in-vehicle units, and the base station equipment.

Annual maintenance costs are estimated to be purchase price of the equipment divided by the typical service life. Only equipment unique to the AVL system is considered. That is, the cost of maintaining the 800 MHz radio system is a cost that would be incurred regardless of whether or not an AVL system is implemented, so the implementation of AVL adds no incremental cost to the maintenance of the radio system. The cost of the in-vehicle units is estimated to be $3,500 each. Assuming the statewide implementation would involve 585 KDOT vehicles, and assuming a 7-year service life based on Schweiger, et al (1999), the average annual maintenance cost of the in-vehicle units would be $292,500. Assuming one base station at each area office with an initial cost of $7,000, also with a service life of 7 years, the annual maintenance cost of the base stations would be $26,000.

The incremental maintenance costs incurred by the addition of a dedicated data channel were estimated based on the KDOT Replacement Life Cycle of 12 years, assuming that an average of 1/12 of the equipment will be replaced each year. Under this assumption, each year's maintenance would be equal to the cost of the entire system ($6,000,000, see Investment Costs on page 56) time the percentage of the system deployed divided by 12. The total annual maintenance cost of the system, once fully deployed, would be $818,500.

5.3 Expected Benefits

The nature of the expected benefits can be drawn from the experience of other agencies combined with the operational characteristics of KDOT maintenance crews. Benefits that can be expected to include the following.

- More timely response to emergencies.
- Improved resource management by analyzing past activities to improve efficiency.
- Reduced snow-related accidents due to reductions in snow removal times.
- Increased security for drivers.
- Reduced legal costs from tort claims allegedly involving KDOT maintenance vehicles.
- Reduced material costs with more efficient application strategies.
- Reduced time associated with routine paperwork.

- More timely pavement condition information.
- Enhanced locational accuracy of various inventories and map segments.
- Increased completeness of various inventories (e.g., PMS).
- Automatic and continuous updates of pavement conditions for KDOT maintenance.
- Potential feed of near real-time information to KDOT Advanced Traveler Information Systems (ATIS) (e.g., web site, dial in, 511 (eventually)).
- Improved efficiency and effectiveness of roadside maintenance.

To develop an objective comparison of the costs and benefits associated with the implementation of AVL, a subset of the benefits listed above were quantified and compared with the maintenance costs over a 20-year period.

5.3.1 Benefits Survey

Nearly a year following the initial survey, at the end of the next winter season, a follow-up survey was conducted to gather additional information regarding the benefits, particularly those related to snow removal and paperwork reduction. Of the 15 agencies contacted, 7 provided estimates of their efficiency savings in snow removal due to the implementation of GPS. The values cited ranged from 5% to 50% improvement, with an average of just over 20%. Only 3 agencies provided estimates of savings due to reduced paperwork. The values were 10% and 20%, with one agency citing an increase of 15% in paperwork to facilitate analysis. The minimum and average values were used for the cost/benefit analysis discussed in the following sections (the increase in paperwork to facilitate analysis was ignored).

In addition, other benefits were emphasized. The following is a list of comments provided during the follow-up benefits survey.

- A need for 2 new trucks was anticipated, but the efficiency improvements due to AVL implementation reduced the need to just 1 truck. The savings in equipment costs plus the money saved on claims more than offset the cost of the system.
- Paperwork increased due to analysis
- AVL helped set optimal speeds
- Takes the paperwork away from drivers
- Locates the deadheading
- 50% improvement due to accountability
- 25-50% reduction in materials--big help in tracking how much de-icer is used
- Once fully implemented, all related paperwork will be automated.
- Reduced deadheading.
- Saves a lot on materials by monitoring usage rates and segments treated.

The following sections detail the savings in several areas, followed by a cost-benefit comparison for three different implementation scenarios. Two sets of estimates are presented in the sections that follow. Conservative estimates are detailed, representing the least magnitudes cited in the follow-up survey. The probable benefits are represented by moderate estimates, using the average of the values cited in the follow-up survey.

It should be noted that because only one agency provided a value for savings in materials, this factor was not included in the costs/benefit analysis. The efficiency improvement cited was 25-50 percent, which would represent substantial monetary savings, in addition to those included in the analysis.

5.3.2 Savings in Paperwork

The savings resulting from reduced paperwork are calculated on the basis of the daily and weekly reports filed by maintenance crews and paint crews. The calculations assume the reports require 25 minutes daily for each maintenance vehicle and 20 minutes weekly for each sub-area supervisor. An hourly wage of $10 is used, and the AVL system is assumed to reduce the time required to fill out the paperwork by 10%, which was the smallest of the values reported in the benefits survey. The results based on these assumptions are shown in Table 14.

Table 14. Statewide Savings Due to Reduced Paperwork (Conservative Estimate).

	Annual Cost		Annual Savings	
Maintenance	Pilot	Statewide	Pilot	Statewide
Form 306, Individual Daily Report	$ 24,917	$ 633,750	$ 2,492	$ 63,375
Form 303, Weekly Traffic Line Report	$ 1,040	$ 19,413	$ 104	$ 1,941
Paint Crews	Pilot	Statewide	Pilot	Statewide
Form 306, Individual Daily Report	$ 1,083	$ 6,500	$ 108	$ 650
Form 340, Weekly Traffic Line Report	$ 1,040	$ 19,413	$ 104	$ 1,941

Total Annual Savings: $ 67,908

A moderate estimate of 15% time savings—the average of the values reported in the benefits survey—would result in an annual savings of $101,862.

5.3.3 Savings from More Efficient Fleet Management

By recording and analyzing fleet activities, vehicles can be used more efficiently, reducing the overall mileage incurred and the associated costs. For maintenance vehicles, annual mileage was estimated by dividing the service life in miles by the service life in years. 200,000 miles / 11 years = 18,182 miles/yr. An operational cost of $0.47/mi was assumed. The conservative and moderate estimates of savings were taken as the minimum and average values, respectively, that were reported in the benefits survey. The conservative estimate of 5% savings would result in an annual savings of $398,864, while the moderate estimate of 20% savings would result in an annual savings of $1,595,455, as shown in Table 15.

Table 15. Statewide Savings from More Efficient Fleet Management (Conservative Estimate).

	Overall Annual Costs		Overall Annual Savings	
	Pilot	Statewide	Pilot	Statewide
Maintenance (Mileage)	$ 313,636	$ 7,977,273	$ 15,682	$ 398,864
Paint Truck (hrs)	$ 57,787	$ 346,720	$ 2,889	$ 17,336

Total Annual Savings: $ 416,200

For paint trucks, a similar calculation was performed using the same percent savings estimates (none of the agencies surveyed were using AVL in paint trucks). Using the vehicle service life, an annual average was calculated for the hours of use. 10,000 hours / 15 years = 667 hrs/yr. Assuming an operational cost of $71.88/hr and a 5% improvement in efficiency due to the implementation of AVL, an annual savings of $17,336 would be realized. The moderate estimate of annual savings is $69,344.

5.3.4 Savings from Reduced Accidents

Accident costs were calculated based on USDOT recommendations. (USDOT, 1994) Costs per accident were adjusted to 2002 dollars using the implicit outlay deflators recommended by the US Bureau of Economic Analysis. (USA, 2001) The accident counts used were statewide counts taken from the Kansas Accident Records System (KARS) database for the year 2000. (KDOT, 2001) To ensure a conservative estimate, the number of accidents was used, rather than the number of parties involved. If more than one party was injured in any given accident, only the maximum injury as indicated by KARS was considered. The data was filtered to extract only accidents, in which the reported pavement condition was snow covered, snow packed, or ice covered. It should be noted that while winter maintenance operations planning is done in terms of winter seasons which span two consecutive years, both weather records and accident records (as well as economic parameters) are archived based on the calendar year. Consequently, snow-related accidents for the year 2000 will involve accidents that occurred in two different winter seasons. The calculations performed are valid, however, so long as the time frame used is consistent.

To estimate the effects of AVL implementation on accident costs, it was assumed that efficiency in snow removal would be improved by 5% for the conservative estimate, with a corresponding 5% reduction in snow-related accidents in each severity category. For each of those accidents affected, it was assumed that injury accidents would have fallen into the next less severe category (property damage only accidents would be averted). For example, for every 100 accidents resulting in a debilitating injury to at least one occupant, it would be assumed that implementing AVL would result in five of those accidents (5%) being classified as non-debilitating injury instead of debilitating injury. Downgrading accident severity was used rather than simply reducing the number of accidents in each category in order to ensure a conservative estimate. Based on these assumptions, the total annual statewide savings in accident costs due to AVL implementation is conservatively estimated to be $5,865,296, as shown in Table 16.

Table 16. Statewide Savings in Accident Costs (Conservative Estimate).

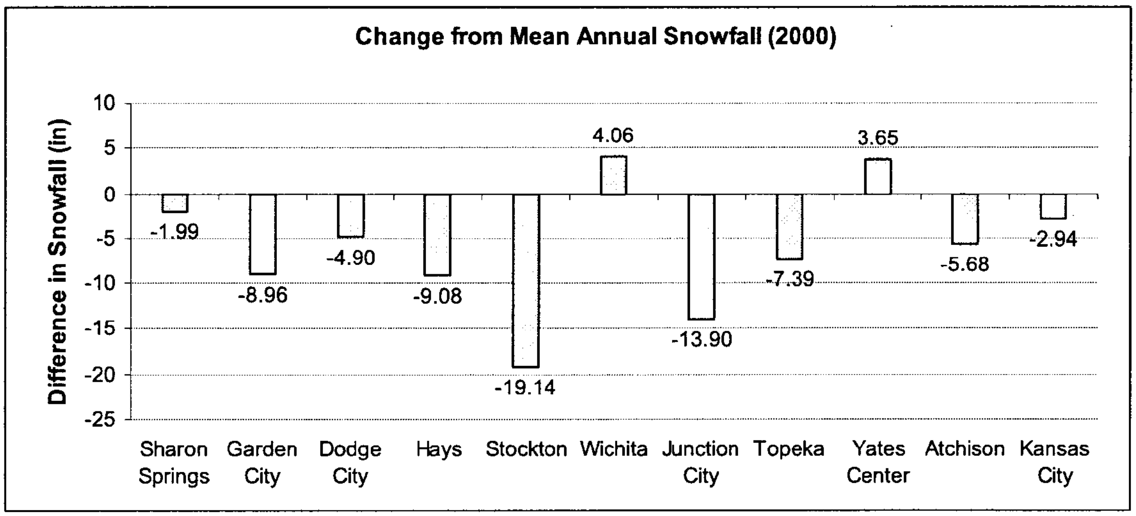
KARS severity code	F	D	I	P	N	
Description	Fat	Debilitating	Non-Debilitating	Possible	PDO	Notes
Cost per event (1994 dollars)	$ 2,600,000	$ 180,000	$ 36,000	$ 19,000	$ 2,000	1
Cost per event (2002 dollars)	$ 2,981,557	$ 206,415	$ 41,283	$ 21,788	$ 2,294	2
Accidents	24	100	516	600	5421	3
Involved Parties	43	134	794	967	8185	4
Total Weather Costs	$ 71,557,369	$ 20,641,549	$ 21,302,078	$ 13,072,981	$ 12,433,093	
Accidents Affected	5%	5%	5%	5%	5%	5
Savings	$ 3,330,170	$ 825,662	$ 502,966	$ 584,844	$ 621,655	6

Total Accident-Related Savings $ 5,865,296

1) Data Source: FHWA, 1994 Technical Advisory
2) Adjusted for 2002 using deflators from the Bureau of Economic Analysis
3) Source: 2000 KARS Data
4) Shown for comparison only. To ensure a conservative estimate, accidents are used in calculations.
5) Percentage of accidents affected was arbitrarily set as a conservative estimate.
6) Savings result from 1% of accidents in each category being downgraded to the next lesser severity.

Because the amount of snowfall can vary widely from year to year and from one location in the state to another, historical records were examined to determine what relationship the snowfall in the year 2000 has to the average annual snowfall. Data was obtained from the High Plains Regional Climate Center at the University of Nebraska, Lincoln. (HPRCC, 2002) For the year 2000, the snowfall relative to the annual average for various locations across the state is shown in Figure 14. The corresponding data is provided in Table 17. The data shows that the winter of 2000 was a relatively mild winter compared to historical averages for Kansas, at least with respect to snowfall. Of the eleven locations considered, nine experienced snowfalls below normal, five of them by more than 6 inches. Wichita and Yates Center, the two locations that experienced snowfall above normal for the year, exceeded the annual averages by just 4.06 and 3.65 inches, respectively. Based on this data, the use of snow-related accident data from the year 2000 is likely to be a conservative estimate of what can be expected annually.

Figure 14. 2000 Snowfall Relative to Annual Averages.



Source: High Plains Regional Climate Center, University of Nebraska at Lincoln

Table 17. 2000 Snowfall Relative to Annual Averages.

	Sharon Springs	Garden City	Dodge City	Hays	Stockton	Wichita	Junction City	Topeka	Yates Center	Atchison	Kansas City
Avg	24.99	19.96	19.00	20.28	25.54	15.84	20.40	19.59	15.35	20.58	18.54
2000	23.00	11.00	14.10	11.20	6.40	19.90	6.50	12.20	19.00	14.90	15.60
Difference	-1.99	-8.96	-4.90	-9.08	-19.14	4.06	-13.90	-7.39	3.65	-5.68	-2.94
(as pct)	-8%	-45%	-26%	-45%	-75%	26%	-68%	-38%	24%	-28%	-16%

Source: High Plains Regional Climate Center, University of Nebraska at Lincoln

To generate a moderate estimate of accident savings, a percent reduction of 20% was used. Additionally, the number of parties involved in accidents was used in place of the number of accidents. For example, an accident involving two cars in which 4 people were injured would count as 1 in the conservative estimate and 2 in the moderate estimate. Some adjustment for snowfall is merited, though the data available is not sufficiently detailed to provide any statistically based adjustment. The average percent difference between the average annual snowfall and the year 2000 snowfall for the locations shown in Table 17 is a 27% decrease. Because the most heavily populated areas, Wichita, had above normal snowfall, a conservative adjustment is warranted. For the moderate estimate of cost savings due to AVL implementation, it was assumed that the typical year would experience 13.6% more snowfall than occurred in 2000 (half of the average across the locations cited in Table 17), and a corresponding increase in snow-related accidents would occur. The average value reported in the benefits survey, 20%, was used as the moderate value. The resulting calculations are tabulated in Table 18.

Table 18. Statewide Accident Savings (Moderate Estimate).

KARS severity code	F	D	I	P	N	
Description	Fat	Debilitating	Non-Debilitating	Possible	PDO	Notes
Cost per event (1994 dollars)	$ 2,600,000	$ 180,000	$ 36,000	$ 19,000	$ 2,000	1
Cost per event (2002 dollars)	$ 2,981,557	$ 206,415	$ 41,283	$ 21,788	$ 2,294	2
Accidents	24	100	516	600	5421	3
Involved Parties	43	134	794	967	8185	4
(Adjusted for avg snowfall)	49	152	902	1099	9298	5
Total Weather Costs	$ 145,643,098	$ 31,421,391	$ 37,236,693	$ 23,934,711	$ 21,325,380	
Accidents Affected	20%	20%	20%	20%	20%	6
Savings	$ 27,112,023	$ 5,027,423	$ 3,516,799	$ 4,283,053	$ 4,265,076	7

Total Accident-Related Savings $ 44,204,374

1) Data Source: FHWA, 1994 Technical Advisory
2) Adjusted for 2002 using deflators from the Bureau of Economic Analysis
3) Source: 2000 KARS Data
4) Shown for comparison only. To ensure a conservative estimate, accidents are used in calculations.
5) Increased by 13.6% to account for below average snowfall in 2000, the year from which accident data was used.
6) Percentage of accidents affected was arbitrarily set as a conservative estimate.
7) Savings result from 1% of accidents in each category being downgraded to the next lesser severity.

Based on the moderate assumptions, the total annual savings in snow-related accident costs resulting from a statewide AVL implementation would be $44,204,374.

5.4 Cost-Benefit Comparison

Three implementation scenarios were considered. After the pilot test completion in 2004, the aggressive implementation assumes one district is added to the system each year until the system is complete. The moderate implementation assumes full implementation occurs over 10 years, and the conservative implementation assumes the full implementation occurs over 20 years. Table 19 and Table 20 show the net annual savings, net present value (NPV), and benefit-cost ration (B/C) for each implementation scenario based on conservative assumptions and moderate assumptions, respectively. The investment cost figures shown in the tables are based on the total implementation cost shown in Table 13, converted to 2002 dollars to account for the differing implementation schedules.

It should be emphasized that this analysis only considers those benefits that can be foreseen and can be quantified with reasonable confidence. Some benefits, such as reducing response time for emergency situations, cannot be reliably expressed in monetary figures, but are nonetheless real benefits. They should be considered in addition to those represented in the quantitative cost-benefit analysis. Additionally, there will almost certainly be benefits that cannot be foreseen. AVL is a mature technology, but its development has occurred mostly in the commercial vehicle, transit, and emergency services communities. The application of AVL to highway maintenance is relatively recent, and the spectrum of potential benefits is still being explored.

Table 19. Conservative Estimate of NPV for Statewide Implementation.

Disc. Rt. 5%	Aggressive Implementation		Moderate Implementation		Conservative Implementation	
Year	Pct Complete	Net Savings (2002 Dollars)	Pct Complete	Net Savings (2002 Dollars)	Pct Complete	Net Savings (2002 Dollars)
2003	0%	$ -	0%	$ -	0%	$ -
2004	17%	$ 836,115	10%	$ 501,669	5%	$ 250,835
2005	33%	$ 1,592,601	20%	$ 955,560	10%	$ 477,780
2006	50%	$ 2,275,144	30%	$ 1,365,086	15%	$ 682,543
2007	67%	$ 2,889,072	40%	$ 1,733,443	20%	$ 866,722
2008	83%	$ 3,439,371	50%	$ 2,063,623	25%	$ 1,031,811
2009	100%	$ 3,930,710	60%	$ 2,358,426	30%	$ 1,179,213
2010	100%	$ 3,743,533	70%	$ 2,620,473	35%	$ 1,310,237
2011	100%	$ 3,565,270	80%	$ 2,852,216	40%	$ 1,426,108
2012	100%	$ 3,395,495	90%	$ 3,055,945	45%	$ 1,527,973
2013	100%	$ 3,233,805	100%	$ 3,233,805	50%	$ 1,616,902
2014	100%	$ 3,079,814	100%	$ 3,079,814	55%	$ 1,693,898
2015	100%	$ 2,933,156	100%	$ 2,933,156	60%	$ 1,759,894
2016	100%	$ 2,793,482	100%	$ 2,793,482	65%	$ 1,815,763
2017	100%	$ 2,660,459	100%	$ 2,660,459	70%	$ 1,862,321
2018	100%	$ 2,533,771	100%	$ 2,533,771	75%	$ 1,900,328
2019	100%	$ 2,413,115	100%	$ 2,413,115	80%	$ 1,930,492
2020	100%	$ 2,298,205	100%	$ 2,298,205	85%	$ 1,953,474
2021	100%	$ 2,188,766	100%	$ 2,188,766	90%	$ 1,969,890
2022	100%	$ 2,084,539	100%	$ 2,084,539	95%	$ 1,980,312
2023	100%	$ 1,985,276	100%	$ 1,985,276	100%	$ 1,985,276
Total		$ 53,871,697		$ 45,710,829		$ 29,221,770
Inv. Cost		$ 7,225,610		$ 6,595,465		$ 5,322,254
NPV		**$ 46,646,087**		**$ 39,115,364**		**$ 23,899,517**
B/C		**3.0**		**2.9**		**2.6**

Table 20. Moderate Estimate of NPV for Statewide Implementation.

Disc. Rt. 5%	Aggressive Implementation		Moderate Implementation		Conservative Implementation	
Year	Pct Complete	Net Savings (2002 Dollars)	Pct Complete	Net Savings (2002 Dollars)	Pct Complete	Net Savings (2002 Dollars)
2003	0%	$ -	0%	$ -	0%	$ -
2004	17%	$ 6,825,780	10%	$ 4,095,468	5%	$ 2,047,734
2005	33%	$ 13,001,485	20%	$ 7,800,891	10%	$ 3,900,446
2006	50%	$ 18,573,551	30%	$ 11,144,130	15%	$ 5,572,065
2007	67%	$ 23,585,461	40%	$ 14,151,277	20%	$ 7,075,638
2008	83%	$ 28,077,930	50%	$ 16,846,758	25%	$ 8,423,379
2009	100%	$ 32,089,063	60%	$ 19,253,438	30%	$ 9,626,719
2010	100%	$ 30,561,012	70%	$ 21,392,709	35%	$ 10,696,354
2011	100%	$ 29,105,726	80%	$ 23,284,581	40%	$ 11,642,290
2012	100%	$ 27,719,739	90%	$ 24,947,765	45%	$ 12,473,883
2013	100%	$ 26,399,751	100%	$ 26,399,751	50%	$ 13,199,876
2014	100%	$ 25,142,620	100%	$ 25,142,620	55%	$ 13,828,441
2015	100%	$ 23,945,353	100%	$ 23,945,353	60%	$ 14,367,212
2016	100%	$ 22,805,098	100%	$ 22,805,098	65%	$ 14,823,314
2017	100%	$ 21,719,141	100%	$ 21,719,141	70%	$ 15,203,399
2018	100%	$ 20,684,896	100%	$ 20,684,896	75%	$ 15,513,672
2019	100%	$ 19,699,901	100%	$ 19,699,901	80%	$ 15,759,921
2020	100%	$ 18,761,810	100%	$ 18,761,810	85%	$ 15,947,539
2021	100%	$ 17,868,391	100%	$ 17,868,391	90%	$ 16,081,552
2022	100%	$ 17,017,515	100%	$ 17,017,515	95%	$ 16,166,639
2023	100%	$ 16,207,157	100%	$ 16,207,157	100%	$ 16,207,157
Total		$ 439,791,381		$ 373,168,650		$ 238,557,229
Inv. Cost		$ 7,225,610		$ 6,595,465		$ 5,322,254
NPV		**$ 432,565,771**		**$ 366,573,185**		**$ 233,234,975**
B/C		**28.4**		**27.4**		**24.3**

Based on the moderate estimates, the agency savings in reduced paperwork and improved fleet management total \$1,766,661/year. Annual maintenance costs are estimated to be \$818,500/year. According to these numbers, the system would more than not pay for its operational costs in efficiency savings.

The Benefit-Cost Ratio would be at least 2.6 (based on the conservative assumptions) and would probably 24 or higher (based on the moderate assumptions). Depending on the implementation schedule, AVL would likely result in a net savings of between \$230 million and \$430 million over 20 years (Net Present Value, 2002 dollars).

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Because the application of AVL to highway maintenance is a relatively recent phenomenon, quantitative data that defines the benefits are not available. In the FHWA's most recent report on ITS benefits, when AVL and other operations and maintenance applications are discussed, the authors summarize the state of the practice, "As implementation of these systems expands, quantified benefits of their use will become apparent. However, there are no benefits data available at this time." (Proper, et al, 2001) This lack of data emphasizes the need for including the evaluation from the outset of the implementation planning. As an afterthought, evaluation seldom gains the momentum necessary to generate funding.

In spite of the lack of quantitative studies, the evidence seems clear that there are real benefits and that the likely magnitudes of those benefits are large enough to justify deployment, from a cost-effectiveness perspective. The literature and the results of the survey conducted during this study suggest that AVL/MDT can provide a significant benefit to highway maintenance operations. The cost benefit ratio is almost certainly greater than one and probably seven or higher. A moderate estimate of the net present value of statewide implementation ranges from $230 million to over $430 million over 20 years, depending on the implementation schedule. The annual efficiency savings for the Department are estimated to be nearly twice the annual maintenance cost of the system.

So, in addition to paying for itself, the system will provide excess fiscal benefit that can be used to improve other aspects of maintenance.

6.2 Recommendations

Based on the results of the cost-benefit comparison presented in Chapter 5, it is recommended that funding be sought for conducting an AVL pilot test. Additional recommendations pertaining to the pilot test include the following.

1. The test should comprise one Area. District 6 is recommended because the maintenance engineer has demonstrated enthusiasm for such a project and is knowledgeable of the implications.
2. The existing 800 MHz radio system should be used as the communications link. Other communications media are either too expensive (e.g., satellite), or do not provide adequate coverage (e.g., CDPD)
3. A dedicated channel on the 800MHz radio system should be made available exclusively for data transmissions. Leasing of equipment should be considered if available.
4. A project champion at the local level should be identified and empowered to make key decisions.
5. An independent evaluator should be identified and contracted to participate in the planning of the test to assure that the system is designed so that the necessary data can be collected, for the sake of both the evaluation and the eventual statewide implementation.
6. The test should span 3 years, including the following components.

a. Execution of the necessary contracts;
b. Planning, design, procurement, and testing of system components and software; generation by the independent evaluator of an evaluation plan detailing the measures of effectiveness and the analysis procedures to be used in the evaluation; (6 months)
c. System activation; the system should be used for logging data related to operations *without* AVL; (12 months)
d. Personnel should be given the necessary training to integrate use of the system into all applicable maintenance activities; the data logged during this period will be compared with the previously logged data to assess the incremental benefits; (12 months)
e. Data post-processing and analysis; generation of the project report. (6 months)

7. 12 month-before and after test periods may be insufficient for obtaining statistically significant quantitative results from the evaluation effort, particularly if accident data is to be analyzed. Quantitative assessment of agency efficiency and qualitative evaluation operational changes may be feasible in that time frame, however. The final decision regarding the length of the test periods should be made during the planning stage in consultation with the evaluator.
8. Multiple systems and vendors should be considered before making any selection. Of the 15 systems identified in the survey, 7 involved Orbital

TMS and 4 involved Compass.Com (one deployment involved both). 12 other companies were involved in at least one project.

The potential for AVL to improve the efficiency and effectiveness of highway maintenance operations appears to be significant. Because the technology is well established and there is some precedent among transportation agencies from which to learn, AVL implementation can be done cost-effectively and with a high level of confidence that the system will prove beneficial. The agency and user cost savings afforded by AVL make the technology a very appealing tool for highway maintenance activities, and the state of the practice is ready to support reliable deployment. With proper attention to planning and evaluation, AVL can help KDOT further improve the quality of highway transportation throughout Kansas.

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APPENDIX A: PRELIMINARY SURVEY

Which of the following seven choices best describes your agency's experience with **Automatic Vehicle Location (AVL)** and **Mobile Data Terminals (MDTs)** used in **maintenance vehicles**?

☐ Implemented AVL without MDT
☐ Implemented AVL with MDT
☐ Currently planning AVL without MDT
☐ Currently planning AVL with MDT
☐ Currently considering AVL
☐ Have not considered AVL
☐ Considered AVL and chose not to proceed at this time
Please list the primary reason(s) for not pursuing AVL farther.

____

Who is the best person to contact for additional information?
☐ You should contact me (the one to whom this survey was mailed).
☐ You should contact:

(Name) ____________________
(Agency) ____________________
(Address) ____________________
(City, State, Zip) ____________________
(Phone) ____________________

Are you aware of any other county or local agencies using AVL in maintenance operations in your state?

1. (Name) ____________________
(Agency) ____________________
(Address) ____________________
(City, State, Zip) ____________________
(Phone) ____________________
2. (Name) ____________________
(Agency) ____________________
(Address) ____________________
(City, State, Zip) ____________________
(Phone) ____________________

APPENDIX B: DETAILED SURVEY

Contact information

Name:

Agency:

Survey questions

1. Does the system include Mobile Data Terminals (MDTs)?

   Yes ☐ No ☐

2. What kind of technology is being deployed?

   For determination of vehicle locations:

   GPS ☐

   Others ☐

   Please specify: ____________________

   For communication purposes:

   Radio ☐ Band:______ Mhz

   Satellite ☐ Service provider:__________

   Analog Cellular ☐ CDPD ☐

   Others ☐

   Please Specify: ____________________

   Comments:

3. No(s) of installed-vehicles:

   a) Type of vehicle ____________________

      Existing No. (s) _______ Expected No. (s) __________ by the year_______

   b) Type of vehicle ____________________

      Existing No. (s) _______ Expected No. (s) __________ by the year_______

4. These vehicles are being used for which purposes:

☐ Snow removal

☐ Right of way/pavement maintenance

☐ Striping

☐ Other (specify)

1. Which private agency has worked for deploying these technologies?

2. Approximate COSTS:

Startup costs:

a) Hardware at the control/dispatch center: ____________________

b) Software at the control/dispatch center: ____________________

c) Installation cost per vehicle: ____________________

d) Other costs: ____________________

Operational costs:

3. How does the system help operations?

☐ More efficient snow removal

☐ Reduced liability

☐ Reduced paperwork

☐ Other (list)

APPENDIX C: 2003-04 ITS SET-ASIDE FORM

Kansas ITS Project Form

Project Name (with ITS Involvement):
Automatic Vehicle Location (AVL) Pilot Deployment

KITS ID:

Project Champion (Name/Bureau):
Jaci Vogel / Ron Hall

KDOT Project No.:

Project Description:
An AVL system will be implemented in Area X of District 6. The deployment will include 23 maintenance trucks, 1 paint truck, and one base station located at the Area Office. A thorough evaluation will be conducted to assess the likely cost-effectiveness of a subsequent statewide deployment.

Resources: Advisory Project Team

- ☒ KDOT District # 6
- ☐ FHWA
- ☐ Office of Chief Counsel
- ☐ Bureau of Computer Services
- ☒ Bureau of Construction & Maintenance
- ☐ Bureau of Design
- ☐ Bureau of Traffic Safety
- ☐ Bureau of Local Projects
- ☐ Bureau of Traffic Engineering
- ☐ Bureau of Transportation Planning
- ☐ Office of Transportation Information
- ☐ Kansas Highway Patrol
- ☒ Universities - KU
- ☐ Other -

Applicable User Services/Functional Areas:

Metropolitan:

- ☒ Traveler Information
- ☐ Freeway Management
- ☐ Traffic Signal Control
- ☐ Transit Management
- ☐ Electronic Toll Collection
- ☐ Electronic Fare Payment
- ☐ Incident Management
- ☐ Emergency Management
- ☐ Highway/Rail Intersection

Rural:

- ☐ Emergency Services
- ☒ Fleet O&M
- ☒ Infrastructure O&M
- ☒ Safety & Security
- ☐ Traveler Mobility
- ☐ Commercial Vehicle Operations
- ☐ Tourism & Traveler Info

Other:

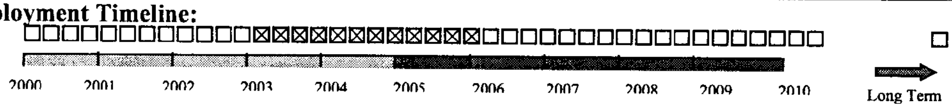
- ☐ Telecommunications

Related Projects/Interfaces:
Transition to 800MHz; Allocation of a dedicated data channel; KDOT traveler information systems

Telecommunication Needs/Considerations:
A dedicated data channel will need to be added to the 800MHz radio system. (This cost is included in the figures below.)

Design Needs and Considerations:

Deployment Timeline:



Estimated Costs:
Study: $ 50,000
Design: $ 30,000
Capital: $ 869,000
O&M: $ 8,000
Total: $ 957,000

Benefits:

- ☒ Safety
- ☐ Travel Time
- ☒ Customer Satisfaction
- ☒ Cost Savings
- ☐ Throughput
- ☐ Environmental

Funding Sources:

- ☐ Federal %
- ☐ State %
- ☐ Local %
- ☒ ITS Set-aside
- ☐ Local Projects
- ☐ System Enhancement
- ☐ K-TRAN
- ☐ ENTERPRISE
- ☐ Public/Private
- ☐ Other -

Project Type:

Project Status:

Completion Date:

APPENDIX D: PROJECT FORM FOR SYSTEM DESIGN

KANSAS DEPARTMENT OF TRANSPORTATION
CONSTRUCTION PROJECT AUTHORIZATION

X Program Addition		Project Funding			Route, Co., Proj. No.	106 K-8199-01
District	VI	Fund Source	Percent	Maximum	FA Project No.	State Funds
County		State	100		Program Fiscal Year	2001
Length (Km)	--	Federal			Fund Class	PE = K
STP Class	N/A	County			KDOT Fund No.	4100
Env. Class.	Class II, Type A	City			DA Account No.	0697
Oversight		Railroad			KDOT Program No.	9916
Funct Cl/Syst	N/A				1998 AADT	
INITIATED BY:	Bureau of Transportation Planning				Prog Cat / Sub Cat	Major Mod / ITS
Signature Matthew A. Volz			Date 5/19/00		3R / AASHTO Stds.	AASHTO

LOCATION: District VI.

SCOPE OF IMPROVEMENT: PE to design an Automated Vehicle Location and Mobile Data Terminal System for maintenance vehicles. The system will be demonstrated in District VI with future deployment Statewide.

PRELIMINARY COST ESTIMATE			1999			Inflation	1999	SUBTOTALS
ROADWAY:	Construction Type	Length Kilometers	Cost Km			Rate 7.60%	Construction Cost	Construction Cost
Grading:								
Surface:								
Shoulders:					1999	1999		
BRIDGE Fund Class	Program Category	Br. No.	Width Meters	Length Meters	Sq. M.	Cost Sq. M. / FHWA Suff Rating		

OTHER

This is a FY 2000 ITS Set-aside Project that is now programmed for FY 2001.
Related Projects:
KTRAN Project (Study of AVL/MDT), KU-01-5.

Total Construction Cost.		
Construction Engineering.		
Right-of-Way Cost.		
Utility Cost.		
Preliminary Engineering		100,000
CURRENT TOTAL PROJECT COST		100,000

PREVI. TOTAL PROJ. COST	--
ORIG. 883 COST ESTIMATE	100,000

Comments:

Chief of Program Management 5/30/00 Date

OFFICE OF ENGINEERING SUPPORT | Scheduled Letting Date N/A

Comments:

Project Control Engineer 6-12-00 Date

FHWA Concurrence
Envir. Classification
Design Criteria
Date/Signature

PROJECT AUTHORIZATION
✓ Approve
Disapprove

State Transportation Engineer 6-13-00 Date

Rev. 10-99 DG JUN 14 2000 DOT Form No. 883

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