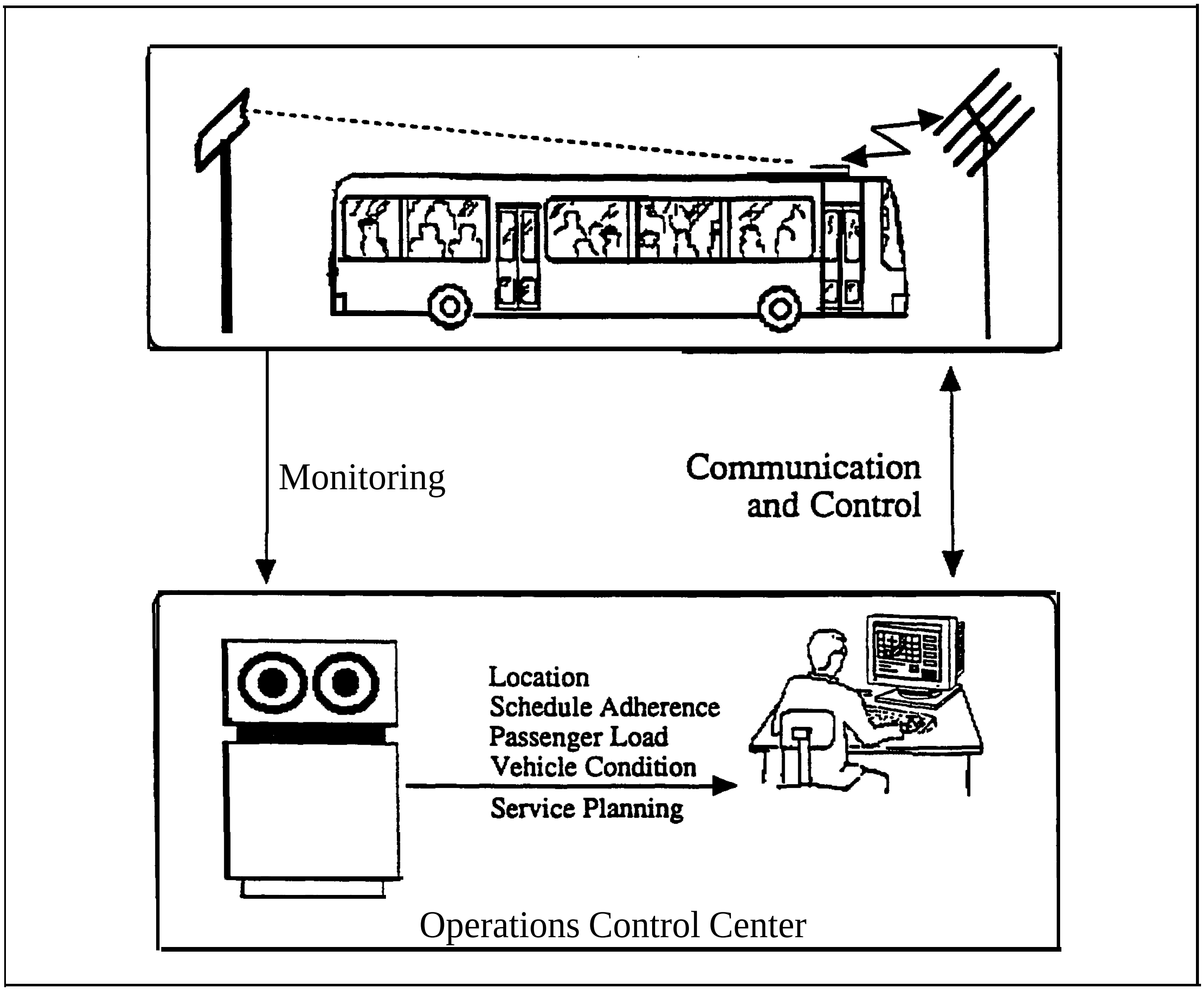
U.S. Department
of Transportation

Advanced Vehicle Monitoring and Communication Systems for Bus Transit

Benefits and Economic Feasibility

September 1991
Revised March 1993



FEDERAL TRANSIT ADMINISTRATION

Advanced Vehicle Monitoring and Communication Systems for Bus Transit

Benefits and Economic Feasibility

Final Report
September 1991
Revised March 1993

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Prepared for
Univeristy Research and Training Program
Office of Technical Assistance
Federal Transit Administration
Washington, DC 20590

Distributed in Cooperation with
Technology Sharing Program
U.S. Department of Transportation
Washington, D.C. 20590

DOT-T-94-03

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Technical Report

This report analyzes the feasibility of advanced vehicle monitoring and communication (AVM/C) systems for bus transit in the United States. Such systems are widely used in Europe and Canada to provide more reliable and efficient bus services, but have seen little deployment in the U.S. Many systems are now available from both American and foreign vendors, and thus the question of whether or not to deploy such a system is coming to the forefront in many transit agencies. In this report, the potential benefits of such a system are discussed, including benefits to current and new riders in the form of better service, to the agency in the form of increased revenues and reduced costs, and to communities in a variety of ways including "town watch" functions. This sets the stage for a discussion of the actual experience of foreign and domestic agencies that have introduced such systems, including costs and benefits. A method for evaluating the feasibility of AVM/C systems is presented, for both outright purchase and for leasing - a very attractive alternative that conserves scarce capital resources. Calculations for typical U.S. conditions suggest that these systems should be quite cost effective, improving both agency finances and passenger satisfaction. Agencies should consider them carefully.

Executive Summary

This report addresses one of the most important and potentially effective ways to improve the attractiveness of bus transit services: the use of advanced information technology to monitor and control bus operations. Specifically, it focuses on the use of automatic vehicle monitoring (AVM) systems, which are more properly referred to as ***advanced vehicle monitoring and communication (AVM,/C) systems.*** AVM/C systems have great potential for improving the productivity and attractiveness of bus services. As the name suggests, essential components of these systems include an element which can track vehicle location in real time and an element which provides direct digital data, and often voice communication between each vehicle and the dispatcher. In addition, the computer system manages and processes the data in real time to assist the dispatcher in better controlling bus operations. These systems can also be used to provide information for purposes of route and schedule planning, maintenance management, and operating statistics, and can provide the basic data for real time passenger information services.

The purpose of this report is to provide a knowledge base for transit managers that will enable them to evaluate the potential of AVM/C systems for application to their particular transit systems. The main sections of this report address the following topics:

- Identify the various AVM/C systems and options.
- Identify possible benefits and likely costs of such systems.
- Describe the experience to date with AVM/C systems on properties in North America and elsewhere.
- Provide a methodology by which the feasibility of such systems can be determined, including various public/private financing options.

A summary of our findings follows. ***There is no standard AVM/C system for bus transit, but rather there*** are ***many such systems, consisting*** of ***different types of hardware elements and performing a variety of different functions.*** The basic elements which characterize any AVM/C system include: a means for automatic vehicle location (AVL), a communication system between bus drivers and dispatchers, including digital and/or voice interface, a computer and software for assembling and managing, in real time, the data on bus location and any other data gathered (e.g., passenger loads, vehicle condition), software for comparing actual with desired performance (e.g., actual operations to schedules), and assistance to the dispatcher in correcting undesirable situations. Critical to the success of AVM/C systems is appropriate training of dispatchers and drivers.

The benefits of AVM/C systems are potentially quite widespread. One broad class of benefits derives from the better real time control of operations, which leads to improvements in schedule adherence and service reliability, reduced overcrowding and in general improvements in the quality of service ***from the standpoint of the user. Concomitant with this are various improvements from the standpoint of the transit agency, including***

the ability to reduce slack time in schedules and thereby reduce the fleet size, number of drivers, and vehicle miles operated to achieve a given ***level*** of ***service.*** Thus, there is clearly a range of possibilities for justifying AVM/C systems, between, at one extreme, the benefits being derived entirely from service quality improvements and, at the other extreme, providing the same quality of service at reduced cost. Most agencies, of course, choose to achieve some intermediate target consisting of both service improvements and cost reduction. ***The improved quality of service generally leads to increased ridership,*** and this benefits the agency in the form of increased passenger revenue. In addition there are variety of somewhat secondary benefits, such as enhancing the image of the agency through its use of advanced technology, and the potential to use this technology to not only monitor bus operations but ***also to perform a "town watch" service to communities served*** by the transit system. Also, the enhanced information on the location of buses can be used to provide very reliable information to passengers regarding expected bus arrival times, via message signs at bus stops or via telephone.

A number of transit systems have introduced AVM/C systems and some have, to varying degrees, ascertained the magnitude of the benefits. While the benefits in any one particular application are likely to deviate from those in another, these do give some idea of the relative benefits. For example, in Toronto, where a very advanced AVM/C system has been installed on the routes of the Wilson garage, it was found that routes equipped with such a system could be operated with significantly fewer vehicles and drivers than routes without. Also, the town watch benefits seem to be significant; police response times to emergency situations were observed to decrease by about 30%. The experience of Seattle illustrates the potential benefits in terms of reducing the cost of obtaining the traffic and operating data necessary to periodically revise routes and schedules. With the AVM/C system these data could be obtained at a cost of about $250,000 in contrast to previous expenditure of about $2 million per year. In Cincinnati, early experiments with an AVM/C system led to the conclusion that the same or better level of service could be provided with approximately 7% fewer bus miles and 8% fewer driver platform hours on the routes originally equipped. These routes were those for which the benefits were exceptionally high, but extrapolation to the remainder of the system indicated that overall there would be a 2% reduction in operating cost. In Dublin, much attention was paid to the reliability of service. It was observed that gaps in service greater than 15 minutes were reduced by 60% and that the number of runs lost due to excessive traffic congestion was reduced by 30%. Correspondingly, a decline in ridership was reversed with these service improvements. While these are just a smattering of the benefits that have been observed, they do indicate the nature and approximate magnitudes of benefits that might be obtained.

As for the cost of installing and operating an AVM/C system, current evidence is fragmentary and inconclusive. Part of the reason for this is the newness of these systems, and the different pricing and marketing strategies employed by the various suppliers. For example, some may offer systems at a low price, hoping to garner market share and then increase prices and profitability, while others might follow the more traditional pricing strategy of initially pricing high in order to recover the development costs and then reducing prices as sales increase. With these caveats, ***it nevertheless appears as though the average recent price for such systems*** is ***approximately $8,000 per bus, but it must be remembered that substantial deviations from this figure are observed.***

An important issue is how a transit agency might evaluate the feasibility or desirability, of an AVM/C system for its operation. The first task must be a determination of the kind of system appropriate for that particular agency, in the sense of the functions to be performed. For example, should an automatic passenger counting (APC) function be included? Once the configuration of the system has been determined, then the issue of whether or not the benefits will justify the costs can be addressed. ***For determining the feasibility of an AVM/C system, we suggest a breakeven analysis, in which the*** necessary ***gains*** in ***terms of either cost reductions or ridership improvements are compared with the expected cost of a particular system. This can be done using data of the type that is obtained for Section 15 reports, along with the magnitudes of gains experienced by systems which have already adopted AVM/C technology.*** This type of analysis is developed and is illustrated by an example in the report.

A byproduct of the example application is a determination of the approximate magnitude of gains necessary to justify an AVM/C system. Using data for operating costs that represent the average of all U.S. transit systems, and using a cost of $8,000 per bus, it was ascertained that an AVM/C system could be justified by, for example, a 0.7% reduction in bus miles and a 1.6% reduction in fleet, with no increase in revenue. This obviously represents a very modest gain, and suggests that ***AVM/C systems are very promising for improving transit service and recouping their entire cost directly from operating and capital cost savings.*** Of course, it must be added that the potential in any particular system could deviate significantly from that for the national average.

Given the likely attractiveness of AVM/C systems, it was deemed prudent to explore the potential for innovative financing of these systems. This is particularly important because of the capital shortage facing transit agencies in the U.S. at the present time. ***Specifically considered was the leasing of the AVM/C system by the transit agency from the manufacturer or a third party.*** Although not true in all cases, generally this would lead to a slight increase in the equivalent annual cost of deploying an AVM/C system. ***However, the increase in cost over purchase can be modest, and thus the financial gains in the form of reduced costs and*** increased ***revenue to the agency may still easily offset the additional costs, making leasing a very attractive alternative.*** The alternative of postponing purchase, in contrast to a lease, was also explored, and a method devised to ascertain which is more attractive from an overall benefit cost standpoint. Again, results will depend upon specifics of particular applications, but in general it appears that, provided benefits were at least twice the cost of a system, leasing would be preferable whenever the postponement would be more than a few years.

Acknowledgements

The research upon which this report is based was supported by the Urban Mass Transportation Administration of the US Department of Transportation, through University Research and Training Grant No. PA 11-0035, and by the UPS Foundation Professorship in Transportation at the University of Pennsylvania. This support is gratefully acknowledged but implies no endorsement of the findings or conclusions.

In the course of preparing this report, the authors benefitted greatly from the assistance of numerous individuals in the transportation industry. In particular, the Technical Monitor, Mr. Richard Steinmann of the Office of Budget and Policy, Mr. Al Neumann, of the Office of Grants Management, and Denis Symes, were especially helpful. Also, we would like to thank numerous individuals associated with transit agencies and AVM/C system vendors, too numerous to mention, but in particular would like to single out for a special thanks the following:

Roger Clarke, Teleride Sage Corp., Toronto, Ontario
Barry Collins, CIE Consult, Dublin, Ireland
Douglas Daetz, Hewlett Packard Corp., Palo Alto, California
Tom Friedman, Seattle Metro, Seattle, Washington
Bill Frost, Toronto Transit Commission, Toronto, Ontario
Antoine Gregoire, CTCRO, Hull, Quebec
Jim Hathaway, The Metro, Kansas City, Missouri
Tom Lucek, VIA Transit, San Antonio, Texas
Peter MacNeil, Hamilton Street Railway, Hamilton, Ontario
Chris Prentice, Metro Transit, Halifax, Nova Scotia

And we wish to express our appreciation to Noranne Bonner who typed the manuscript and prepared it for publication.

Of course, full responsibility for this report rests with the authors.

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1 Introduction

There is no question that there is a continuing need to improve the attractiveness of transit services. For an existing service, there are basically two ways that this can be accomplished. One is to provide better vehicles and facilities, and the other is through improved operations. In the last two decades the main emphasis with respect to bus services has been to improve the fleet, and today's bus fleets are undoubtedly far superior to their predecessors - air conditioning, advanced suspensions, and attractive interiors now being commonplace. However, relatively little has been done to improve the operations of bus systems, primarily because the technology to do so was not available. The use of public streets and the difficulty of controlling vehicle movements thereon did not permit the use of sophisticated monitoring and control systems like those of rail transit, for example. However, technologies for monitoring and controlling bus operations are now readily available - indeed already in use, in Europe and Canada and to a lesser extent the U.S. Thus the opportunity to make comparable improvements in bus operations is now at hand.

The specific improvements we are talking about are those that arise from the use of what are increasingly being known as Advanced Vehicle Monitoring and Communication Systems (AVM/C Systems). This refers to a broad group of technologies that together form a system for improving the supervision and coordination of transportation vehicles, so as to provide reliable and efficient operations.

There is no one definition for what constitutes an AVM/C system, but certain elements are essential. For bus transit applications, these would include an Automatic Vehicle Location (AVL) subsystem, a communication subsystem providing two-way voice or data connections between the drivers and dispatcher(s), a data processing and computational subsystem to assist the dispatcher, and an Automatic Passenger Counting (APC) or load monitoring subsystem. Also included may be equipment to monitor the condition of the bus' mechanical and electrical components, often referred to as an AVM (for Automatic Vehicle Monitoring) System in the trucking other non-transit industries. Yet, as this report will make clear, the AVM/C system is not complete with only hardware and software. The technological subsystems are really only a decision support system; the complete system includes the personnel (dispatchers drivers, and others) their training and their ability and willingness to use it,

The benefits of this type of system can be very far reaching. First of all, these systems provide up to the minute (or even second) information on exactly how the system is performing - where the buses are, how many passengers are on the buses, and the condition of various mechanical and electrical parts of the system. This information can then be used by dispatchers to anticipate problems or monitor problem situations as they occur, such as buses becoming overcrowded or beginning to fall behind schedule. The dispatcher can then devise a plan for recovery of the system to schedule, and communicate instructions directly to the driver and other field personnel, Thus operations are improved substantially from the standpoint of customers, through higher quality transit service. This system basically completes the information loop between the drivers and others who actually provide the service and the dispatchers and others in the central office who need to know what is happening in order to provide system-wide quality control. In the jargon of industry, it enables Total Quality Management of transit service.

A second broad class of benefit is that AVM/C systems can reduce the cost of providing transit service. The enhanced control of vehicle operations enables service of the same quality to be provided with fewer buses and drivers, as a result of such actions as reducing layover times at terminals between runs. Thus this system can help to alleviate already hard pressed transit budgets. A third major benefit is enhancing the image of transit in the community, through the use of new technology and the provision of high quality service. This can be of immediate value in obtaining and maintaining community support - financial and otherwise - for the transit agency. Finally, since AVM/C technology is a major element of Intelligent Vehicle/Highway Systems, it provides a linkage by which transit can participate in and contribute to this exciting new era in highway traffic management.

A comment is in order at this point regarding terminology. In transit applications, the most commonly used designation of the types of systems to which we are referring is AVM. However, other designations are also used, including AVL (as noted earlier), and AVMC or AVM/C systems. Crucial elements of the system are both monitoring (e.g., of location) and communication, so ideally the latter designations would be used. But since AVM is commonly used, we will use both AVM and AVM/C interchangeably.

The following section describes the subsystems and elements that constitute complete AVM/C systems in some detail. The third section will try to systemically organize and analyze the potential benefits of AVM/C systems, paying particular attention to dependency of benefits within the framework of our system. Section 4 presents case studies which indicate costs and configurations of various systems. The last section demonstrates methods of analyzing the financial feasibility of installing AVM/C systems.

2 System Composition

There is a variety of equipment and elements that can be combined to create an AVM/C system. Moreover, there are often several different technologies that can perform the same function, one example being Automatic Vehicle Location (AVL) subsystems. It is therefore important to describe equipment and elements in a functional or generic way, and then to describe the different technologies that can perform each function. It is also important to identify functions as either basic or optional. Basic implies that this functional element is part of the minimum package required to create an AVM/C system. The criterion is that, to be considered basic, a functional element is necessary in order to both collect sufficient data and use these data so as to significantly enhance the operations of the agency. Optional implies that there are additional enhancements, or building blocks, that could be added to make further gains.

2.1 Basic Elements of Transit AVM/C Systems

2.1.1 Basic Elements of Real-Time AVM/C Systems

Associated with the dispatcher location are three closely related items; a central computer that collects data from the fleet (not necessarily a very powerful computer), some form of processing software to sort, filter and perform short-term storage of the data, and an interface that will present and interpret the data for the dispatcher. The interface system will also include the connection to the means of communicating with the drivers in the field.

Associated with the vehicles are an Automatic Vehicle Location (AVL) system for providing the location information, and a driver interface system for communication with the dispatcher. The interface system must be of a type that is complementary to the dispatcher's system.

All of the hardware and software elements form no more than a decision support system and can at most be advisory in nature. No direct control of vehicle operation is normally possible in a bus transit system (in contrast to rail application, where, for example, trains might be brought to a halt by a central command directly). This stresses the importance of training, as it is only through training that dispatchers, drivers, or supervisors can make use of the newly available data. There must be a set of tactics which are to be followed when a less than desirable situation is noted. Some formal training would be required upon implementation, but as experience is gained, self-learning will also take place. With adequate institutional support and employee morale, refined tactics will be passed along to future generations of drivers and dispatchers both through observation and improved training. Thus, AVM/C systems are best viewed as a combination of technological elements and the human element that evolves over time.

2.1.2 Basic Elements of Transit Management Information AVM System

So far, the discussion has been of the elements required to use an AVM/C system for affecting operations on a current, or real-time, basis. Yet, the information provided by an AVM/C system can and has been used for longer term planning as well. Indeed, in some cases this could actually be a more significant application than the real-time one. Given that the data have been collected anyway, it is logical to store a certain portion of it for post-processing analysis. Such analysis could give insight into routing, scheduling and other improvements.

There are several elements required to perform post-processing analysis. One is a computer upon which to store and process data. This could be the same computer used by the dispatcher, or one shared with another use such as payroll, or a dedicated machine. Another closely related element is a link between the different computers if more than one is involved, and the hardware and software required to establish this link and to post-process the data. Finally, there must be an analyst trained and able to digest this data to draw useful conclusions. The efficacy of post-processing, like real-time processing, depends upon the active effort of the personnel involved.

2.2 Optional Elements

There are several optional elements that have been developed or proposed that can further enhance the capabilities of an AVM/C system. Such enhancements involve not only the previously mentioned dispatcher and driver functions, and the ability to post-process data, but also can permit real-time data to be disseminated to passengers. One enhancement at the dispatcher's work site consists of software and displays that highlight irregular situations and that will propose a course of corrective action to assist and expedite the dispatcher's work. Similarly, the driver's interface could include more than oral communication or limited menu items; a detailed tactical instruction could be received (e.g., for a specific bus/block number, skip selected stops).

The post processing analysis of data with the intent to improve routes and schedules could be facilitated and expanded with the development of analysis software and the use of personnel with the capability to write and use such software. Interface of the database to existing operations scheduling and planning software is one of the most promising avenues for development.

The analysis function can also be readily expanded to include a vehicle maintenance system (VMS) given that the data links to the buses are already established. Several technical variants are possible.

One of the most important enhancements is the provision of up to date information to passengers. The bus location information provided by AVL can be readily exploited to inform passengers of the estimated time of arrival as opposed to simply the scheduled **time** of arrival. This can be done in a variety of ways, from conventional manual telephone information centers to message boards at stops and synthesized voice telephone.

The elements and equipment of an AVM/C system are summarized in **Table 2.1.**

Table 2.1: Components of Transit AVM/C Systems

Basic Equipment and Elements

Central Computer for Real-Time Data
Real-time Processing Software
Dispatcher Interface Systems
Location Monitor (AVL)
Driver Interface System

Dispatcher and Driver Tactical Training

Post-Processing Computer (possibly same as above computer)
Hardware/Software Link Between Computers

Optional Equipment and Elements

Tactical Response Assistance Software
Enhanced Driver Interface System

Automatic Passenger Counting System (APC)

Passenger Information System

Route and Scheduling Planning Assistance Software

Vehicle Maintenance System (VMS)

2.3 Variants

Many of the elements of AVM systems can have varying degrees of sophistication and capability. It is also the case that several entirely different technological solutions may have similar capabilities and be almost interchangeable (although not necessarily of similar cost). These variants will be discussed below. In the 1970s much attention was paid to testing the accuracy of various AVL technologies for their suitability for bus location determination in cities, It appears that there are several approaches that could work, but their relative merit might vary on a site-specific basis. One is to use the Loran-C beacon system used by ships and some airplanes. It requires no extra ground equipment, only units on board the vehicle. Another is the Navstar Global Positioning System (GPS) that is providing increasing coverage on the planet. Like Loran-C, it requires no other ground equipment, only vehicle equipment. There are also new commercial services such as Radio Determination Satellite Service (RDSS) and the Mobile Satellite Service (MSS). All of these systems may suffer from dead spots due to hills or large buildings. A system of radio signpost is a solution that provides as much coverage as desired or required by placing signposts at calculated intervals along routes. However, this requires the purchase and installation of signposts as well as the vehicle equipment. There is also the old established method of deduced or “dead” reckoning, but is suitable only for shorter distances. Finally, it is possible to combine technologies to get a very high locational precision. Such an example would be deduced reckoning or tachometer measured distance past a signpost. The basic operating principle of each of these systems is given in Appendix A.

There are several variations of the dispatcher interface (the communications aspects will be covered in the paragraph on driver interfaces), but they are all built around a CRT display, plus perhaps a model board, that indicates the position, times, and identifiers of all vehicles assigned to the dispatcher. Some kind of exception identification is highly desirable and is usually accomplished by color coding and/or graphic display of early and late vehicles to speed interpretation by the dispatcher. A large increase in sophistication and productivity is possible if a recommended tactical response is displayed or available by query, for any significant deviations of service from that which is planned. One can also provide the supervisors at major connecting and timed transfer points displays of system or division status, planned changes to schedules, etc. The system may also permit them to input revised plans into the system.

The driver interface can have a wide range of capabilities, and it is not strictly necessary to add any new capabilities to any existing pre-AVM interface, although this might clearly limit effectiveness. The most basic system is the open channel radio, and many if not most bus systems have such a system, Such a system would be impractical on all but the tiniest of transit systems for issuing instructions, because of the possible confusion, and because particular drivers must wait for a chance to report or respond as necessary. Private radio channels are a clear improvement but could prove very slow when issuing numerous instructions. Digital interfaces have the advantages that they allow the dispatcher to quickly select particular vehicles or groups of vehicles for communication, that standardized messages can be sent or received and less transmission time is consumed on congested frequencies. The ultimate in sophistication is when a digital interface receives a customized message indicating a particular or detailed tactical instruction and displays it to the driver. A combination of voice radio and digital communication allows oral messages in addition to the digital ones.

Passenger load monitoring can be added to determine the load factor and level of service (i.e. crowding) available along routes. Passenger load monitoring at its simplest and most approximate is when the driver orally reports the vehicle's load factor. In the late 1970s several agencies experimented with two different approaches to automatically counting passengers, doorway treadle mats and electric eyes mounted in the doorways. Both system initially had reliability problems. Today both are acceptably reliable and have accuracy similar to manual counting, in the experience of some operators. Others have found them still inadequate. At least one manufacturer has developed a system that uses payload weight as a proxy for the number of passengers [Italtel, 1988]. This has the disadvantage that the number of passengers is not known as accurately. On the other hand, no additional sensors may be needed if the bus is already equipped with load cells for weight compensating air suspension. Furthermore, weight may actually be a better indication of crowding and level of service than number of passengers.

There are several methods of linking the data from real-time operations to any separate post-processing facility. A simple way involving a minimum of development and storage requirements is to simply transfer data by tape or some other medium periodically. A more elaborate, and perhaps unnecessary, way is to transfer the incoming data as it is received. Automatic data analysis routines could be developed that would greatly improve and simplify the task of the analyst to discover problems, trends, and variations within the data set.

Related to the post processing database for analysis of schedules and routes is the vehicle maintenance database. Like the other database, maintenance data could be received either in batch or near real-time. In addition, there is the possibility of not sending much of the maintenance data through the AVM/C system at all, but periodically up-loading the data from memory units on the bus. There are several elaborate relational database programs for maintenance on the market that would facilitate automatic exception reporting, trending, flagging of problem vehicles, etc. Such a system would rely on the AVM/C system for some of the data input. Finally, there is also the possibility of providing the driver interface unit with menu items that the driver could use to transmit maintenance items requiring immediate attention.

There are a variety of ways that the information made available by AVM/C could be passed along to the passengers. Services such as "TeleRider" [see Appendix A] could be linked to AVM to provide specific revised schedules instead of published schedules. Bus stops could be fitted with displays, or even inquiry panels, to provide revised schedule information. In-bus displays or a synthesized voice could provide revised connecting and schedule change information. Finally, the dispatcher could directly announce any operational changes.

The aforementioned variants are summarized in Table 2.2.

Table 2.2: Variants of AVM/C Subsystems Elements

Automatic Vehicle Location (AVL)	**Driver Interface**
Loran-C **Radio** Signposts GPS MSS Deduced Reckoning Passive ID Tags Infrared Detection Combined System (using tachometer, etc.)	Voice Radio, Open Channel Voice Radio, Private Channel Digital Communication, Menu Driven Digital Comm., Enhanced Tactical Combination
Automatic Passenger Counter (APC)	**Dispatcher Interface**
Doorway Electric Eye Counter Doorway Treadle Mat Counter Weight Sensors Hand-Held Electronic Data Logger Manual Counting	Basic Display of Positions and Times Basic Display plus Exception Report Display with Recommended Tactical Response Remote Displays for Supervisors
Hardware/Software Link	**Passenger Information**
Real-time Data Transfer Batch Transfer Automatic Data Integration and Analysis Combined System	**Call-In** (Updated "TeleRider" System) Bus Stop Display Bus Stop Inquiry Panel In-Bus Display In-Bus Synthesized Voice In-Bus Dispatcher Announcements
Vehicle Maintenance System (VMS)	
Real-Time Database Update Batch Transfer Data Upload from Fleet Automatic Exception Report Software Driver Interface Items	

3 Generic Benefits of AVM/C Systems

There are two distinct ways of using AVM/C systems, both of which can yield substantial benefits. These are: 1) the use for real-time controls to respond to undesirable situations through immediate, albeit temporary, intervention, and 2) the use of compiled data in a Management Information System to plan permanent (or long lasting, e.g., a schedule cycle) changes to routes, schedules, fleet and personnel deployment, etc. The relative importance of the two types of benefits could vary depending upon several factors. In this section, a systematic framework for assessing the potential benefits of both uses of these systems is presented.

The calculation of benefits from an AVM/C system is not a straight-forward process. Such a system is not of the nature of a technological improvement that will give a known increase in productivity or decrease in resource inputs, which is then compared to the cost of purchase and operation. The complications arise because some of the benefits are only potential benefits, and require assumptions about how the system will be used by the transit agency's employees (dispatchers, drivers, planners, etc.). Similarly, the response of current and potential passengers to improved service is uncertain - in magnitude if not direction. Also, some of the benefits may be of an intangible nature, but not insignificant. Thus, a complete assessment cannot consist only of a simple revenue and cost analysis, but requires considering the non-monetary elements, as well. However, it may well be possible that relatively predictable and quantifiable monetary benefits alone could justify the system, and additional benefits would simply make the system all the more attractive.

3.1 Benefits for Real-Time Operations

Once a basic AVM/C system is installed and functioning correctly, the impact can then be viewed as a sequence of actions, market responses, and consequences. The degree of impact will vary depending upon the presence of the other elements of the system, and the training, ability and willingness of the transit agency personnel to exploit this capability. Figure 3.1 should be referred to in the course of the discussion as a summary flow chart of the impacts being discussed.

To the extent that the information provided by the AVM/C system about vehicle positions and loads is acted upon by the dispatchers, with appropriate driver response, the first impact is to improve dispatcher tactical intervention and control over service. This will result, in bus operations that are more punctual, have more uniform passenger loading, and compensate for traffic problems and other disturbances more quickly and effectively. This has several consequences. The riders will notice better service which will increase their satisfaction. Some of the drivers and field supervisors will notice better working conditions and/or a reduced workload.

The improved information and better performance could then directly allow some intelligent short run changes to operations. Examples would include changes to avoid

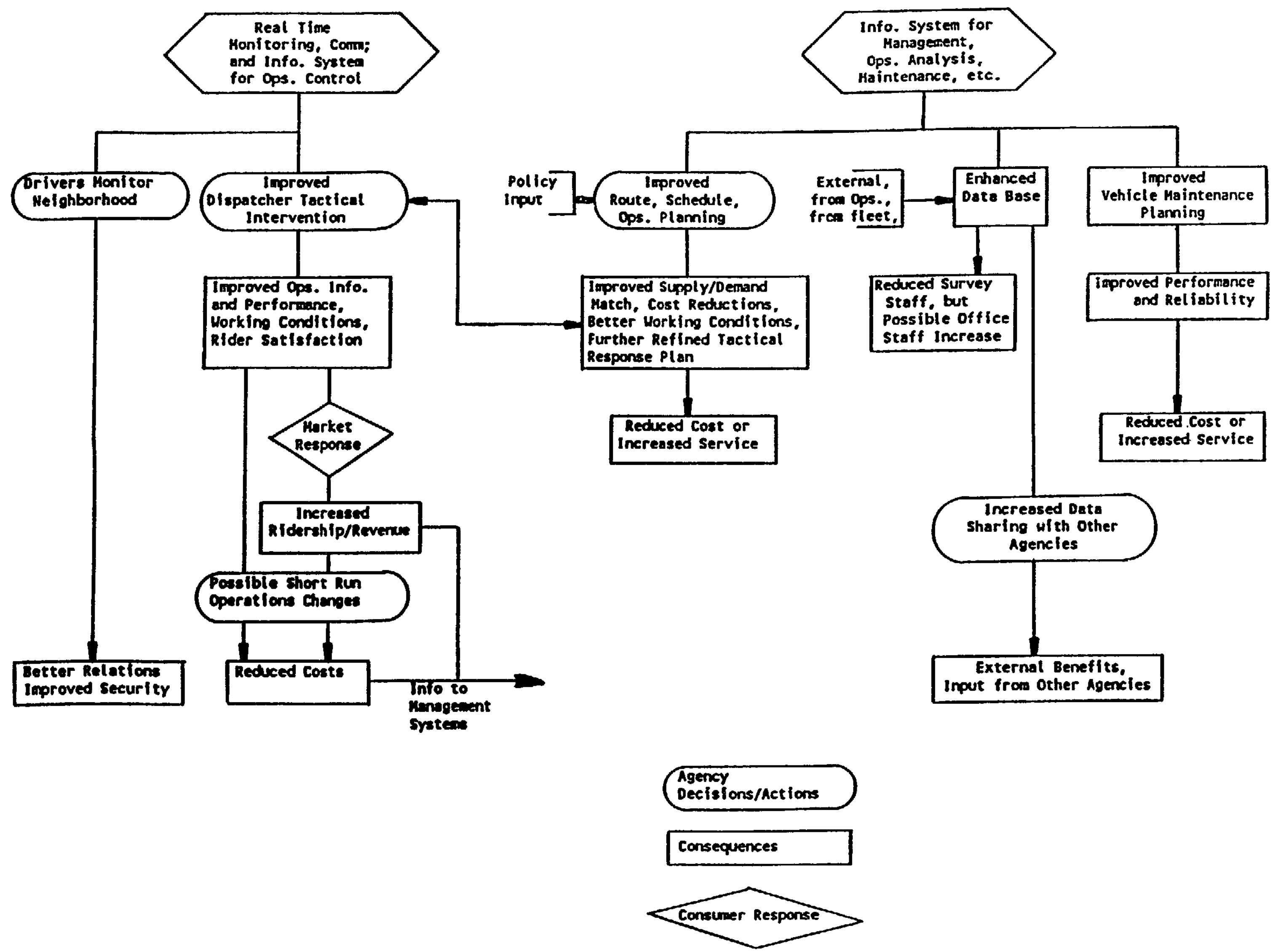


Figure 3.1: Use and Importance of AVM/C Systems in Bus Transit.

chronic problems that have been revealed and to redeploy reserve drivers, reserve fleet, and supervisors to where they are most needed. The end result is reduced operating costs to achieve the same or better performance.

The increased rider satisfaction will presumably translate into increased ridership as riders come to expect more reliable or quicker journeys and as word spreads of the improved service. There is also an intrinsic value to the transit agency in being seen to use high technology to provide better service; AVM is an image enhancer. The increased rider satisfaction and image should result in both increased ridership and revenue.

The increased ridership and revenues will again be a basis for allowing some short run changes to operations. Service can be adjusted to suit the demand, and the increased passenger volume generally will necessitate increased frequency (or higher capacity buses - unlikely in most situations) and hence improved service. Over and above this likely necessary and "automatic" improvement, the agency will generally experience a gain in revenues relative to costs, and this surplus can be used in either of two ways. It could choose to invest part or all of it to further increase service, or it could retain most or all of it in order to reduce the deficit. The chain of improved tactical intervention leading to increased ridership and revenue is summarized in the left half of Figure 3.1.

It is important to note that all costs (normalized for system size, e.g., per bus-mile) will not necessarily be reduced; a few costs may be incurred or increase as well! There is the initial cost of the AVM system and its maintenance cost. Also, there may be increased road calls to service buses with faulty equipment. But these are the costs of improved service.

Optional advanced tactical software can reduce the dispatcher workload. Advanced driver tactical displays and communication systems also have as a partial motivation reducing the time and effort required by the dispatcher. Viewed in another way, such systems can provide elaborate instructions to more drivers using the same personnel. If the instructions are clearer and more complete than they would have been with radio-only communication service would be enhanced further. Also rider satisfaction could be significantly increased with the addition of a passenger information system. On routes with long headways and those prone to unavoidable delays, the reduced waiting time and better planning made possible for passengers is certain to further increase ridership.

In addition to the benefits that follow from improved dispatcher intervention, there is another potential benefit path essentially unrelated to operations. The fact that the driver of an AVM equipped vehicle is out in the community, often moving at slow speeds, and is equipped with an accurate location device and good communications, makes that driver a good surveillance agent. The driver can function as a significant element of a neighborhood watch and as an important complement to police, fire, and emergency personnel. Not only is this service a community benefit, it reflects back to the agency as a benefit in enhanced image and community relations [Toronto Transit Commission, 1986, p. 1021 and, quite likely, increased community support for the transit system.

3.2 Benefits from Post-Processed Management Information Data

The increased information that is potentially available provides for at least three different ways to extract benefits. The first one requires only the basic elements of an AVM/C system, while the other two require some additional optional elements.

The first way is to analyze cumulative data to see how the routes, schedules, and operations in general could be improved within the policy guidelines of the agency. The results should be improved tailoring of supply to demand, more efficient fleet and personnel deployment, and better working conditions for employees. Further refinement in tactical response plans should also be possible due to the insights gained which can be readily passed on to the dispatchers. The dispatchers, in turn, can relay back to the analysts what they have noted as effective. In this fashion, the operating staff and the office staff interact and constructively criticize one another's procedures.

The final result of the aforementioned improvements will be either reduced costs, if a policy decision is made to provide the same quantity of service, or increased service if the decision is made to use the savings towards expansion. The latter decision would elicit a market response thus resulting in feedback to the ongoing operations in the form of increased ridership. It should be noted that in general some improvement in service would be expected, e.g., improved on-time performance, even if a policy decision were made to attempt to try to reduce costs and maintain the same level of service. Actions to reduce costs, such as reducing the number of buses assigned to a route through reducing layover times, would probably not eliminate all service quality benefits.

The cumulative database provides opportunities for both more extensive and sophisticated analysis and the reduction of needs for certain positions. The level of analysis is a function of how much optional effort and expense in software and personnel the agency chooses to apply. There is some evidence from existing operations that the benefits would greatly exceed the costs as many fewer surveyors and check riders would be needed if data is collected, processed, and analyzed automatically [Frost, 1988; Attanuchi and Vozzolo, 1983]. Other tedious functions such as compilation of many UMTA Section 15 statistics could be automated as well. In addition to more sophisticated and extensive analysis and the reduction of personnel, an enhanced database opens the possibility for increased data sharing with other agencies. Examples would include speed distributions of deadheading buses through corridors for the benefit of traffic engineers, or maintenance and performance data of bus fleets of similar design, etc. Enhanced systems provide a benefit of "rolling laboratories" and data pooling for external organizations as welI as an internal benefit when data is reciprocated.

Another possible avenue of benefits arises by using the increased data to improve vehicle maintenance planning. If a vehicle is carrying optional sensors, it is possible to transmit or store information about the vehicle's condition. Relational database programs that organize such data are readily available. The degree to which such programs automatically upload and process the data would be dependent upon the effort used to set up the requisite software and hardware needed. Such effort may really not be a large addition, but instead be incorporated in the specifications of the enhanced database at the planning stages. The result of improved vehicle maintenance planning will be improved performance and reliability. Once again, the end result is the choice between reduced costs for the same service or increased service for the same cost (or deficit, taking into account possible revenue effects). It should also be noted that if the fleet were previously characterized by numerous in-service breakdowns, the increase in reliability will also manifest itself in reduced dispatcher workload and elicit a market response resulting in increased ridership and revenue, This is another example of a feedback effect to the real-time operation.

The nature of the relationships discussed here are shown in the right half of Figure 3.1.

3.3 Relative and Absolute Levels of Benefits

This chapter has contained an identification and discussion of the many potential benefits of a transit AVM system. In the next chapter we review the experience of many transit agencies that have been using AVM systems, including - to the extent they are known - the magnitudes of various benefits. However, before leaving this discussion it is important to note that if a basic system is installed for any purpose, the incremented cost of additions that enable it to be used for another purpose could be very small; for example, a neighborhood watch could be almost “free.” It is therefore wise to consider this when evaluating the proposed system and selecting its overall configuration and options.

4 Case Histories

Numerous agencies and consultants have attempted to assess the benefits from AVM/C systems. Analysis has varied from cursory estimates to rather detailed investigations. None has been able to fully assess all potential impacts. Assessing the full range of possible benefits cited in this report to a high degree of precision could be difficult, if not impossible, in most cases. Other variables and changes to operations need to be controlled or minimized for several years. One would also need to isolate the impacts of the AVM system on improving the management and administrative decisions of the agency. This could prove to be highly unrealistic, particularly in a rapidly changing economy and region.

Upon review of some of the assessments that have been made, recalling the impact and benefit tracing methodology suggested by Figure 3.1, it is often possible to suggest other likely impacts that may have been overlooked, or that should be monitored in the long term. Indeed, the authors of the various reports almost always state that all of the potential benefits have not been fully explored.

There are a few particular studies that have been done in the English language that merit special attention because of the relative detail and depth of analysis. There may be some in other languages or that our search and contacts within the industry could not uncover.

Two quite thorough studies were done in the late 1970s and early 1980s in the United States, a period of extensive experimentation with AVM systems or components. One was performed in Los Angeles, the other in Cincinnati. More recently, the Toronto Transit Commission has conducted or sponsored several cost-benefit studies based upon experience with a sizable fleet of AVM/C-equipped buses. The experience of each of these three cities will be discussed, followed by briefer summaries of several other experiences in the United States and Canada, as well as a few from Europe.

4.1 Southern California Rapid Transit District

A large scale demonstration project was performed in the Los Angeles bus system of the Southern California Rapid Transit District (SCRTD) in the period from September 1977 to September 1981. This demonstration project was funded by UMTA, with much staff input to planning and development of the technology and system specifications by TSC. According to the UMTA Program Manager, Denis Symes, the original plans were for a multi-phase demonstration project, that would extend over many years, with this project serving as not only an operational test of a complete AVM/C system (including passenger information displays) but also as a mechanism to help other agencies understand how to use AVM/C systems and the benefits to be derived therefrom. The premature termination of the project (in September 1981), due to budget cuts, and loss (or transfer from the project) of key staff persons, resulted in many elements of the original evaluation plan not being undertaken.

This demonstration was a joint effort of UMTA, TSC, and SCRTD. The Los Angeles system was selected after careful' consideration of most larger U.S. systems. SCRTD agreed to provide a number of test routes, and all were to be operated exclusively with AVM/C equipped buses. Dispatchers and other participants were to be selected on the bases of qualifications and presumably traits suited to the new technology, and training manuals were prepared for them as well as street supervisors and drivers. SCRTD was on record as fully supportive of the system and the demonstration. While the initial phases were to focus on tactical or real time control, later phases were planned to deal with management information and planning issues. But because of the funding cutbacks and early termination, only a limited trial of the tactical control system was accomplished. However, much was accomplished in system design, in hardware development (e.g., development of new passenger counters), and in training materials, and these have been used in later demonstrations and implementations of systems.

The only written evaluation of the impact of this demonstration was prepared by Systan, Inc. [Daetz and Bebendorf, 1982]. Systan was not involved in the original program. The purpose of their review was intended to provide information to other potential users and to UMTA regarding the desirability and feasibility of AVM for transit applications.

In this application, 200 buses out of an approximately 2800 bus fleet were equipped with AVM/C equipment. This included a location system and passenger counters, but until near the end, according to the Systan report, none of the buses had a driver interface unit (beyond conventional radio and a silent alarm). Towards the end, some of the buses did receive a driver interface unit. The locating technology was of the radio signpost variety. A total of 220 signpost transmitters were installed along four routes and in central Los Angeles.

In retrospect, the actual implementation of the AVM/C system was not as carefully controlled as it could have been, or as it apparently had been planned. The Systan report states that rather than training personnel before-hand in tactical techniques that could be implemented using the real-time information from AVM, dispatchers were largely left to develop these and improvise on their own [Daetz and Bebendorf 1982, pp. 2-4]. This would needlessly slow down the learning process. In addition, there were factors that should have been controlled or avoided such as the introduction of non-AVM equipped buses during the period when data regarding schedule adherence were collected. Nevertheless, useful experience resulted from this demonstration project.

One major lesson was that "continuous management commitment" is required in order to realize the full range of benefits. Of special note is the consultants statement: "Proper selection and adequate training of dispatchers are crucial for successful real-time control" [Daetz and Bebendorf, 1982, p. 3]. This underscores the inclusion of "Improved Dispatcher Tactical Intervention" in Figure 3.1 where it emphasizes the role of agency actions in the realization of the benefits.

Data analysis showed that real-time control of buses appeared to be at most only slightly improved. Early buses were reduced on a couple of the routes, but the share of late buses also increased, so that in most cases there was only a slight net increase in the percentage of buses within 3 minutes of schedule. In recent discussions with the UMTA Program Manager, he offered one explanation: The street supervisors, who were not “in the loop” of the AVM/C system, would often countermand dispatcher’s directives. Again, this underscores the need for full management commitment. The applicability of these results to other agencies is debatable due to the erratic use of the AVM/C system and the other confounding and descriptive factors.

The authors point out that one of the intuitively most valuable uses of AVM is to recover from line disruptions, but it is not amenable to statistical analysis since it is not known how bad the disrupted service would have been without AVM.

The security benefit was universally appreciated, and seemed to have far outweighed the concerns of being “watched.” Tests demonstrated that supervisors could consistently find AVM equipped buses much more rapidly than non-equipped buses, particularly when the bus was off-route or off-schedule.

As stated earlier, no management information system was in use during this demonstration project. Referring again to Figure 3.1 this corresponds to entirely foregoing all potential benefits indicated by the process on the right hand side of this figure. This also eliminates the feedback effect into the learning process of the dispatchers and drivers that comes from analysis and revision of procedures, and must surely have been one of the contributing factors for the low level of dispatcher intervention and resulting marginal impact upon operations.

This project showed that in order to accurately quantify the increased performance of operations using AVM in real-time, both careful planning and adherence to those plans are required. A careful control data-base must be acquired, with special attention paid to what techniques are presently used and how long it takes to recover from delays. There will always be factors such as changes in economic activity that can not be controlled, but anything within the purview of the agency should be tightly controlled. Selection of demonstration routes may also prove critical to the results. One of the routes chosen in this project, Route 83, runs along Wilshire Boulevard, a road often exhibiting extreme congestion and arguably an exceptionally difficult case in which to exercise real-time tactics. Furthermore, buses on this route also operated from three different divisions making coordinated control very difficult.

Although this project did not contain even most of the systems required to obtain most of the potential benefits from real-time control and management information, the authors of the assessment estimated that any agency that had 2% to 3% “slack” in operations could receive enough monetarily quantifiable benefits to offset the additional costs imposed by installing and using AVM. Here “slack” refers to additional running and layover time that is added to compensate for operating uncertainties.

4.2 Cincinnati

Another major demonstration project was performed at Queen City Metro (QCM) which serves the Cincinnati, Ohio, area. This demonstration extended from June 1977 to March

1978, beginning at about the same time as the SCRTD project, but of much shorter duration. Interestingly, it concentrated on exploring the benefits from the management information side, and did not attempt to exercise real-time control to extract benefits on this side at all. In a sense, it was complementary to the SCRTD project. Thirty of the QCM buses were equipped with AVL technology of the radio signpost variety and passenger counting devices of the infrared beam variety. Transmission of the data was through the existing radios after some modification. There was no provision for real-time involvement of the drivers or dispatchers as no interface units or other required equipment was provided. Emphasis was placed on software that could report passenger movements as a function of the bus i.d., time, and location as well as bus movement statistics regarding schedule adherence, travel times, and frequency of stopping. The entire package was called the Transit Information System, or TIS. The methodology was to run these equipped buses on five routes, all of which served the same corridor. Data from over 8000 round trips was collected during the test period. The results of the analysis indicated that by reducing frequencies, by more evenly spacing headways along the trunk section, and with several other refinements to the schedule such as short turns, the agency could show significant savings without serious changes in the level of service. Although on average the frequency decreased, the analysts felt that the increased regularity of service more than compensated so that the perceived level of service could be as high or higher than before [DeLeuw, Cather, and Co., 1979, pp. 8-9].

The resulting service revisions reduced the weekday bus miles by 261, or 7.2 percent, and the platform hours by 24.9, or 8.2 percent. Accounting for the fact that the chosen Reading corridor was not representative of the network, some estimates of the benefits if TIS were implemented system-wide showed savings of about 2 percent of the total QCM budget. Major sources of savings would include a reduction of 8 peak hour buses out of 380, and 2 percent of operating costs for the remaining fleet. Approximately 10 percent of the savings was estimated to be in the reduction of traffic checkers, in analysis time and effort, UMTA Section 15 report compilation, etc.

The report summarized above is conservative in that it assumes that service frequency cuts do not impact the remainder of the system, when in fact, as alluded to in Figure 3.1, the freed capacity could quite likely be translated into level of service increases and revenue increases elsewhere in the system. More importantly, it totally disregards the potential benefit from real-time control that may far outweigh the marginal cost of adding real-time provisions to the existing hardware and software package.

Moreover, the feedback effect for improving tactics and schedules by having both real-time and management information systems could have provided increased benefits. Even with such a conservative analysis, the conclusion was that the TIS system had a positive economic benefit under all but the most conservative financial assumptions. The recommendation was made to increase the fleet size being equipped with the TIS system to 91 from 30 so that the entire service area of QCM would employ the TIS system.

The authors of the final report also provide several insights that are worth discussing in detail. The first is because much of the cost of implementing AVM is fixed regardless of fleet size (e.g., software and the central computer system), the unit cost per bus is highly sensitive to the fleet size. Another point is that in larger transit systems, the general size and complexity "represent major obstacles to the collection of accurate and comprehensive data by conventional procedures." The logic of these points suggest that the unit costs are lower and potential benefits higher from management information systems for larger transit agencies.

Finally, the issue is raised of the idea of "gross" versus "net" benefits. A "net" benefit is one that is incremental over that which could be achieved by conventional data collection and analysis procedures, while a "gross" benefit is the entire benefit that can be extracted by using TIS in place of the status quo. The question arises whether some of the benefits could have been obtained without the need of the additional information provided by TIS, and thus should not be counted as real benefits of the technology, i.e, only net, and not gross, benefits should be counted. Indeed, at QCM it was already well known that smoothing out the headways on the trunk by jointly scheduling three routes could improve the operation. Thus, some argued that all of the savings could not be attributed to the TIS system. On the other hand, some argued that information from conventional manual methods would not have been detailed enough to identify the possibility of eliminating some trips on the outer loops and thus the manual alternative did not even really exist. But a more fundamental argument was that QCM had never given this "known" information a high enough priority to actually make any of these possible changes. Thus, if TIS prompted the changes, the entire, or gross, benefit should be attributed to the TIS system.

Depending upon which school of thought one follows, the resulting monetary difference in the benefits could be quite large. This issue must be resolved for every application. Yet, it seems that in general the distinction between "gross" and "net" benefits is really a comparison of two different institutional changes. The alternative to using a management information system is not necessarily a change from the present system to one that deploys more traffic checkers and more actively rationalizes schedules based upon manually collected data. Bather, the only realistic alternatives may well be a new AVM/C based system and the status quo.

4.3 Toronto

The Toronto Transit Commission (TTC) began a study in 1972 to determine the feasibility of an AVM/C system for buses and has been actively involved ever since. The experiences of TTC should be of special value because it is widely considered one of the premier transit agencies in North America. Its AVM/C system is now fully operational on its entire surface fleet - buses and streetcars - except for 80 trolley coaches that are due for replacement soon.

The current system is primarily a real-time control system and referred to as the Communications and Information System, or CIS. For each division, a central computer is connected to sampling on-vehicle mini-computers and to three dispatcher consoles. Each dispatcher console has specialized keyboards and can issue data commands as well as conventional voice radio or text. The driver interface consists of a rugged dashboard mounted unit that contains a voice/data radio, a microcomputer, with standardized keyboard, and display. This display shows the time and current schedule deviation, if any, along with any text messages. The driver interface unit is called TRUMP, for Transit Universal MicroProcessor. There are numerous peripheral devices, including a speaker that is connected to the dispatcher's office. The location technology is of the microwave radio signpost variety, combined with an odometer. There is no Automatic Passenger Counting (APC) equipment in use as the accuracy and reliability of the units tried was found inadequate. The intention is to install APC units as soon as ones of either sufficient accuracy and reliability are on the market, or when an algorithm is developed that can systematically correct for the inaccuracy.

The development program at TTC has been done in discrete phases. The aforementioned feasibility study was the first phase. Phases II, III, and IV involved designing and testing the hardware and software for functioning and reliability. Phase V was the first large scale operational testing, which dated from 1976 to 1981 and was a trial on 100 diesel buses. The results were promising enough to justify proceeding with the next phase. Phase VI added further improvements to the system and expanded it to the entire fleet of 262 buses at the Wilson Division.

Upon completion of Phase V, which included a major study of benefits from the CIS system, the Ministry of Transportation and Communications (MTC) steering committee was already satisfied that CIS was an "important tool" for transit systems. They indicated that Phase VI need be primarily to determine capabilities of a divisional control center and overall design guidelines for system-wide CIS. Two aspects in particular were mentioned as not needing further study, the ability to improve published schedules that allow improved schedule adherence, and the decreased emergency response time. Both had been established and accepted as real benefits [TTC, 1986, p. 50]. A management reporting system, i.e. one that could be used as an input for a Management Information System of the type referred to in the right hand side of Figure 3.1, was designed and used in Phase V. It was considered "largely a disappointment" in large part because it required 100% accurate data that could not be acquired. In Phase VI new management reports were designed and their effectiveness reviewed. (More recently, traffic checkers have begun using micro-processor based hand-held logging devices from which data is uploaded over modem to a central computer. This would imply that a program is now being used to automate manual jobs and that their management information system is evolving. Such hand-held devices are an approach that is somewhere in between the manual methods and the APC method.) By September 1984, the Phase VI equipment and methods were deployed on the entire Wilson Division, and preparation of the Final Report, including a cost and benefit analysis of the project, began. This report also included an extrapolation of costs and benefits from expanding CIS to the entire system-wide fleet.

Both the Phase V and Phase VI evaluations had some practical difficulties because of the test timings, computer system physical constraints, and other uncontrolled factors. The uncontrolled factor that would most greatly complicate attempts to separate changes due to CIS from other reasons was the dynamic nature of the Toronto region – ridership all over the service area had been steadily increasing, while development and road congestion were also increasing. Further complicating the before/after comparison was the change or disruption of routes due to road construction in the Wilson Division operating area.

The Phase VI system was operational only a short period of time before evaluation began and was undergoing extensive debugging. This resulted in inaccurate data whenever the system crashed and in excessive time spent by inspectors to establish voice contact. Also, much of the studied data was collected in a vacation period when 10% of the workforce was on vacation, resulting in almost ideal operation conditions and minimizing the need for tactical intervention. On the other hand, a rider survey conducted in February 1985 had another bias; service is generally poorest at this time of year due to road and weather conditions. The initial scope included using passenger information systems at all of the transfer points with the subway, but the computer facilities were reaching capacity and could not accommodate the additional software required, so only one station was so equipped. Despite the admitted test bias and other difficulties, analysis could still reveal many valid conclusions.

Despite the allegedly poor management reports available during Phase V, sufficient data was available and used to affect scheduling of operations. Comparison of actual running times to scheduled running times revealed two routes where the number of vehicles could be reduced without reduction in level of service; Sheppard West went from 6 vehicles to 5 in the off-peak, while Wilson Heights went from 4 vehicles to 3 in the off-peak.

That savings could be had in the peak as well as the off-peak was established by a new statistical analysis performed during Phase VI. This analysis, using two different time periods during Phase V (before and after a major schedule change that disrupted the continuity of the data), was performed to compare bus utilization rates between the routes using the 100 CIS-equipped buses and the other routes using the non CIS-equipped buses. All routes were experiencing the need for increased service due to increased ridership. But the routes with CIS-equipped buses required from 4.3 percent to 9.2 percent fewer buses than non CIS routes, for similar ridership increases.

Over the duration of the entire Phase V test period, vehicle traffic volumes were estimated to increase as much as 30% and there were 13% to 21% increases in passengers per bus, yet it still appears that service regularity improved during the off-peak times, at least on the Jane Street route, the test route chosen for comprehensive measurements. During the afternoon peak period, an improvement was judged probable, but less certain.

The security impact evaluation during Phase V showed that the “Yellow Emergency” key on the TRUMP unit was used on average 35 times a month. This is to cover all incidents requiring outside intervention except those where the silent alarm is deemed more prudent. Interestingly, almost 44 percent of the calls were for incidents observed by the operator but not involving TTC. Thus, the “neighborhood watch” is a very real benefit to the community (and in public relations for the agency) even if hard to quantify.

There has been a 100 percent increase in reporting of police incidents and 30 percent reduction of police response times over the duration of Phase V. Operators have expressed opinions that they recognize CIS as a benefit in that it increases their security and that of their passengers. One specific key available to the operators is for fare disputes. This has been received favorably by the operators as a security benefit and as contributing to an improvement in the working environment, as over 80% of all disputes are now settled by discussion with the control center instead of the driver.

Using the Phase VI equipment, 3 persons could effectively control the entire Wilson division at peak times, each controlling 70 to 80 buses. The number of inspectors in the field has not been reduced despite the improved information available with CIS. Instead, it has been TTC's policy to use them more effectively, by focusing their attention on problem sites, increased contact with operators, and other duties. While the size of the Wilson Division fleet has increased steadily in recent years, the supervisory staff has not kept pace but remained approximately constant. Clearly, the supervisors are more productive and can perform more functions than without CIS.

With the advent of passenger information at the subway stations (signs giving the times of the next 2 buses per route), better schedule regularity, and better security, it would seem certain that ridership should increase. But the Phase VI Final Report made little effort to estimate what percentage of the increased ridership was actually due to CIS and what growth would have occurred in any case (discussed below).

Although the results from Phase VI seemed to show that it was a success and stated that it would be worthwhile to implement system-wide, an independent consultant was assigned to make a new evaluation based upon data collected from 1985 to 1987 before a final recommendation was made.

This new report, by M.M. Dillon, Ltd., [1988], sheds more light on vehicle and manpower utilization and on how much the CIS system can increase ridership.

Certain efficiency measures showed a decrease in the TTC system as a whole in the period from 1985 to 1987, largely due to the increasing traffic congestion in the region. The reduction in passengers carried per peak hour bus in 3 other comparable divisions ranged from 1 percent to 3 percent at two to more than 7 percent at the third. Meanwhile, the Wilson Division showed an 0.8 percent improvement, the only improvement within the entire system. Furthermore, the authors of the Dillon report believe this understates the potential contribution of AVM type systems:

> It is believed that this improvement is all the more significant in view of the fact the Planning staff have not been making full use of the management reports for analysis purposes and the passenger counters are not yet functioning. If a more detailed analysis of routes was undertaken on an ongoing basis, it is believed that vehicle utilization efficiency at Wilson Division would improve further. [M.M. Dillon, Ltd., p. 6]

The authors estimate a further 1 percent improvement at Wilson is possible with more use of management information reports and APC and that a 2 to 3 percent saving is possible on the rest of the surface system. The percentages would be higher in off-peak services and lower for peak-services when broken down by time of day.

Ridership per mile figures also show that only one other division had larger ridership increases than Wilson, a large portion of its increase attributed to new development at Scarborough. The 5.3% increase at the Wilson Division was roughly twice as much as other divisions, from which the authors conservatively conclude that CIS must contribute at least a one-half to one percent increase in ridership.

The test route along Jane Street that was analyzed previously for schedule adherence was revisited. It showed that from 11 a.m. to 2 p.m. and from 4 p.m. to 6:30 p.m. adherence deteriorated “somewhat”, while it improved substantially in the time period in between. The authors advised that this data should also be considered in light of the worsening traffic congestion. This recalls the difficulty discussed by the authors of the SCRTD report of comparing the result to how much worse the results might have been without an AVM/C system.

The Dillon report shows that the CIS has had an impact on the number of service calls and the number of requests to change-off vehicles. From 1984 to 1987, the Wilson Division has been operating substantially fewer miles between road calls than 3 comparable suburban divisions, and has been performing between approximately 15 percent to 20 percent worse in frequency of calls than the system average. Corresponding data was not available for prior to Phase VI implementation so it could not be confirmed that Wilson was not already worse than average, but the ease with which one can call or order change-offs using CIS is the likely reason. Based upon this, it was calculated that these road calls were a net loss to the TTC, and that the losses would be proportionally larger if expanded to the whole system.

This reasoning that change-offs are a net loss assumes that the calls are made when they are not warranted. If so, the proper solution is to establish clearer guidelines when to order a road call. If not, then the increase in road calls should actually be a net benefit by saving further damage to the vehicle or by reducing the discomfort or inconvenience to the passengers.

Phase VII was the implementation of the CIS system fleet-wide. The management reports are being improved so that they better provide the information that is needed for supervisors and for management. Although in both Phase V and Phase VI studies there have been claims that these reports have not been used much, it appears to an outsider that this is an exaggeration. The Planning Department has clearly been using the stored data, even if all departments have perhaps not used it yet to the fullest extent possible. Phase VII will prove to be an interesting project to many other potential users of AVM/C systems. The TTC has prepared for the implementation and for a new cost-benefit study by delegating responsibility to various departments to insure that the raw data is collected and redistributed to the right persons. Combined with data from recent non-CIS operations, this new data set should provide a more thorough and accurate cost-benefit analysis than the previous ones. The proposed study methodology is given in TTC, [1990].

4.4 Other Selected Cities

Seattle - Seattle Metro has been experimenting with AVM systems, particularly the APC subsystem, since the late 1970's. They now use signpost transmitter location finding technology coupled with APC subsystems on a portion of the fleet. One hundred and twenty seven of the eleven hundred buses in the fleet are so equipped with thirty more currently being fitted out. The resulting system is strictly a management information system with emphasis on collecting and processing data useful for route planning, scheduling, and other market related functions. The actual computation is not done in-house but by leasing time on King County's mainframe computer periodically. No study of costs and benefits has been performed, apparently on the belief that the analysis is too difficult to perform. Yet, there would appear to be some savings in personnel. An estimated 4.5 to 5 full-time equivalent personnel are employed to operate and interpret the data from this system at an estimated cost of $250,000 per year. By contrast to collect and possess this data manually was estimated to cost $2 million dollars per year. As has been discussed with previous cases, it is doubtful that one could really get analysis results of equal detail at all using manual methods.

Despite any hard quantitative evidence of benefits, enough value has been shown to date that Metro is planning to add real-time AVM/C capability and equip the entire fleet, and has accepted bids from vendors [Friedman, 1990].

Baltimore - In the interest of improved service reliability the Baltimore Mass Transit Administration (MTA) has made the commitment to install an AVM system fleet-wide. It will include both real-time and management information capabilities. The locating technology uses the Loran-C navigation aid system. MTA is currently installing the system in 50 buses and 4 supervisor vehicles. After driver feedback and other operational difficulties have been noted, all 900 buses in the fleet as well as 100 non-revenue vehicles will be equipped. Based upon current cost estimates, MTA has calculated that a 4 to 5% ridership increase would be required for payback of the investment in 3 years. This would require an increase in ridership from 9.7% of the workforce to 10.2%, a goal **MTA** is confident it could achieve with the better service AVM will provide [Rao, 1989].

It should be noted that 3 years is a short time and unless the system chosen turns out to be a very poor choice, will certainly have a longer depreciation period in which case smaller ridership increases would be required. This analysis is also conservative in that it ignores all other possible benefits to MTA, both monetary and non-monetary.

Hull, **Quebec** (Outaouais Region) - The Outaouais Regional Transit Commissions operating agency (CTCRO) has one of the most comprehensive and furthest developed applications involving AVM technology. It has been in service for approximately 6 years. The name of the system is SAGEPAS, and it is referred to as an "Urban Transit Management Macro System." For location data it uses radio signposts, combined with odometer readings for very high locational accuracy. Also included is APC technology of the treadle-mat variety, and a driver interface unit showing current time, early/late status and vehicle malfunction alerts. But the impressive aspect of this system is its state of development of management information and passenger information software. Several key components are listed here. The route and schedule planning assistance planning software is well developed; much of the raw collected data can be used by the well known scheduling program "HASTUS." Real-time arrival information is available to passengers for each bus-stop using the "Telerider" system within a larger module called INFOBUS. Maintenance alarms are reported in real-time to both the driver and control center, and can also be sorted as historical data for management uses.

The CTCRO used to use inspectors in the field as dispatchers. Based upon times at a few reference points, tactical decisions would be made. With the advent of SAGEPAS, the dispatching has moved indoors to a control center and is essentially a new job known as a "regulator." There are two for the 144 buses in the peak, and one for the 45 buses in the off-peak. Despite no longer being in the field, apparently relations with drivers has improved because of the increased accessibility. The regulators are now said to perform the key functions of supervision, analysis and decision making very well. The system is still undergoing further improvement and increases in its capabilities. In the near future performance indicators will be computed automatically, while real-time exception reports are under development. The APC sub-system tends to be unreliable and with a counting accuracy of only plus or minus **10%,** so a new approach is being considered; passengers, including transfer passengers, would use magnetic farecards upon boarding. This would provide improved passenger counts on boarding as well as transfer demand information. Combined with the less accurate alighting data from the APC, close estimates of origin-destination demand could be obtained.

No rigorous cost-benefit analysis has been performed, but a "quick and dirty" analysis done by CRCTO reportedly states it is worthwhile [Gregoire, 1990].

Halifax, Nova Scotia - Metro Transit, which services the Halifax/Dartmouth region, has developed a system functionally similar to the system used by CRCTO known as the "GoTime" system. It is both a real-time control system and management information system, using similar technologies and with similar capabilities. However, the actual components, software, and output formats from the management information are not the same, because the City of Halifax developed this system independently using a good deal of in-house capability. Only a few of the key similarities and differences will be summarized here. Metro Transit uses a driver interface unit that appears to be outwardly similar to CRCTO's and to provide the driver with the same information. Like SAGEPAS, "GoTime" also incorporates the "TeleRider" subsystem within the total package.

The technology used for the odometer is different than most; a proximity switch is mounted on the left front wheel of the bus which updates the position every 8 revolutions of the wheel.

Of special interest are the added features of its passenger information system. Selected stops have pushbuttons which will provide the same information as if one had called the telephone number. Major shopping and business centers have color video screens that can provide information for up to 10 routes at a time, with additional space for advertisements and service notices.

The system is under further development with funding arranged for further enhancements. Two priority areas are further automation of management information data processing, and provision of more efficient radio communications and data transfer due to an inadequate number of radio frequencies available. A cost benefit analysis was performed prior to installation, and the system now appears to be doing what was expected. One particular benefit has been identified that is specific to the Metro Transit region by virtue of its geographic characteristics. Many routes are through winding roads and terrain where there are limited cross roads. In such a poorly accessible area, monitoring by supervisors is greatly assisted by an AVM system. [Prentice, 1990]. The impact on ridership in particular, however, has been difficult to test. The ridership had been declining slowly, due to the increasing prosperity and car ownership in the region, and to fare increases. Yet, the decline has been stopped and it is largely attributed to the improved service with the advent of "GoTime."

Dublin, Ireland - The Transit agency - Dublin Bus - has been using a type of AVM system since the early 1970s. The choices of technology and evolution of the system have been different from most. The labor relations environment has also had a major influence that would not have been as prevalent for a North American agency.

Dublin's first "AVM" was in fact a voice radio based system. By 1974, 540 buses operating out of 7 depots were being controlled by voice contact. Each depot had between two to four controllers that would call each bus individually every half-hour or less for a location fix. Each bus would be plotted on a route chart. Despite the coarse nature of the location information, immediate improvements were seen as passenger surveys showed 24% reductions in excess wait times and frequency distributions of buses more closely matched the schedules. Such a system is not, strictly speaking, an AVM/C system, but a computer-aided dispatching, or CADis, system. However, the principle is similar, so the obvious next step was automating it to greatly increase its capabilities.

In 1980, the first buses began receiving the new system and by 1984 the entire 900 bus fleet was equipped. The vehicle location technology is basically of the deduced reckoning variety. The driver indicates when departure is made from each terminal. After that, the periodic sampling collects only mileage since departure, and not directly the actual location. But, 120 buses at the Ringsend depot were also equipped with infra-red transceivers to control signalized intersections. These units did not only perform the standard signal control function, but were interconnected with the AVM computer. Thus, they can verify bus location data and correct it as necessary, functioning in much the same manner as a radio signpost system. The service benefits have been substantial. Gaps in service greater than 15 minutes have been reduced by 60% while bunches of less than one minute have been reduced by 64% and lost miles due to congestion have been reduced by 30%. As a result, the decline in ridership has **been** reversed. [Collins, 1989.1 In addition, the working environment for operators and staff has improved. Finally, the management reports are better and produced in a fraction of the time that they were previously, it being estimated that one-half hour is required to compile the same operating statistics for a route that took 100 hours before. [Collins, 1990.]

With the introduction of AVM, it was necessary that its impact on labor productivity be determined in order that labor and management could agree on any resulting changes in compensation. The Labour Court was involved and part of the conclusion reached was that time savings to passengers and other benefits of a qualitative nature were the primary ones, with few quantitative benefits. Yet, if the service improvements are as large as have been claimed, it is possible to provide approximately the same level of service to passengers with a reduced fleet at reduced cost. It is also possible the traffic checking and data processing staff could be reduced, also saving costs. Therefore, it is reasonable to assume that Dublin Bus has experienced a cost savings.

Dublin Bus is aware that the technology currently in use is obsolete, but until recently emphasis has not been given to AVM despite its successful implementation. Instead, emphasis has been on conversion to one-person operation on the double-decker buses. Currently interest has been renewed in updating the system.

An APC system is now being installed which will not transmit in real-time but rather upload boarding and ticket sales data periodically. Thus, it is designed to support a management information system and not for real-time control. (The ultimate goal is to use magnetic fare cards to collect transfer information as well.) In order to prepare specifications for an AVM system to replace the current one, studies have begun to determine how inspectors perform their tasks, what information they need, and what kinds of control strategies should be used.

Torino, Italy Torino was the first of several cities in Italy to use AVM/C systems. It was also the largest with about 200 of its approximate 1,000 bus fleet equipped during the Pilot Phase which ended in 1988. The system has both real-time and management capabilities and has several unique features and performance capabilities.

This system uses an uncommon localization technology, It amounts to a deduced reckoning system that uses infrared detection at stops and software and hardware that are aboard the bus to give a very precise location estimate. Thus, all location finding capability is self-contained on the bus. One consequence of this system is that a “service plate” must be installed for each route. The high precision was desired to permit optimal control of traffic signals. The control room software and displays feature color coded time-distance diagrams and advanced tactical decision support software to help the dispatcher select the appropriate response to “macro-irregularities.”

The passenger counting system also has some unique features. At least 50 of the buses have both treadle mats and passenger weighing devices. The results are said to be of better precision than with conventional systems, but as of the end of the Pilot Phase were not “fully operative” for use by the larger fleet.

Passenger information displays showing arrival of the next bus and service messages were in operation at selected stops as well as during the Pilot Phase.

The system performance as of the end of the Pilot Phase was apparently judged a success, as shown by the decision to equip 600 buses by 1990 and the entire fleet by 1991. Service irregularity has shown a significant decrease, while management information such as passenger counts has been exceptionally accurate. The number of inspectors was to be reduced but had not been accomplished as of the end of the Pilot Phase.

In addition to being expanded fleet-wide many further improvements are close to being implemented or are planned. The passenger information system will provide time of next arrival at many stops, as well as route information at railway station connections. The operations planning program HASTUS will be implemented with a connection to the AVM/C management information database to allow for a more automated and responsive planning system.

4.5 Summary

Virtually all of the users that have published reports or have been contacted in the course of this study have been satisfied with AVM/C and believe that it is worthwhile, although some have experienced serious hardware or software difficulties, particularly involving the APC subsystems.

The agencies that have been particularly successful and are most aggressively developing their systems further tend to have a large component of local development and input. This provides a motivation for the needed employee input and effort that is required to extract benefits from AVM/C. It also gives the agency more insight into the capabilities and limitations of AVM/C, thereby better directing and stimulating future development. Another advantage is that it means that the agency is not as dependent upon outside vendors for support, selection or interfacing of new or improved subsystems. Finally, local involvement allows custom tailoring of hardware and report outputs to suit local conditions and requirements. One lesson of relevance to turnkey system vendors is that results are likely to be better if elements of the system are left open or flexible for local development and adaptation. Currently not all vendors agree on the extent of the degree of participation at the local agency that is optimal with respect to maximizing the value of the resulting system. Given that AVM/C provides a tool not just for better management of transit operations, but provides a needed competitive edge for attracting passengers, it is likely that within the coming decade AVM/C systems will come to be a standard part of most transit agencies.

5 Feasibility Analysis Of AVM/C Systems

The purpose of this chapter is to provide guidance to transit agencies which are faced with the decision of whether or not to install an AVM/C system. Given the financial conditions facing U.S. transit systems, this question really decomposes into two related questions. The first is whether or not an AVM/C system should in fact be implemented, and the second is whether it would be preferable to purchase the system outright or to lease it. Because the answers to these questions will depend upon local circumstances, general answers applicable to all situations cannot be given. Thus a method by which the answers can be obtained will be presented.

The first question is essentially whether or not an AVM/C system is feasible, in the sense of whether or not its benefits are at least as great as its costs. Thus the answer to this question involves a comparison of the anticipated benefits to the anticipated costs. Turning first to the benefits, as has been discussed in Chapters 3 and **4,** the benefits can be very diverse and widespread. Furthermore, there are many options with respect to the features of an AVM/C system (such as whether or not to include an APC system or a VMS system), and thus the design of the system would influence the nature and quantity of benefits as well as costs. Moreover, while some of the benefits are readily quantified and easily put in monetary terms, many others are much more elusive and very difficult if not impossible to quantify. For these reasons, for a comprehensive evaluation it is necessary to use a multi-objective evaluation methodology which can consider both non-quantified and quantified impacts. Such a methodology will be presented in the next section.

In addition, a comprehensive evaluation will also be desirable in most situations to assess the financial impact of installing an AVM/C system on the transit agency itself. If such an evaluation were to reveal that installing an AVM/C system were desirable from a purely financial perspective, then surely it would be even more desirable from a more comprehensive perspective, since impacts such as a better levels of service for users and enhanced image are only partly captured in revenues (or cost changes). Thus a financial evaluation would be a conservative one. For these reasons, the benefit-cost methodology that is applied to only financial impacts (in contrast to the more comprehensive social benefit cost analysis) is also presented here.

There is yet another value of the financial impact analysis, It is well known that transit agencies face a shortage of capital, in the sense that the desired capital program usually cannot be funded with the monies available. An alternative to outright purchase is leasing, presumably with operating funds. Thus a strategy of leasing can be used to enable deployment of an AVM/C system even in circumstances where a shortage of capital funds would otherwise make it unthinkable. The leasing option is especially significant for a transit agencies because, as we have seen from the case studies, AVM/C systems can reduce operating and capital costs and increase passenger revenues. Thus the entire cost of leasing may be more than offset by direct cost reductions or increases in revenue, making the agency better off financially as a result of leasing. Therefore a section this chapter is devoted to the leasing option.

5.1 Comprehensive Evaluation

Returning first to the comprehensive evaluation, this must necessarily involve both quantified and non-quantified benefits and costs of an AVM/C system. As was discussed in Chapters 2 and 3, AVM/C systems can provide far reaching benefits to a variety of groups in a variety of ways, and it is essential in any comprehensive evaluation to attempt to include all of these even if they cannot be quantified. Similarly, while some of the costs are clearly quantifiable-especially the cost of purchase from a vendor-other activities, such as retraining of employees and providing help and incentives for employees to use the system carry with them hidden costs which should also be considered. Thus the comprehensive evaluation approach discussed in this section will necessarily involve elements that are both subjective as well as objective. Of course, in any application some or all of the subjective items could be omitted if they were deemed too controversial or their significance were in doubt.

Broadly speaking, the benefits to the system can accrue to the agency itself and its employees, to passengers and potential passengers of the system, and to the community as a whole. The major impacts on all of these parties are identified in Figure 5.1. This figure represents the broadest range of possible impacts, reflecting the most elaborate type of system. Also included in this figure are various disbenefits or costs, borne primarily by the transit agency itself.

Figure 5.1 also presents various options in the system, from the elements of the basic system through various optional features in the area of communications, passenger information, software, and employee staff restructuring. The reason for including these is to permit indication of the extent to which various elements of the system would provide benefits (or disbenefits) in each of the identified categories. Thus depending upon the types of benefits that are desired for a particular system, certain elements may be omitted. For example, a system might be installed primarily to reduce fleet size and operating cost for the agency, and in this case optional elements for enhanced passenger information would not be included. As another example, if all the routes for which AVM/C is being considered (e.g., all routes operated from a particular garage) operate at very short headways, there may be little advantage to having enhanced passenger information in the form of telephone call-in or even information at bus stops. Of course, in other situations, an enhanced passenger information subsystem may be extremely desirable. Thus Figure 5.1 is intended to provide general guidelines regarding the options that can be selected for the system and the types of benefits to be obtained. It is intended to be used by agencies that are considering investing in an AVM/C system and need to consider various system options.

A comprehensive evaluation would basically take the design features of the system as given and identify the significantly affected groups and impacts to be expected from such a system. Based on the information contained in the previous discussion and case studies, the degree of benefit or impact for each of the parties and categories would be estimated in at least a qualitative manner. The form this would take is illustrated in Figure 5.2, which arrays the benefits and affected groups as rows. This figure has been constructed for a hypothetical situation, in which a basic system was to be implemented and the entries indicate judgement regarding the potential impact on the various affected groups. The purpose is to compare the anticipated costs (and other disbenefits or difficulties in implementing the system) with the expected benefits.

5.2 Financial Feasibility

This section describes the methodology for a financial breakeven analysis of a proposed AVM/C system. As discussed earlier, this is a very conservative evaluation, because it includes only those benefits accruing to the agency in the form of financial impacts.

The next subsection will give some approximate cost data as determined by a survey of properties with systems in use or recently ordered. These are to serve as a guideline for an agency to make its own cost estimates. The subsequent subsection will derive a **1** model in which these cost estimates will be needed. The model is designed so that it can be built using readily available data such as that supplied annually in conformance with FTA Section 15 regulations.

5.2.1 Recent Costs of AVM/C Systems

Collecting precise cost information on AVM/C systems is not possible due to several factors. One is that there is no standard definition of what constitutes an AVM/C system. Therefore, there is bound to be some misunderstanding and ambiguity when prices or development costs are quoted. Also, costs and prices will vary from one system or application to another due to differences in performance and capabilities. Furthermore, in at least one case only the incremental cost of giving a new radio system additional capability for AVM/C was viewed as the AVM/C system cost. Yet, the entire system was purchased simultaneously with the clear intent to deploy it as an AVM/C system, so it could also be argued that the total cost is the relevant cost. Great care **must** be taken in defining both the relevant system and its performance features before any comparative costing can be considered.

A related difficulty is the definition of deployment costs. Some of these can may be hidden in expenditure categories that make attribution to AVM/C deployment difficult or impossible, e.g., overtime of dispatchers to allow for training on the job. Other costs may be joint costs with other investments or projects, making exact allocation difficult. Moreover, the development costs borne by one agency may not be incurred by other users. Subsequent users of AVM/C systems will be the beneficiaries of hardware and software developed earlier by others, and by the learning and trial and error experiences in prior implementation efforts. Toronto and Dublin are two systems where AVM/C has been developed since the early 1970s. Their efforts undoubtedly have helped improve AVM/C systems in general and the knowledge base available to other agencies. Thus, the relatively high cost of the investment by the Toronto Transit Commission is not

		Selected Elements of Basic System						Selected Optional Elements							
		Communication		Sensors		Employees		Comm.	Passenger Information			Software			Employees
		Disp Int	Driver I	AVL	PLM	Tact. Training	Analyst	Enhanced Driver In	Call-In	Bus Stop	In-Bus	Tactical Response	Routing/ Scheduling	Maintenance	Programming Analyst Tean
<u>Passenger Benefits</u>															
Reliability:	Earliness	S	S	S	W	S	S	W				W	S	W	S
	Lateness	S	S	S	W	S	S	W				W	S	W	S
	Bunching	S	S	S	W	S	W	S	W	W	W	W	S	W	S
	Crowding	S	S	S	S	S	W	S	S	S	S	W	S	W	S
	Connection	S	S	S	S	S	S	S	S	S	S	W	S	W	S
Passenger Information:	Call i	S		S	W	W	S		S			S	W		S
	Bus Stop	S		S	W	W	S			S		S	W		S
	In-Bu	S	W	S	W	W	S	W			S	S	W		S
Security		S	S	S		W		W	S	W					-
Increased Service		W	W	W	W	W	S	S				W	S		S
<u>Community Benefits</u>															
Neighborhood Watch		S	S		W	-	-		-	-	-	W	W		

S = Strong, W = Weak

a. Passenger and community benefits.

Figure 5.1. Relationship of benefits to AVM/C system elements. (continues on next page)

	Selected Elements of Basic System						Selected Optional Elements							
	Communication		Sensors		Employees		Comm.	Passenger Information			Software.			Employees
Agency and Employee Benefits	Disp Int	Driver Int	AVL	PLM	fact. Training	Analyst	Enhanced Driver Int	Call-In	Bus Stop	In-Bus	Tactical Response	Routing/ Scheduling	Maintenance	Programming Analyst Team
Improved Image		S	S		W	W	S	S	S	S	W	W		W
Increased Revenue	W	W	S	W	S	S	W	S	S	S	W	S	W	S
Reduced Cost	w	W	S	W	S	S	W	W	W	W	S	S	S	S
Dispatcher Effectiveness	S	S	S	S	S	S	S	W	W	W	S	S	S	S
Fewer Inspectors	S	S	S	S	S	S	S				S	S	S	S
Fewer Surveyors	W	W	S	S		S	W				W	S		S
Scheduling/Planning			S	S	W	S		W	W		W	S	S	S
Statistics			S	S	W	S		W			W	S	S	S
Maintenance Planning	W	W	S	S		S	S				W	W	S	S
Fuel Consumption		W	S	W	W	S	W				W	S	S	S
Defective Vehicles	S	S	W		W	W	S				S	W	S	S
Reserve Fleet	S	W	S	S	S	S	S				S	S	S	S
Disbenefits														
Purchase & Installation	S	S	S	S			S	S	S	S	S	S	S	
Upkeep	S	S	S	S			W	S	S	S	S	S	S	S
Training Requirements	S	S	S	W	S	S	S	W			S	S	S	S
Dispatcher Requirements	S	S	S	S	S		S	W	W	W	S	W	W	S
Data Analysis	S		S	S	W	S		S	S	S	S	S	S	S
Labor Relations	S	S	W	W	S	S	S	W	W	S	S	S	S	S

S = Strong, W = Weak

b. Operator and employee benefits

Figure 5.1. Relationship of benefits to AVM/C system elements. (continued from previous page)

Summary of Anticipated Impacts of AVM/C System for Willowbrook Garage Routes

System Features

- Automatic Vehicle Location
- Communication - two-way radio and digital link
- Driver Interface - phone, screen and PA system on bus
- Dispatcher Interface - phone, screen with windows, performance measurement windows

Passenger Benefits

- Reliability, Headway, Schedule Adherence: Substantial Improvement
- More even passenger loading
- Security: Rapid Emergency Response

Agency Benefits

- Costs: At least 5% reduction in peak vehicles and peak period vehicle-miles
- Revenues: At least 4% increase in ridership and revenue
- Image: Provides positive development that will form nucleus of publicity/advertising campaign and will create good will with citizens and municipal councils

Community Benefits

- Town Watch feature in high crime areas will enhance image and increase support from community

Investment Cost

- $880,000 for a fleet of 110 buses, paid by local government (25%) and federal grant (75%)

Figure 5.2. Example evaluation format for a basic AVM/C system

likely to be repeated by agencies currently considering installation of an AVM/C system.

The duration of the development and deployment phases at some agencies introduces two problems. One is that the portions of development and acquisition done in different years should be converted to current or, at least same-year, dollars. Unfortunately, the inflator to use for sophisticated electronic products that are not in widespread use can only be roughly estimated. The second problem is that the records of development and purchases may be either incomplete or difficult to locate.

Attempts to obtain price estimates from vendors has also proven frustrating. Inquiries regarding actual bids encountered numerous situation where more than one company bid jointly, and one firm is not free to reveal the others' prices. There are also different sales philosophies to consider; one vendor may emphasize a "turn-key" solution that must be tailored to an agency's particular needs, while another may trust software development to someone else and just sell hardware. These different approaches make comparable bids for hypothetical situations difficult to construct.

Finally, it must be remembered that prices are not costs. One reason for this is simply that the average cost per system over the life of sales of that system is essentially unknown, until the end of production. Since we are in the early stage of development and sales of AVM/C systems for transit, the long run production costs are unknown. Coupled with this vendors can adopt different pricing strategies, reflecting different approaches to market development. One approach is to price high, in an attempt to cover the fixed (and sunk) cost of development quickly, before competition precludes this. This follows the consumer product (e.g., TV) example. Another is to try to facilitate market development with low prices, to induce a high volume of sales. With this strategy quoted bids are often loss leaders and do not reflect full long run average costs. It is technological advances that enable the prices demanded by the surviving vendors to remain unchanged or decrease with time; otherwise prices would have to increase dramatically to recover costs.

For the reasons outlined above, the information provided here should be used as only a rough guideline. Construction of better cost estimates will require preparation of careful performance and quality specification specific to the agency's needs and submissions to several vendors.

Toronto Transit Commission. Toronto Transit Commission has had a multiphased development program that has proceeded from prototype units, to a fleet of 100 buses, then to the entire Wilson Division of over 250 buses, and recently to the entire surface fleet of over 1900 vehicles. Adoption of the system fleetwide was approved in 1990. This AVM/C system is a comprehensive one including both real-time control and management information subsystems. Not included is an Automatic Passenger Counting (or APC) subsystem. (A brief summary of the system appeared in Chapter 4.)

TTC [1986] estimated the total development and acquisition cost for the entire fleet of about 2200 to be C$37.4 million in 1986 dollars with an annual operating and maintenance cost of C$1.7 million. M.M Dillon Company [1988] revised the latter figure to

C$2.2 million in 1988 dollars. As of the summer of 1991 the actual total investment is expected to be less than the original (X37.4 million.

MTA Baltimore. Rao [1990] has estimated that the cost of implementing a comprehensive system for the entire fleet of 950 buses and service vehicles to be within the range of $6 to 7 million. As of this writing, the system is still in the 50 bus pilot stage. Revised costs may be available by direct contact with the agency.

VIA Transit, (San Antonio). A fleet of 539 buses was equipped with a primarily real-time AVM/C system (no APC system), being phased in over a period from April 1984 to January 1989. The vendor was paid $3.43 million but is said to have lost money. Bids were received ranging from $2.4 to $5.4 million for 470 buses plus 35 support vehicles (in 1984 dollars).

Rhode Island PTA (Providence). A fleet of 236 buses has been equipped with a primarily real-time system that was purchased in 1988 for approximately $2 million. (The system is not yet operational as of this writing, because of delays unrelated to the vendor or technology.)

Kansas City Area Transportation Authority. In 1989 and 1990 a basically real-time AVM/C system was installed in a fleet of 279 buses. A radio system was installed concurrently and is attributed with the majority of the expense of $2.09 million with the addition of the Automatic Vehicle Locating system adding an increment of only $0.18 million for a total of $2.27 million. (As of this writing, the system is still in the test phase.) Maintenance cost are estimated at $50,000 per year.

Seattle Metro. 130 buses, a small portion of the entire fleet, are using an APC system for a primarily management information application. These buses are rotated around different routes for collecting travel time, passenger boarding and alighting information, etc. The system was installed in phases from 1980 to the present. The hardware was purchased for $440,000 while the software was developed in-house at a cost of $100,000. The time distribution of these investments were not specified, so it would be difficult to estimate the value in current dollars. Maintenance of the system is reported to require one full-time employee.

CTCRO (Outaouais Regional Transit Commission; Hull, Quebec Region). The SAGEPAS system is a very comprehensive system including but not limited to real-time and management information systems, the INFOBUS real-time passenger information system, the HASTUS scheduling program, and other components. All 145 buses are equipped, 30 of which also have APC subsystems. (A more detailed description appeared in Chapter 4.) Estimates of the development and installation cost range from $C2.6 million to $C2.7 million in 1983 Canadian dollars.

5.2.2 Construction of a Bus Transit Cost Model

In order to include the impact of an AVM/C system on bus system costs, it is necessary to have a cost model. This is described below. (For a general discussion of transportation cost models and the rationale for this type of model, see Morlok [1978], Chap. 9, or Meyer and Miller [1984], pp. 351-360.)

5.2.2.1 Derivation

A widely used and accepted model (or estimating relationship) for the total cost of operating a bus fleet is the following:

$$\text{Total Cost} = TC = A \times (\text{Revenue-hours}) + B \times (\text{Revenue-miles}) + C \times (\text{Fleet Size}) \quad (5.1)$$

Although this is a relatively coarse model, when dealing in incremental cost changes such as in the consideration of an AVM/C system, the error is not as significant as when calculating total cost. The variables Revenue-hours and Revenue-miles refer to these values for the buses (or other vehicles) operated. Usually these variables and all other items are on an annualized (or per year) basis, though any time unit can be used, provided it is used consistently throughout the analysis. The incremental cost or change in cost is calculated from the modified form of the previous equation:

$$\Delta TC = A \times (\Delta\text{Revenue-hours}) + B \times (\Delta\text{Revenue-miles}) + C \times (\Delta\text{Fleet Size}) \quad (5.2)$$

The symbol Δ refers to the difference between before and after deployment of the AVM/C system. (A negative value corresponds to a decrease.) The coefficients A, B, and C are constants that must be determined for each system or property. In order to break even on the investment in an AVM/C system, the reduction in total cost ΔTC, must exactly offset the cost of investment in the system. There is also the possibility that an increase in revenue from increased ridership aids in offsetting the investment cost, but consideration of this possibility will be deferred until the end of the section for simplicity. The Annualized Investment, AI, of the AVM/C system is:

$$AI = (\text{Total Investment in AVM/C System}) \times (\text{Capital Recovery Factor}) + (\text{AVM/C Operating and Maintenance Cost}) \quad (5.3)$$

where

$$\text{Capital Recovery Factor} = CRF = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (5.4)$$

and

i = Minimum Attractive Rate of Return on Capital, or MARR
N = Life of the item (in this case, the AVM/C system)

A value for i of 10% per year is typical for a transit agency assuming all values are in constant dollars (i.e., not including the effect of inflation in the future - the easiest and still a quite valid way to conduct engineering economy or economic evaluation study in the public sector). Since the survey of agencies that have implemented AVM/C systems revealed that the operating and maintenance costs of these systems was very small and generally was thought to be offset by related cost savings (e.g., of replaced radio system, fewer administrative and data costs), the primary added expense will be for the investment. Thus in the paragraphs below AI is often referred to as the annual investment cost of the AVM/C system. However, it should be understood that it represents the total added cost of the AVM/C system, whatever that includes.

The annualized investment cost, AI, must exactly cancel the annual savings. This can be expressed by equating the annualized investment cost (expressed as a negative quantity, hence the minus sign) to the annual incremental cost savings due to an AVM/C system, yielding:

$$-AI = \Delta TC = A(\Delta\text{Revenue-hours}) + B(\Delta\text{Revenue-miles}) + C(\Delta\text{Fleet Size}) \quad (5.5)$$

In the interest of further simplifying this relationship, one can make the assumption that revenue-hours will decrease in a fixed ratio to revenue-miles over the relatively small incremental changes due to use of an AVM/C system. If X is the ratio of Revenue-hours to Revenue-miles then by substitution the previous equation can be rewritten as:

$$-AI = AX(\Delta\text{Revenue-miles}) + B(\Delta\text{Revenue-miles}) + C(\Delta\text{Fleet Size}) \quad (5.6)$$

or, upon collecting terms:

$$-AI = (AX + B)(\Delta\text{Revenue-miles}) + C(\Delta\text{Fleet Size}) \quad (5.7)$$

This simplification to only two variables, the fleet size and revenue-miles, allows for a graphical representation of the combinations of the changes in either variable that will make the investment break even. This can be seen by rearranging the equations into a slope intercept form:

$$\Delta\text{Fleet Size} = \frac{-AI}{C} - (\frac{AX + B}{C})(\Delta\text{Revenue-miles}) \quad (5.8)$$

The graphical interpretation of this formula is shown in Figure 5.3. Any combination of fleet reduction or Revenue-mile reduction that is on the sloped line that intercepts the point $-AI/C$ will breakeven. Any combination of values below this line indicates a profitable investment. In a less conservative analysis one could include the expected increase in revenue by subtracting the estimated increase in annual revenue due to increased ridership from the Annual Investment cost:

$$AI' = AI - \Delta\text{Revenue} \quad (5.9)$$

This will have the effect of shifting the breakeven line upwards as well as changing its slope (angle). In this case smaller fleet reductions or reductions in revenue-miles are required to breakeven, as is demonstrated in Figure 5.4.

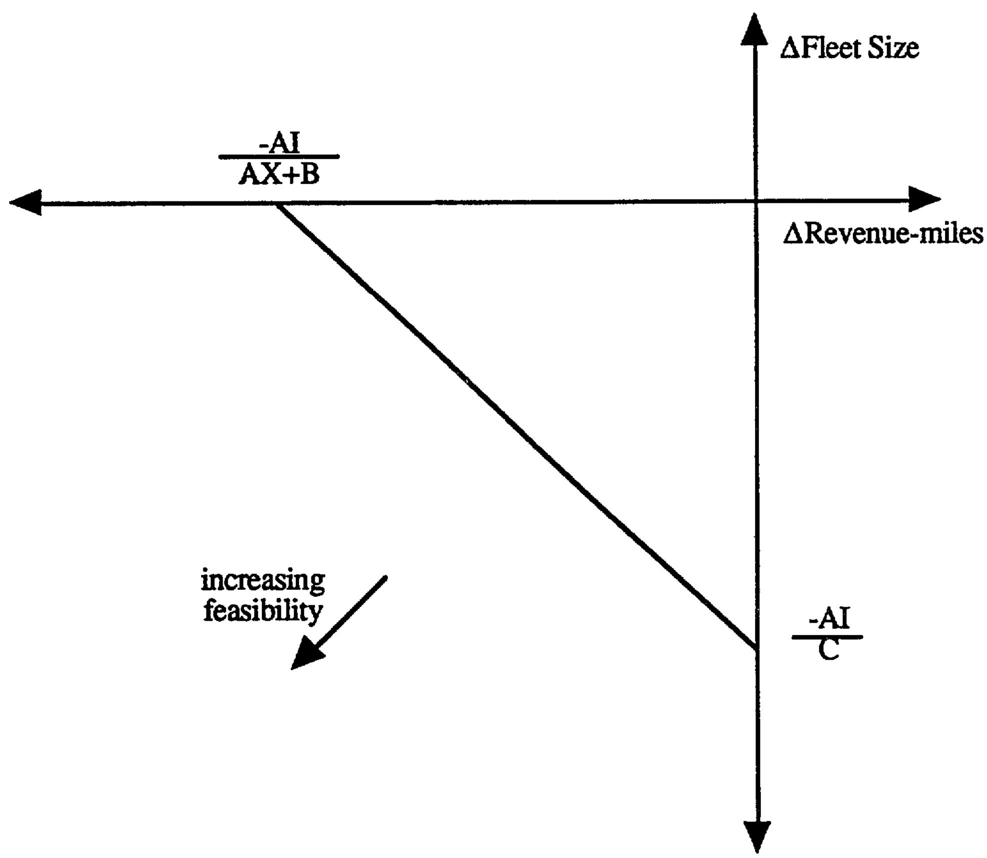


Figure 5.3. Breakeven analysis.

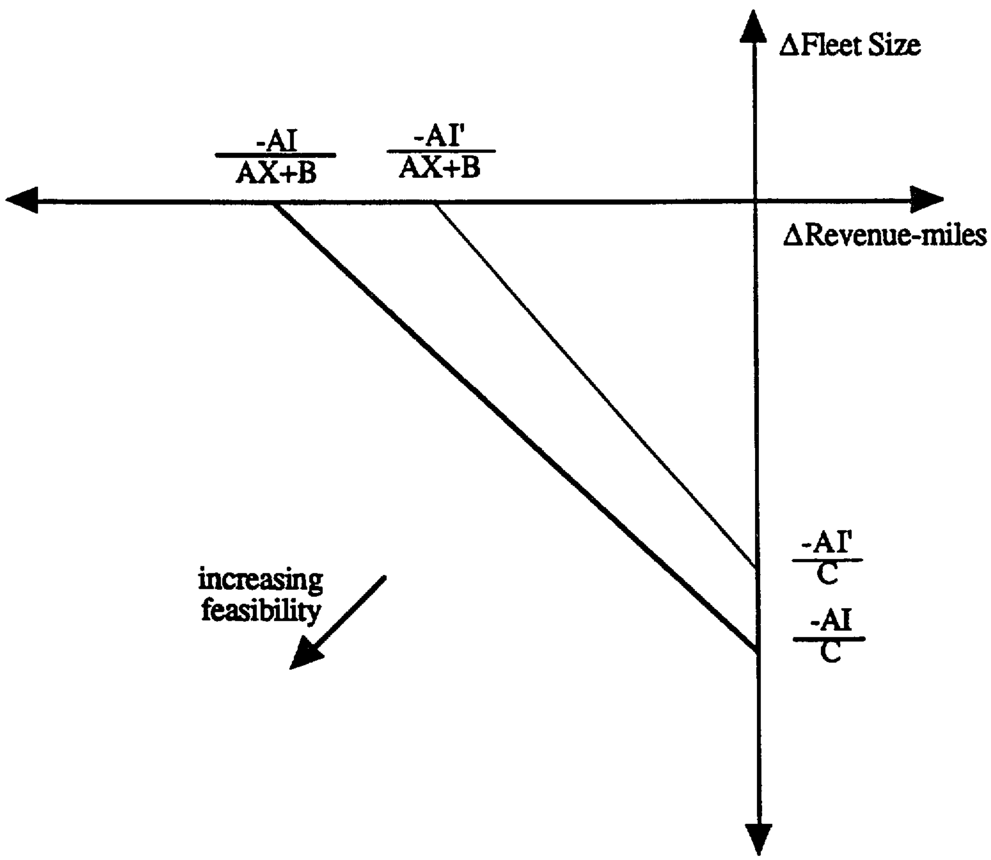


Figure 5.4. Breakeven analysis including revenues from increased ridership.

5.2.2.2 When Fleet Size Is Assumed Constant

For some agencies it will be the case that, for the short to medium term, no reduction in fleet will be possible. If the fleet is relatively new or under long term lease, fleet reduction opportunities may not arise or may carry substantial financial penalties that offset any operational cost savings. In this case it is possible to do a breakeven analysis between the reduction in revenue-miles and increased revenue from increased ridership as a result of using an AVM/C system.

This model is derived by modifying equation (5.7) and using the term AI' from the previous section. Since ΔFleet Size is zero, equation (5.7) becomes (now substituting AI' for AI):

$$-AI' = (AX + B)(\Delta\text{Revenue-Miles}) \tag{5.10}$$

or:

$$-(AI - \Delta\text{Revenue}) = (AX + B)(\Delta\text{Revenue-Miles}) \tag{5.11}$$

Solving for ΔRevenue puts this equation in slope-intercept form and makes the trade-off between ΔRevenue and ΔRevenue-Miles easy to examine:

$$\Delta\text{Revenue} = (AX + B)(\Delta\text{Revenue-Miles}) + AI \tag{5.12}$$

This relationship is shown in Figure 5.5. Any combination above this sloped line will indicate a profitable investment.

5.2.3 Estimation of Coefficients

All three of the coefficients A, B, and C can be estimated using data collected in the fulfillment of UMTA Section 15 requirements. A, the unit cost (multiplier) associated with vehicle revenue-miles, is estimated by using the following values:

$A =$ Vehicle operations expenses percentage $\times$ Total expense/Total Revenue-hours (5.13)

B, the unit cost (multiplier) associated with vehicle Revenue-hours, is estimated by using the following values:

$B =$ material and utilities per vehicle-mile + vehicle maintenance per vehicle-mile (5.14)

C, the unit cost (multiplier) associated with Fleet size, is estimated by using the following value:

$$\text{C} = \begin{matrix}\text{(non-vehicle} \\ \text{(maintenance} \\ \text{(percentage}\end{matrix} + \begin{matrix}\text{general)} \\ \text{administrative)} \\ \text{percentage)}\end{matrix} \times \text{total expense/Fleet size}$$

$$+(\text{bus cost}) \times (\text{CRF}) \tag{5.15}$$

where CRF is the same formula as before. Here, N will be the useful life of the bus

(12 years is a good estimate for most agencies).

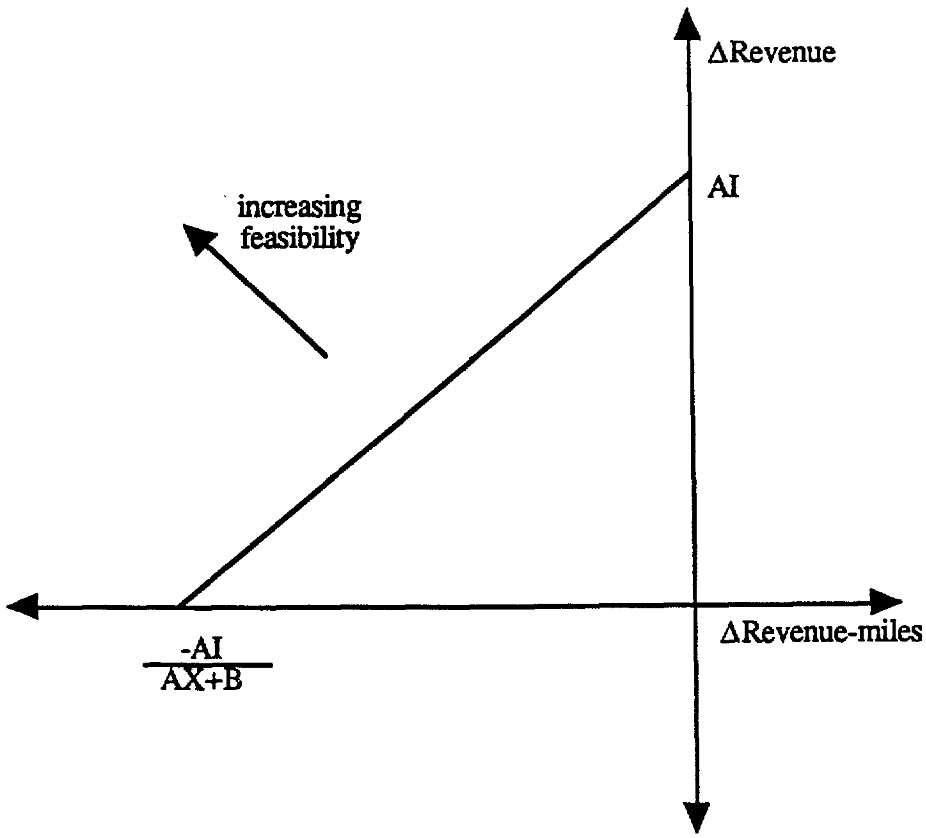


Figure 5.5. Breakeven analysis when fleet reduction is zero.

5.2.4 Modifications for Fleet Size and Incremental Deployment

It may not always be possible to deploy an AVM/C system on an entire fleet at once. The availability of capital funds or concerns about excessive training demands may dictate a partial fleet installation or phased installation instead. This section shows how to revise the previously developed cost model for this situation. This will first require review of some basic concepts.

A complete AVM/C system can be divided into two basic cost components. One is the fixed cost, or FC, component and the other is the variable cost, or VC, component. FC is the cost associated with equipment purchases and installation expenses that are independent of the number of vehicles. These would be likely to include the dispatchers' stations, computers, software, dispatch training, etc. VC is the cost associated with the number of vehicles that are AVM/C equipped. This is likely to include the driver interface unit, antennae, their costs of installation, driver training, etc.

The total investment cost is the sum of the fixed cost, FC, plus the number of buses equipped multiplied by the variable cost, VC:

$$\text{Total Investment Cost} = \text{TIC} = \text{FC} + (\text{Fleet Size})\text{VC} \qquad (5.16)$$

The average cost per vehicle is then the Total Investment Cost, ***TIC,*** divided by the Fleet Size:

$$\text{Average Cost per Vehicle} = \frac{TIC}{\text{Fleet Size}} \qquad (5.17)$$

The average cost per vehicle can be greatly affected by the number of vehicles equipped. As an example, Table 5.1 shows the Total Investment Cost, ***TIC,*** for a hypothetical system on both a percentage and a per vehicle basis for an array of fleet sizes. The reference is 300 buses, the maximum number the hypothical fixed installation can support.

Table 5.1 Effect from fleet size for a system capable of supporting 300 buses

Assumed:
Fixed Cost = FC = $1,500,000
Variable Cost = vc = $3,000 per vehicle
Total Investment Cost = TIC = FC + (Fleet Size) VC

Fleet Size	TIC	ATIC	TIC/vehicle
300	3,000,000	0	$10,000
200	2,500,OOO	-16.7%	$12,500
100	2,000,000	-40%	$20,000
60	1,800,OOO	-40%	$30,000
30	1,650,OOO	-45%	$55,000

Note that when the equipped fleet size is reduced to one-third, from 300 to 100 buses, the average cost per bus is doubled. Even more dramatic, when the fleet size is reduced to one-tenth, from 300 to 30, the TIC reduces by only 45 percent and the per vehicle or average cost increases from \$10,000 to \$55,000 per vehicle.

It is clearly advantageous from a unit cost per bus standpoint to equip as many buses as possible at once, but a phased installation could still provide monetary benefits exceeding its costs. A two phase installation can be analyzed by using modified values in the analysis developed in the previous section. Some further terms need to be defined:

FS_1	=	fleet size receiving AVM/C equipment in first phase
FS_2	=	total fleet size AVM/C equipped after second phase of installation
n_3	=	number of years after start date that the second phase occurs

The modified Total Investment Cost, TIC'', becomes:

$$TIC'' = \text{Total Initial Investment in AVM/C System} + \frac{(FS_2 - FS_1)VC}{(1+i)^{n_2}} \tag{5.18}$$

The modified Annualized Investment, AI'', is:

$$\begin{aligned} AI'' &= TIC''(CRF) + (\text{Initial Annual } AVM/C \text{ Operation and Maintenance Costs}) \\ &+ (\text{Additional Annual AVM/C Operation and Maintenance Costs})\frac{(1+i)^{N-n_2}-1}{(1+i)^N-1} \end{aligned} \tag{5.19}$$

The third term in this last equation accounts for the additional operation and maintenance costs that are generated after AVM/C equipment is installed in the remainder of the fleet during the second phase. For example, an additional electronics technician may be needed. An example application is provided in the following section. Finally, the modified cost coefficients associated with Revenue Miles and Fleet Size are as follows, using the previous coefficients but with correction factors:

$$(AX+B)'' = (AX+B)\left(\frac{FS_1}{FS_2} + \frac{FS_2 - FS_1}{FS_2}\,\frac{(1+j)^{N-n_2}-1}{(1+i)^N-1}\right) \tag{5.20}$$

$$C'' = C\left(\frac{FS_1}{FS_2} + \frac{FS_2 - FS_1}{FS_2}\,\frac{(1+i)^{N-n_2}-1}{(1+i)^N-1}\right) \tag{5.21}$$

The breakeven analysis proceeds almost exactly as in the case of the previous section. It is only necessary to make the direct substitutions of $AI'', (AX+B)''$ and C'' for $AI, (AX+B)$ and C, respectively. The example application in the following sections will make this clear.

5.2.5 Example Application

A hypothetical transit agency (being an average for the entire U.S.) will be analyzed by using the aggregated nationwide data for the year 1987 from National Urban Mass Transportation Statistics (1987). The fleet size for the hypothetical system is obtained by dividing the nationwide fleet by the number of agencies. The approach for a local agency will be similar, with the corresponding data for the particular agency replacing the nationwide data.

Calculate A:

From page 29:

Vehicle operating expenses percentage = 54.2%

Total expense = $6,604 x$10^6$

Hypothetical system fleet size = 110

From page 57:

Total revenue hours (directly operated) = 112,889.9 x10^3

The value of the parameter ***A*** may be calculated from equation (5.13):

$$A = \frac{(.542)(6,604 \times 10^6)}{112,889.9 \times 10^3} = \$31.71/\text{Revenue-hour}$$

Calculate B:

From page 125:

Materials and utilities per vehicle-mile = $0.49

From page 131:

Vehicle maintenance expense per vehicle-mile = $0.88

The value of B may be calculated from equation (5.14) as:

$$B = 0.49 + 0.88 = \$1.37/\text{vehicle-mile} = \$1.37/\text{Revenue-mile}$$

A deadhead correction factor, K, the ratio of vehicle-miles to revenue-miles, can be used as a multiplier for increased accuracy if desired.

Calculate C:

C consists of three components. The first two relate to maintenance and administration expenses.

From page 29:

Non-vehicle maintenance expense percentage = 3.4%

General administration expense percentage = 17.2%

The third is the cost of ownership of a bus, calculated using the capital recovery factor and initial cost of the bus in the same manner as was done in equation (5.3) for the AVM/C system.

From page 47:

Hypothetical system fleet size = 110

With i = 10%, N = 12 years, and an initial bus cost = $160,000

Using equation (5.4) for this CRF, we have:

$$CRF = \frac{(.10)(1.10)^{12}}{(1.10)^{12} - 1} = 0.1468,$$

and thus:

$$\begin{aligned} C &= \frac{(.034 + .172)(6,604 \times 10^6)}{41,984} \quad + \quad 160,000(.1468) \\ &= 32,400 \quad + \quad 23,490 \\ &= \$55,900/\text{bus} \end{aligned}$$

<u>Calculate X:</u>
From page 59:

Total Revenue-miles (directly operated) = 1,444,902 $\times 10^3/383$ = 3,772,600
Total Revenue-hours (directly generated) = 112,889.9 $\times 10^3/383$ = 294,750

$$X = \frac{112,889.9}{1,444,902} = .0781$$

<u>Calculate AI:</u>
Estimating the equivalent annual AVM/C Investment, AI, is straightforward once the investment cost of the system and its useful life is known. Here again $i = 10\%$, and N assumed for the example to be only 6 years, since the system may be obsolete or need replacement at the half-life of the bus:

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1} = \frac{(.10)(1.10)^6}{(1.10)^6 - 1} = .2296$$

In this case, we assume the net AVM/C System Operating and Maintenance cost is almost zero. Total Investment in System = -($8,000/bus) (110) + 0 = -$880,000, and from equation (5.3):

$AI = (-880,000)(.2296) = -\$202,000$ (negative because it is a cost, not savings)

We may now use these values to calculate Δ Fleet Size in terms of Δ Revenue-miles from equation (5.8):

$$\begin{aligned} \Delta\text{Fleet size} &= AI/C - \frac{AX+B}{C}(\Delta\text{Revenue-miles}) \\ \Delta\text{Fleet size} &= \frac{-202,000}{55,900} - \left(\frac{31.71(.0781) + 1.37}{55,900}\right)(\Delta\text{Revenue-miles}) \\ \Delta\text{Fleet size} &= -3.6 - \left(\frac{3.85}{55,900}\right)(\Delta\text{Revenue-miles}) \\ \Delta\text{Fleet size} &= -3.6 - (6.88 \times 10^{-5})(\Delta\text{Revenue-miles}) \end{aligned}$$

To plot the breakeven line, we note that by expanding equation (5.8) we have:

$$\frac{AI}{C} = -3.6 \text{ buses}$$

$$\frac{AI}{AX+B} = \left(\frac{AI}{C}\right) \div \left(\frac{AX+B}{C}\right) = \frac{-3.6}{6.88 \times 10^{-5}} = -52,350 \text{ revenue-miles}$$

Thus, we see that for our system's fleet of 110 buses, one must reduce the peak fleet by 3.6 vehicles or 3.2% (3.6/110) or reduce the revenue-miles by 52,350 or 1.4% (52350/3,772,600) or some combination in between to breakeven. This result is shown in Figure 5.6.

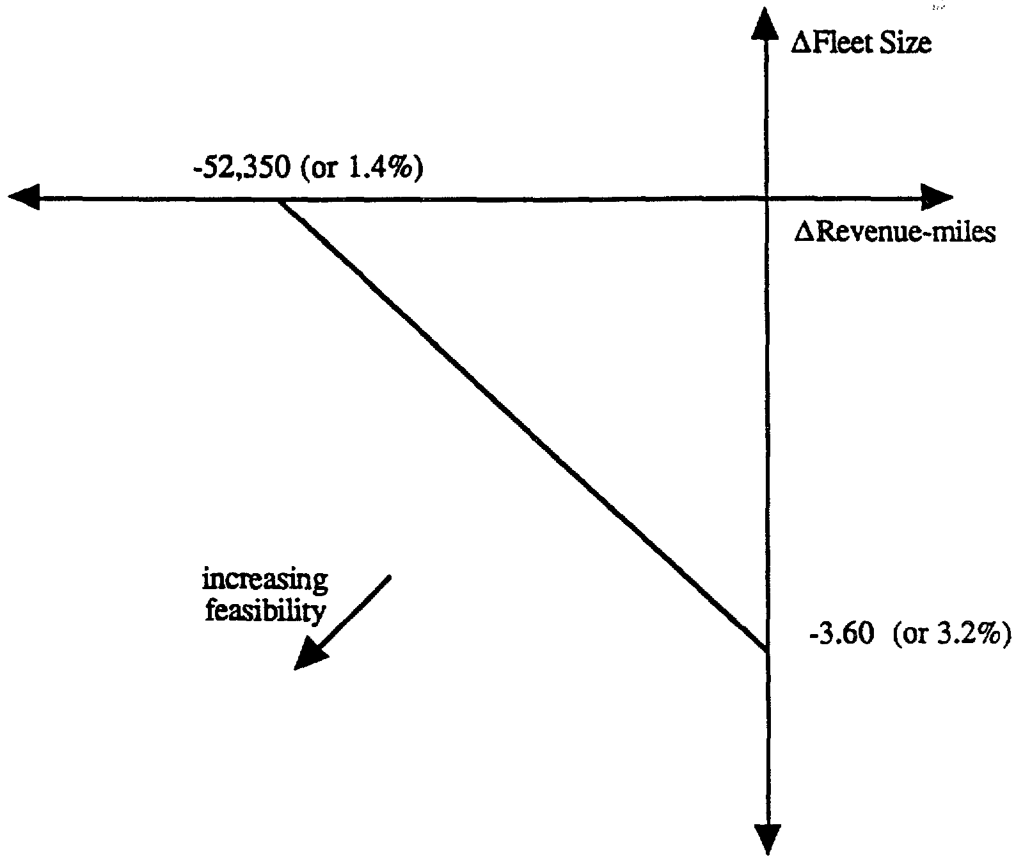


Figure 5.6. Breakeven results using a nationwide fleet example.

5.2.6 Example Application Modified for Two-phase Installation

Let us assume that the same (hypothetical) agency would like to consider installing AVM/C equipment in only 50% of the buses (55 buses) initially, with the rest receiving equipment after 3 years. The total purchase cost for the AVM/C system serving 110 buses was quoted at $880,000, with the fixed cost, FC, representing $506,000 of this cost. **Thus** the **variable** cost, VC, is ($880,000-$506,000)/110 = $3,400 per bus to purchase and install the needed AVM/C equipment. Summarizing the input data:

Total Investment Cost = $880,000
FC = $506,000
VC = $3,400 per bus
total fleet size = FS_2 = 110

initial fleet to receive AVM/C equipment = FS_1 = 55

N = 6 years life for AVM/C equipment, CRF = .2296
$n_2 = 3$ years
$AX + B$ = $3.85/revenue-mile
C = $55,900 per bus
O&M = 0

Total Initial Investment Cost = ***$506,000 + 55 ($3,400) = $693,000.***

Now, using equation (5.18) to get the revised present value of the Total Investment Cost, T1C", for the phased purchase and installation:

$$TIC'' = \$693{,}000 + \frac{(110-55)\$3{,}400}{(1+.10)^3} = \$833{,}500$$

Although the earlier example assumed zero Operating and Maintenance Cost, let us now assume that when the additional fleet receives equipment at the end of year 3, one person must be hired at a full cost of ***$60,000*** per year. This gives the additional cost:

Additional AVM/C Operating and Maintenance Cost = $60,000 per year

The revised Annualized Investment, ***AI",*** is found by investing the appropriate values into equation (5.19):

$$-AI'' = (\$833{,}500)(.2296) + 0 + (\$60{,}000)\frac{(1.10)^{6-3} - 1}{(1.10)^6 - 1} = \$217{,}100 \text{ per year}$$

or

$$AI'' = -\$217{,}100 \text{ per year}$$

The revised cost coefficients a.re found by inserting the appropriate values in equations (5.20) and (5.21):

$$(AX+B)'' = (\$3.85)\left(\frac{55}{110} + \frac{110-55}{110}\,\frac{(1.10)^{6-3}-1}{(1.10)^{6}-1}\right) = (\$3.85)(.714)$$

$$C'' = (\$55,900)\left(\frac{55}{110} + \frac{110-55}{110}\,\frac{(1.10)^{6-3}-1}{(1.10)^{6}-1}\right) = (\$55,900)(.714)$$

The revised corresponding points on the breakeven line are:

$$\frac{AI''}{C''} = \frac{-\$217,100}{(\$55,900)(.714)} = -5.2 \text{ buses}$$

$$\frac{AI''}{(AX+B)''} = \frac{-\$217,000}{(\$3.85)(.714)} = -78,900 \text{ revenue-miles}$$

Some care is required in interpreting these results. The number of buses to be reduced and the number of revenue-miles reduced both refer to the period after n_2 when the entire fleet is AVM/C equipped. It is implicit in the formulae that the savings needed are always proportional to the equipped fleet size. Thus, we see that 5.2 buses must be saved during the three years the full fleet is equipped, compared to only 3.6 buses if the entire fleet is equipped at once. Similarly, 78,900 revenue-miles must be saved annually compared to only 52,350 revenue-miles if the entire fleet is equipped at once. (During the three years that only half the fleet is equipped, (55/110) 5.2 = 2.6 buses or (55/110) 78,900 revenue-miles = 39,450 revenue-miles must be saved in order to breakeven.)

In general, if phased installation is used, the benefits forgone will exceed the costs postponed, so that the system efficiency improvements must be larger in order to still breakeven.

The analysis of phased installation can be insightful regarding the tradeoffs of reduced initial expenditures and operating disruptions versus the reduced initial benefits. But the limitations of the formulae should be remembered. One is that the initial installations cause fleet size or revenue-miles reductions per bus equal to the later installations, in reality, the reductions will probably be higher in later years as experience is gained. The other limitation is that all costs are assumed to increase at the same inflation rate, but in reality there could be differences in capital versus labor inflation rates, which would make this assumption invalid.

5.3 The Leasing Option

Next are presented the results of an analysis which explored the feasibility of a transit agency leasing its AVM/C equipment rather than purchasing it outright. As stated earlier, the main reason for considering this option is that transit agencies rarely have all of the funds for capital improvements that they need, and therefore even beneficial investments may have to be delayed or even postponed indefinitely for lack of funds. While various innovative means of financing have been developed in the past, capital funds for general purposes are expected to continue to be in short supply. However, the nature of AVM/C equipment is such that a lease from the producer of that equipment or other vendor may indeed be possible. AVM/C equipment has many features which are very desirable and attractive from the standpoint of a firm (the lessor) making them available via lease to a transit agency. Included in these are the fact that the equipment has a relatively short life (probably no longer than that of buses, typically about 12 years), most of the equipment is not easily abused or damaged by normal use, and the equipment can be repossessed should the lessee (transit agency) default on the payments.

From the standpoint of the transit agency, leasing can overcome an inability to implement such a system due to lack of capital for such a project. Alternatively, even if funds might be amassed from normal capital sources to implement such a system in the future, leasing would enable faster implementation and thus more rapid experience of the benefits to both the agency and its users. Of course, leasing might be more expensive than outright purchase, in which case the added cost of leasing would have to be compared with the added benefits of earlier implementation.

In order to answer the questions raised by the preceding discussion, this chapter is organized around three basic issues. The first is a determination of the likely cost of leasing, including a comparison with outright purchase and presentation of a method by which transit agencies can estimate leasing costs. The second issue is the comparison of the two acquisition alternatives, in terms of such factors as added costs and experiencing of benefits more rapidly. Finally, the break-even analysis introduced in the previous section is revisited in order to consider the leasing option.

5.3.1 The Cost of Leasing

Leasing costs can be related to the cost of purchase or production of an item, and thus it is possible for an agency to approximate the cost of leasing based on the selling price of AVM/C equipment. There are a number of other factors which will influence the cost of leasing, many of which are difficult to determine with any precision. Some of these relate to elements which are inherently unpredictable, such as the degree to which the future will be characterized by inflation. Others are factors which describes specific business conditions and characteristics of the leasing firm, and which therefore because of privacy or confidentiality considerations would not necessarily be known with precision. However, it is possible to bracket the range of likely values for these items and thereby obtain an estimate of the cost of leasing. This would then enable a transit agency to examine the feasibility of leasing from its perspective even before it entered into detailed price quotation procedures or negotiation with AVM/C system producers or vendors.

To estimate the price that would be charged by a lessor, it is of course necessary to adopt the perspective of that vendor. In order to be attractive to a vendor, a lease would have to provide at least an equal level of financial remuneration for that firm as would outright sale of the item to a transit agency. The basic concept is that of financial equivalence, in which the value of the stream of funds from leasing to the vendor is financially equivalent to the stream that would apply with outright sale, namely the receipt of the purchase price. In most leases of capital equipment similar to AVM/C equipment in value and service (or leased) life, the lease would actually be made with a organization distinct from the producer. This leasing organization, the lessor to the transit agency (the lessee), often is a subsidiary of the producing firm, or may be a completely independent organization. Thus it is the perspective of this lessor which is being considered here.

The actual process envisioned for leasing this equipment is as follows. First, the producer of the AVM/C equipment would sell the equipment to the transit agency. The agency would then immediately resell the items to the lessor, being fully compensated thereby for the purchase. The equipment would then be leased to the agency for an agreed upon period and amount. The corresponding financial transactions are illustrated in Figure 5.7, which depicts these as a cash flow diagram from the standpoint of the three parties involved. The purchase of the item by the lessor is shown, and then following this are vertical arrows indicating the receipt of lease payments. Those shown here are of a uniform amount, as is typical. It is the transit agency, of course, which makes these payments. Also relevant to the lessor are various expenses associated with its activities, including administration of the lease, insurance or reserves in case of lateness or default in payments, etc.

Figure 5.8 diagrams the components of cash flows experienced by the lessor. Also shown here are the cash flows associated with taxes by the lessor, which include depreciation charges over the depreciable life of the equipment (usually a life shorter than the actual lease life). As will be seen, these depreciation charges figure prominently in the resulting lease payments. For the lessor to be indifferent between selling and leasing this series of cash flows must equal zero. The normal profit of the firm is included through the equivalent rate of return on its invested funds, technically referred to as the Minimum Attractive Rate of Return (MARR). The analysis which brings together all of these factors is shown in Appendix B. The result is that the minimum lease payment L is given by the following equation:

$$L = \frac{Y - \sum_j D_j/(1+i_L)^j - \sum_k M_k/(1+i_L)^k - S/(1+i_L)^N}{(1-T)(P/A, i_N/12, N \times 12)} \qquad (B.2)$$

where:

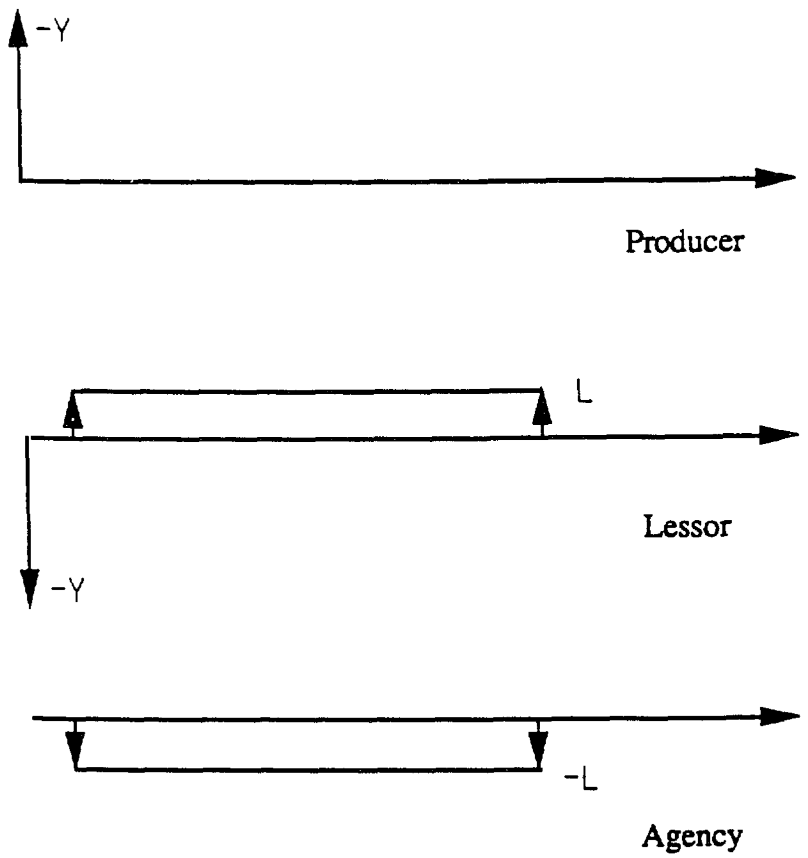


Figure 5.7. Cash flows for leasing option.

Y = Purchase price of AVM/C system

L = Lease payment

T = Tax rate

i_N = Lessor's nominal MARR

N = Term of lease in years

D_j = Depreciation in year j (($j = 1, \ldots\ldots R$, R = depreciable life)

i_L = Lessor's effective annual MARR ($= 1 + i_N/12)^{12} - 1$)

M_k = Administrative expense in year k ($k = 1 \ldots N$)

S = Salvage value of AVM/C system

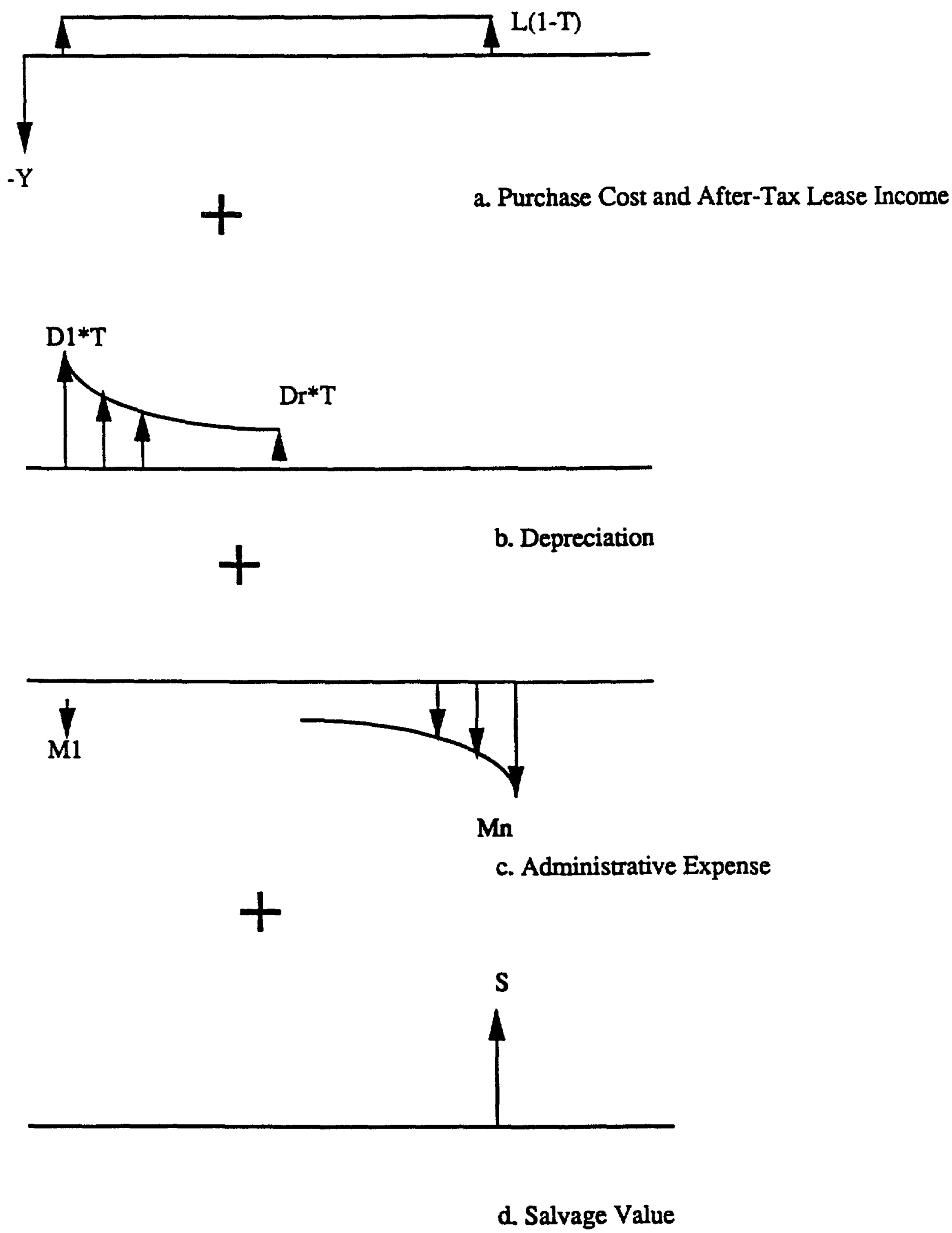


Figure 5.8. Lessor cash flows.

In order to compare the cost to a transit agency of leasing versus outright purchase, the two alternatives will be compared in terms of their present value to the agency. Present value is a concept which takes any flow of funds over time and converts it to its equivalent value at the present time, using the time value of money for a particular organization. The time value of money to a transit agency is generally considered to be the time value of money for public investments in general, which has been ascertained to be 10% per year excluding inflation. By way of illustration of application of this method, and to obtain some idea of the magnitudes of values involved, we will use the previously used (hypothetical) transit system in order to illustrate the concepts. This system consists of 110 vehicles, and the AVM/C system costs and other relevant parameters will be as indicated below. These are considered to be typical values for a system of this size but any specific application could of course deviate from these.

Number of buses = 110
Cost of AVM/C system, if purchased = $880,000
Fixed cost = $330,000; Variable cost = $5,000/bus
Agency MARR = 10%
Administrative cost = $17,600 per year (2% of purchase cost)

The results of the analysis are as indicated in Table 5.2. The first section of this table simply restates the relevant assumptions needed to perform the calculations. The minimum monthly lease was calculated from equation 5.2. We must emphasize that L represents the minimum lease payment acceptable to the lessor. The value of L should be quite valuable to public agencies, since it allows them to evaluate the possibility of pursuing an alternative financing option with relatively little information. Once L has been calculated we evaluate the lease alternative from the standpoint of the agency, again using the NPV technique:

$$NPV_{Lease} = -L(P \backslash A, i/12, N * 12) + B(P \backslash A, i_A, N)$$

$$NPV_{Purchase} = -Y + B(P \backslash A, i_A, N)$$

where:

B = Annual financial benefits from AVM/C system
i_A = Agency's effective annual MARR
i = Agency's nominal annual MARR

Since B, the annual benefits, are the same for both acquisition alternatives, we may just consider the present value of costs for the two options:

$$PV_{Lease\ cost} = L(P \backslash A, i/12, N * 12)$$

$$PV_{Purchase\ cost} = Y$$

Table 5.2 shows that for our sample case the lease option incurs an additional cost or premium compared to outright purchase of $397,170, or about 45%. Indeed for most cases we found that leasing was significantly more expensive.

5.3.2 Important Factors in Leasing Costs

Naturally the various factors which enter the previously derived equation for the minimum equivalent leasing cost will influence the magnitude of the leasing costs. Some of these are inherently uncertain and therefore the sensitivity of the lease cost to these must be explored. Figure 5.9 illustrates the relationship between the present value of the lease for the agency and the agency’s time value of money or MARR. The previous example was continued here, in which the purchase price is $880,000, and the lessor MARR is 15% with the asset being depreciated over 5 years, with a lease of 7 years. Analysis over a greater range shows that when the agency’s MARR is at least 27%, the present value of leasing is in fact less than that of outright purchase, otherwise the cost of leasing is greater. This relationship, it should be noted, is as would be expected, since at higher agency MARRs, the time value of money is greater and distant expenditures in the future have less significance in terms of present value. Higher MARR’s thus tend to mitigate the long term cost of the lease, making it look more attractive. However, it should be noted that with public agency MARR’s typically being the vicinity of 10% (the usual range considered for most analyses is 7.5 to 12.5%), the cost of leasing would indeed be greater than that of purchase. This raises the question of whether the added expenditure is worth it and this issue is discussed in a later section.

The MARR of the lessor also will affect the lease price, and the sensitivity here is illustrated by Figure 5.10. Here the lessor MARR is shown as an after tax MARR, and the variation in lease costs versus this over the most likely range, from about 10% to 20%, is not very great. Figure 5.11 presents in a more encompassing manner the effect of variations in both the agency and lessor MARR on the costs of leases. Each line represents a lessor MARR, while the lower axis represents the agency MARR. As can be seen, over typical ranges of agency MARR from 7.5% to 12.5%, for a given lessor MARR, the variation of lease cost to purchase cost from the standpoint of the agency is rather small.

Table 5.2. Sample calculation of ***L.***

Purchase Price	$880,000
Percentage Administrative	2.00%
Initial Administrative Cost	$17,600
Asset Life	5
Length of Lease	7
Lessor's Tax Rate	34.00%
Salvage Value at End of Lease	$0
Salvage Value at end of Life	$0
Annual Before Tax Lessor MARR	22.73%
Annual After Tax Lessor MARR	15.00%
Annual Effective After Tax Lessor MARR	16.08%
Annual Effective Agency MARR	10.00%

Yr	MACRS Dep	Tax Benefit	PV Tax Ben
0			$201,625
1	$176,000	$59,840	
2	$281,600	$95,744	
3	$168,960	$57,446	
4	$101,376	$34,468	
5	$101,376	$34,468	
6	$49,896	$16,965	
7	$0	$0	

Minimum Monthly Lease $21,203

Lessee (Agency)

Present Value of Purchase Cost	$880,000
Present Value of Leasing Cost	$1,227,170

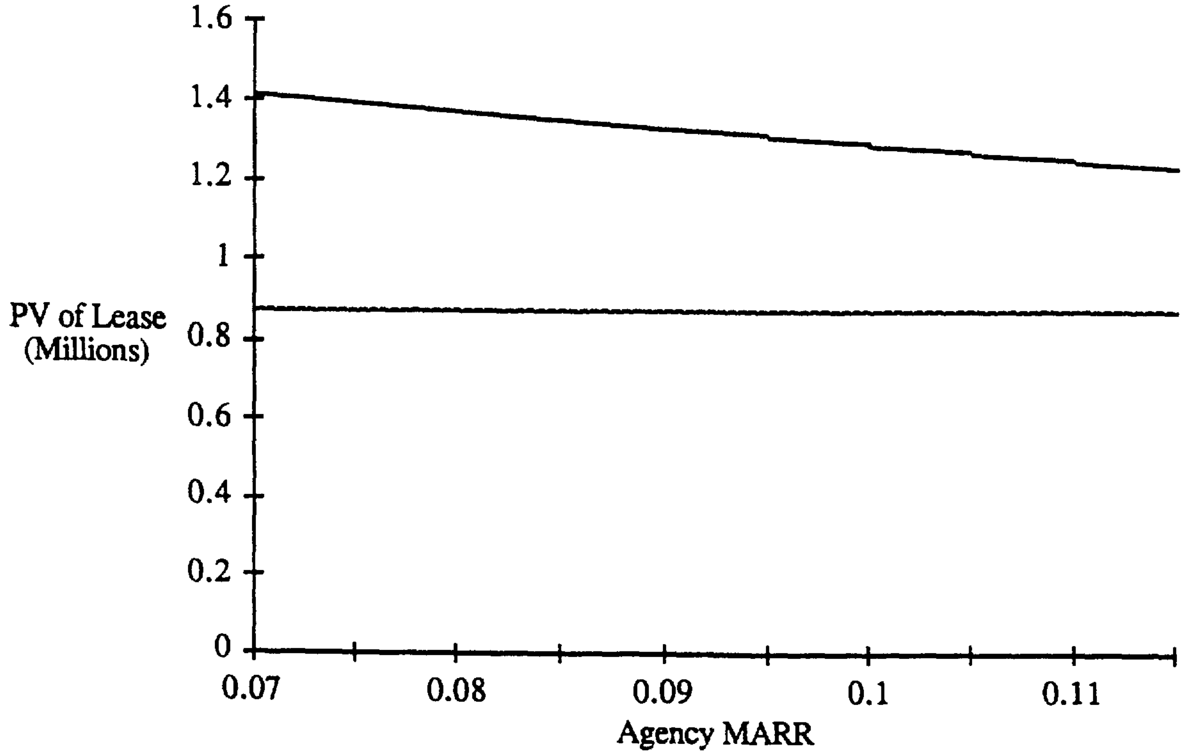


Figure 5.9. Present value of lease vs. agency MARR.

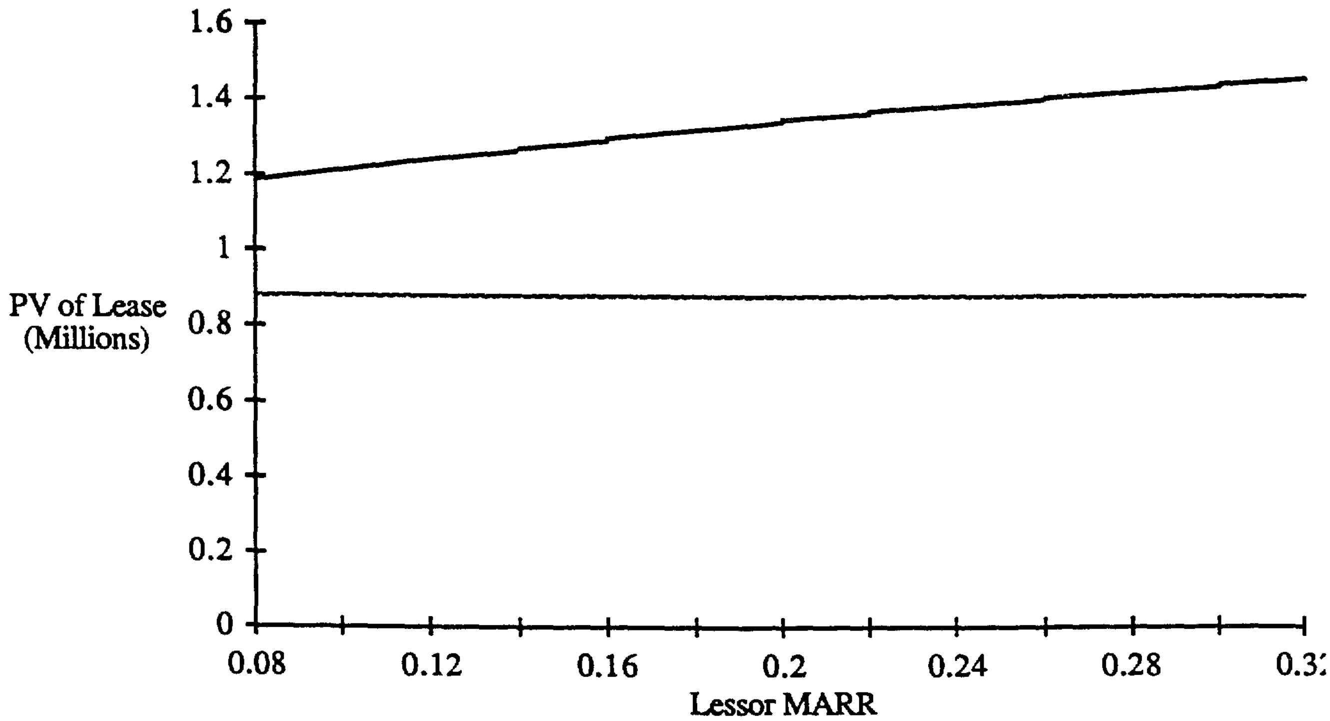


Figure 5.10. Present value of lease vs. lessor MARR.

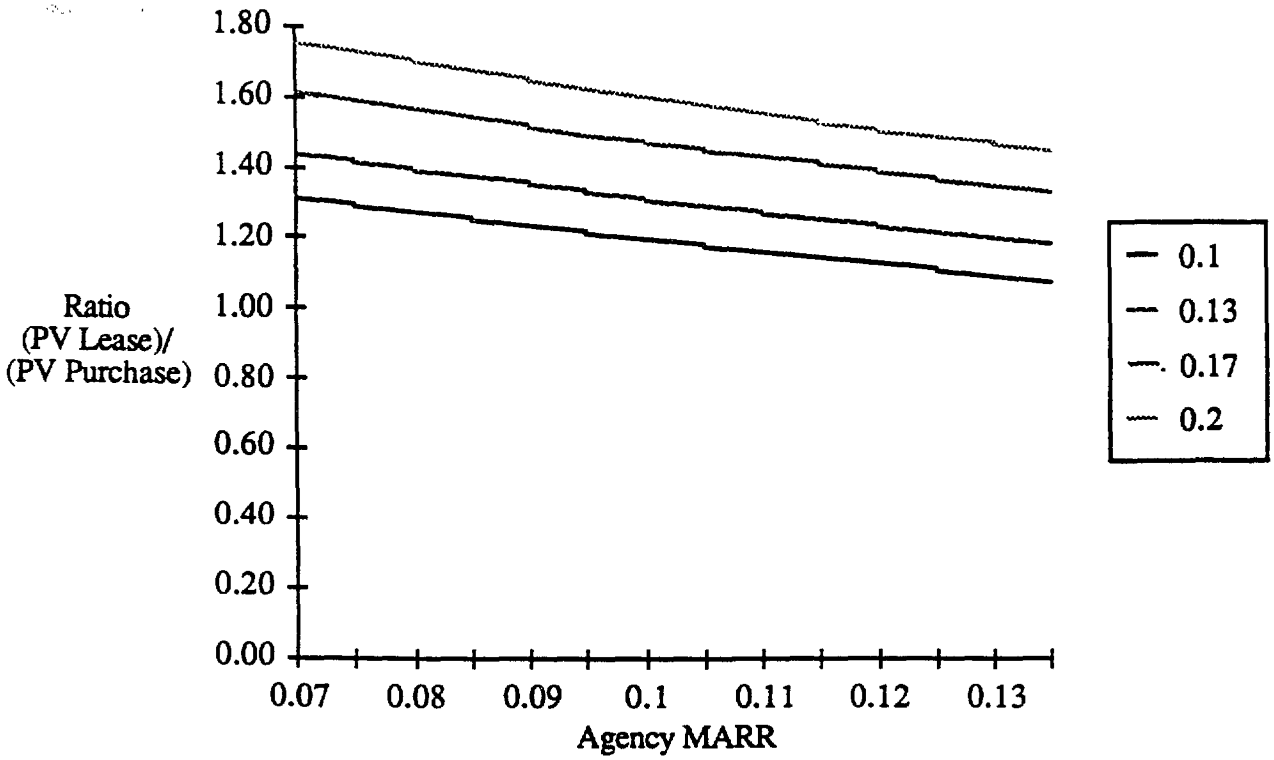


Figure 5.11. Ratio of present value of lease cost to purchase cost for various lessor MARRs.

5.3.3 Inflation Effects

So far we have assumed that administrative costs were fixed over the life of the lease at 2% of the purchase price. However, the administrative costs could differ for this amount, and also could be subject to inflationary effects over the life of the lease.

Table 5.3 demonstrates the effect of inflation on the lease cost. Here it is assumed that administrative costs inflate every year by an inflation rate, **f.** M_1 is the administrative cost in the first year; the administrative cost in the second year is then $M_1(1 + f)$**,** The first section of the table gives the minimum lease payment, L, over a range of initial administrative expanses and inflation rates. The second portion is simply the present value of lease costs, calculated using an inflation adjusted MARR. The last part gives the percentage change on the present value of lease cost over a "base" case assuming no administrative costs and an inflation rate of zero.

For example, if we expect the initial administrative expense (annual) to be 2% of the purchase cost of $880,00, and the inflation rate to be 3%, then the minimum monthly lease cost rises to $24,527 a 6.2% increase in NPV over the lease payment calculated without taking into account administrative expenses and inflation. We might also compare the base case to ***L*** calculated with administrative expenses of l%, but an inflation rate of zero. This value is 3.85% higher in NPV terms. Generally, the inflation rate increase which affects the administration expense does not significantly increase the present value of the lease. Indeed, for any given level of administrative **cost,** higher levels of inflation lead to modest decreases in the present value of cost, in spite of higher lease payments. This seeming paradox arises since inflation affects not only the costs the lessor must recover, but both the lessor's MARR and the agency's MARR. In this analysis an inflation adjusted MARR for the agency is calculated from the formula

$$i_C = i_R + f + f \times i_R$$

where **f** is the inflation rate, i_R is the real interest rate or MARR. Thus, for an agency MARR of 10% and an inflation rate of 2%, the agency's inflation adjusted rate is

$$i_C = .10 + .3 + .10 \text{ x } .3 = 13.3$$

As inflation increases, the higher inflation adjusted MARR mitigates the corresponding increase in prices.

Note in the bottom portion of Table 5.3 that there exists a linear relationship between percentage change in present value of the lease to percentage of administrative cost. Each 1% increase in administrative percentage yields approximately a 3.85% increase in present value of lease costs.

Table 5.3. Lease costs including inflation effect

	Infl Rate	0.00%	2.00%	4.00%	6.00%
	Infl Adj MARR	10.00%	12.20%	14.40%	16.60%
	Pct Admin				
Minimum Lease: L	0.00%	$19,156	$20,305	$21,467	$22,640
	1.00%	$20,375	$21,597	$22,833	$24,081
	2.00%	$21,593	$22,888	$24,198	$25,521
	3.00%	$22,812	$24,180	$25,564	$26,961
	4.00%	$24,030	$25,472	$26,929	$28,401
	5.00%	$25,249	$26,763	$28,295	$29,841
	6.00%	$26,467	$28,055	$29,661	$31,282
	7.00%	$27,686	$29,346	$31,026	$32,722
	8.00%	$28,904	$30,638	$32,392	$34,162
	9.00%	$30,123	$31,930	$33,757	$35,602
	10.00%	$31,341	$33,221	$35,123	$37,042
Present Value of Leasing	0.00%	$1,153,897	$1,143,311	$1,132,138	$1,120,521
	1.00%	$1,227,298	$1,216,038	$1,204,154	$1,191,798
	2.00%	$1,300,698	$1,288,765	$1,276,170	$1,263,076
	3.00%	$1,374,098	$1,361,492	$1,348,186	$1,334,353
	4.00%	$1,447,499	$1,434,219	$1,420,203	$1,405,630
	5.00%	$1,520,899	$1,506,946	$1,492,219	$1,476,908
	6.00%	$1,594,300	$1,579,673	$1,564,235	$1,548,185
	7.00%	$1,667,700	$1,652,400	$1,636,251	$1,619,462
	8.00%	$1,741,100	$1,725,127	$1,708,268	$1,690,740
	9.00%	$1,814,501	$1,797,854	$1,780,284	$1,762,017
	10.00%	$1,887,901	$1,870,581	$1,852,300	$1,833,294
Percentage Change in PV of Leasing Cost Over "Base" case of 0% inflation, 0% admin cost	0.00%	0.00%	-0.92%	-1.89%	-2.89%
	1.00%	6.36%	5.39%	4.36%	3.28%
	2.00%	12.72%	11.69%	10.60%	9.46%
	3.00%	19.08%	17.99%	16.84%	15.64%
	4.00%	25.44%	24.29%	23.08%	21.82%
	5.00%	31.81%	30.60%	29.32%	27.99%
	6.00%	38.17%	36.90%	35.56%	34.17%
	7.00%	44.53%	43.20%	41.80%	40.35%
	8.00%	50.89%	49.50%	48.04%	46.52%
	9.00%	57.25%	55.81%	54.28%	52.70%
	10.00%	63.61%	62.11%	60.53%	58.88%

Infl Rate = Inflation rate
Infl Adj MARR = Inflation adjusted MARR
Pct Admin = Administrative Costs as percenatage of purchase price

5.3.4 Breakeven Analysis with Leasing

The analysis of break even conditions with the leasing option basically follow the same as that with outright purchase. The main difference is that the cost of leasing must be substituted for the purchase cost. However, given that the present value of the lease from the standpoint of the transit agency can be easily obtained from the analysis, this present value can simply be substituted into equation 5.8 as shown below. Continuing with the example presented in Section 5.2, but using the lease cost presented in Table 5.2, we have a present value of the lease of \$1,302,599. Thus the lease option entails an additional expenditure of \$325,599 (\$1,302,599 minus \$877,000). Substituting this, we may obtain new breakeven values which as given below:

$$\begin{aligned}
\text{Cost of AVM/C using Lease Option} &= \$1,277,170 \\
AI &= \$1,277,170 \times CRF \\
&= \$1,277,170(.2296) \\
\Delta\text{Fleet size} &= 5.25 - (3.85/55,900)(\Delta\text{Revenue-miles}) \\
AI/C &= 5.25 \text{ buses} \\
AI/(AX+B) &= 5.25 \div 6.88 \times 10^{-5} = 76,308 \text{ Revenue-miles}
\end{aligned}$$

Thus this translates into a 4.7% decrease in fleet size, or correspondingly a 2% decrease in revenue-miles. The resulting break even curve is as shown in Figure 5.12, from which it can be seen that there has indeed been a corresponding increase in breakeven values for the reduction in fleet size and revenue-miles. However, it is equally significant that the magnitudes of the gains required to justify leasing still remain quite small.

5.3.5 Choosing Between Leasing Now Versus Buying Later

Because of the possibility of a capital shortage, it is likely that if an agency wishes to purchase an AVM/C system it would have to wait some time - perhaps a number of years - before it could obtain the necessary capital funds to purchase the system. In this context leasing should definitely be considered as an option, even if its cost (as measured, for example, by present value) is greater. The reason is that by waiting for the installation of equipment through purchase, benefits that otherwise could be obtained from immediate installation in the years before the actual installation would be foregone. If the value of these monetary benefits foregone is greater than the additional cost of the lease, then the lease would be preferable.

Let us consider an example. If installation of the system were postponed for some period, for example, through year 3, then all of the benefits that would have been obtained from year 1 through year 3 would be foregone. The pattern of these in terms of the present value of these foregone benefits is illustrated in Figure 5.13 for a system with uniform annual benefits of \$200,000.

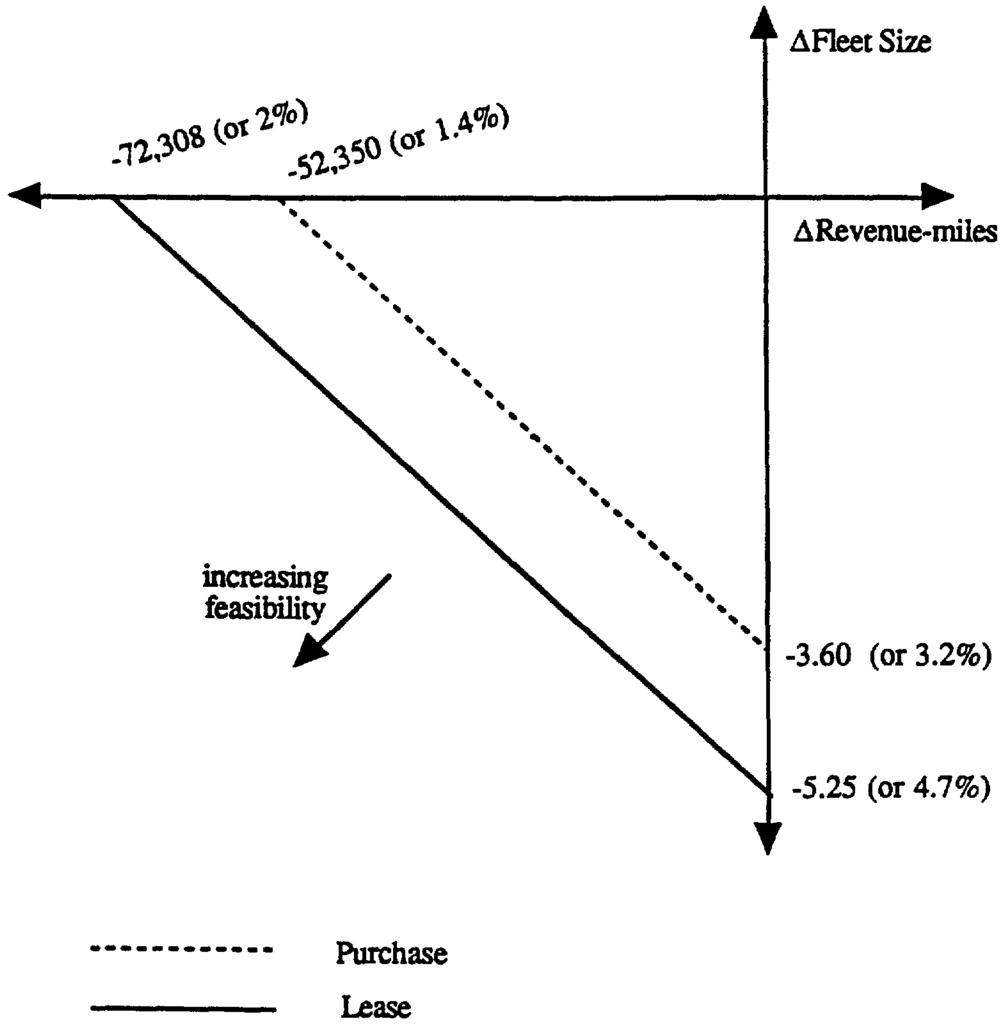


Figure 5.12. Breakeven analysis including additional lease costs.

Clearly once the additional costs of a lease are exceeded by the present value of foregone benefits, then it would be more attractive to lease now rather than wait for some distant time in the future to purchase and install the system. In order to develop the relevant equations, we shall consider two options. The first is that of leasing AVM/C equipment immediately, and reaping the annual benefits, B, starting in one year. The second option entails purchasing the equipment at some point in the future, N'. We assume for both options, that costs and benefits reoccur indefinitely. Thus replacement purchases occur every 12 years at the same cost. The lease cost is also constant, at an annual lease cost of L'. The cash flow diagrams for these options are presented in Appendix C. By equating the net present values for these two options, and solving for N' (as is derived in Appendix C) we find the number of years of foregone benefits that justify the additional costs of leasing:

$$N' = \frac{(\ell n(B - Y(A|P, i_A, 12)) - \ell n((B - L')}{\ell n(1 + i_A)}$$

The results of this analysis are shown in Table 5.4. For instance if our agency were expecting an AVM/C system to yield $400,000 in benefits, and the annual lease costs' were $220,000, N' equals 4.3 years. Thus in this case if it would take more than 4.2 years to obtain a capital grant to purchase the equipment, the agency is better off incurring the additional costs of leasing so as to capture the 4.3 years of benefits. Table 5.4 demonstrates clearly that for a given lease cost a higher benefit level makes the lease option more favorable compared to waiting for a capital grant, as would be expected.

While it is obviously not possible to generalize with respect to the ratio of benefits to costs for AVM/C systems, it is nevertheless clear from Table 5.4 that the breakeven number of years between leasing and purchase can be quite small. Thus, leasing should be considered whenever capital funds are in short supply.

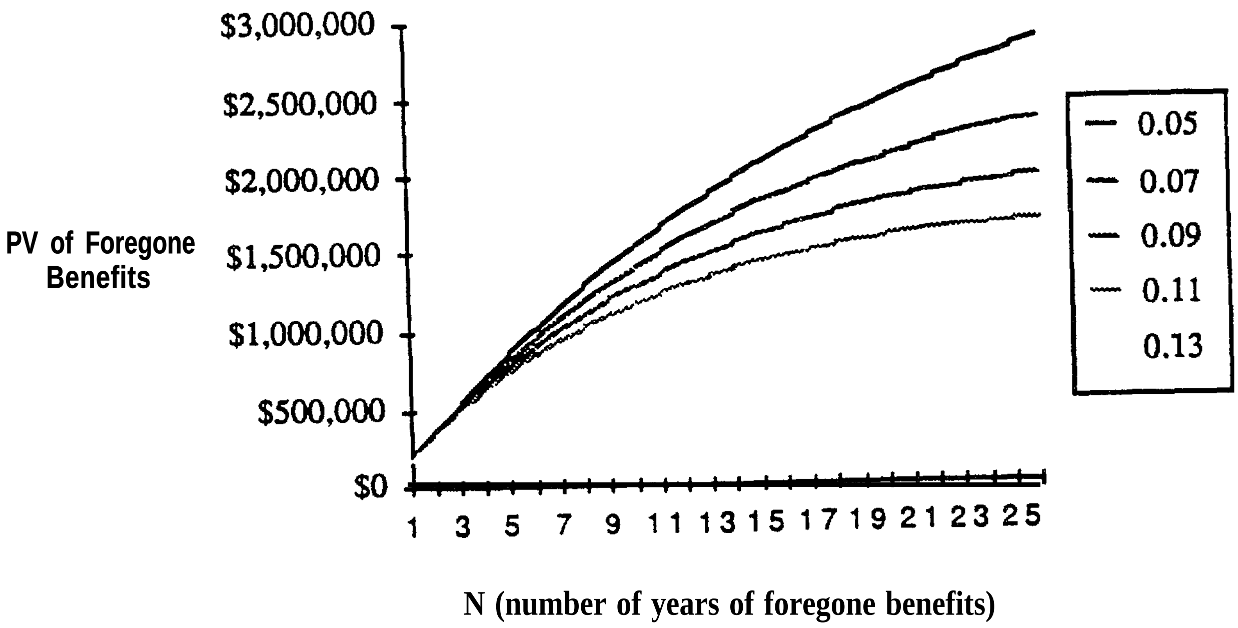


Figure 5.13. Net present value of forgone benefits for various agency MARR's.

Table 5.4. Years of foregone benefit needed to justify lease over purchase.

Purchase Price = $880,000
Agency MARR = 10%

Annual Benefits	Annual Lease (L'), $ 200.000	220,000	240,000	260.000	280,000	300,000
200,000	-[1]	-	-	-	-	-
250,000	9.3	**14.6**	26.1			
300,000	5.6	8.0	11.0	15.2	22.5	-
350,000	4.1	5.6	7.3	9.4	12.1	15.6
400,000	3.2	4.3	5.5	6.9	8.5	10.5
450,000	2.6	3.5	4.4	5.5	6.7	8.0
500,000	2.2	3.0	3.7	4.6	5.5	6.5
550,000	1.9	2.6	3.2	3.9	4.7	5.5

[1]Dash indicates that leasing is never preferred to purchasing.

Appendix A: AVL Technologies with Potential for Transit Applications

Loran-C Radio transmissions are sent from a network of towers. A receiver and computer on the vehicle calculates the position by trilateration. Alternatively, the data can be sent to a central office for processing. The positional accuracy is on the order of 1,000 feet and may be inadequate for some urban applications.

GPS The technique is similar to Loran-C except that NAVSTAR satellites are used instead of towers. The positional accuracy is, however, on the order of 100 feet and a more likely candidate for transit use. However, tall buildings, foliage and terrain can disrupt transmissions and create blind areas; this depends upon location.

RDSS A satellite sends a timed interrogation signal. It is received, labelled, and then retransmitted by the transceiver aboard the vehicle. This signal is then received by at least two satellites which than send the data to the commercial service's computer for position calculation. The position can be sent back either to the vehicle or to the control center. The positional accuracy is on the order of tens of feet. It is also possible to send and receive messages with the same system. Geostar is an example of such a system.

MSS This is primarily a satellite based mobile phone communication system for digital data and/or voice, but can readily be linked to Loran-C or GPS to provide both a communication and location service. It is presently becoming available commercially.

Deduced ("Dead") Reckoning This is the classic approach based upon a magnetic compass and an odometer reading past a known position. The modern systems store an electronic roadmap or route and can display the path and current position on a display in either the vehicle or the control center. Tracking must be continuous and requires regular recalibration. In highway applications the positional accuracy can be on the order of 100 feet, but could be different in a circuitous transit route.

Radio Signposts These are low-level radio transmitters that transmit their identifica**tion** number. When the vehicle passes by, the receiver notes and stores the ID and time and resets the internal odometer. The next time that the control center polls for an update, the current odometer setting will be transmitted as well as the time and last signpost passed.

Passive ID An identification tag that does not have its own transmission power receives a signal from an antenna. The received signal is then reflected back, perhaps with a small battery power boost, to increase range. Tags using the Surface Acoustic Wave (SAW) principle can be read at a distance of 2 to 3 meters. Ones using the Modulated Backscatter (MB) principle can be read over a range of 5 - 10 meters and much farther with battery boost. Note that a passive system cannot provide any more information than when the last antenna was passed [Redding, 1988].

Infrared Detection The vehicle carries a detector which reads a marker, generally located at a stop. This marker will be compared to a stored sequence of ID's to ascertain position. When combined with an odometer, it gives exceptional locational accuracy. It is unique in that no external hardware is required other than a passive marker, but instead a specific dataset must be loaded for each route.

"TeleRider" A tradename for a product of Teleride Sage Corporation. This system provides each bus stop with a unique telephone number. The rider can call this number to get the scheduled time of the next two buses for each route serving this stop. In a more advanced application, the schedule is updated in near real-time to provide revised schedules based upon actual location of vehicles.

Appendix B: Derivation of Minimum Monthly Lease

$$
\begin{aligned}
NPV_L &= NPV \text{of leasing from lessor perspective} \\
&= -Y - L \times T(P|A, i_N/12, N \times 12) + L(P|A,\ i_N/12, N \times 12) \\
&+ \sum_{j=1}^{R} D_j/(1+i_L)^j \times T \\
&+ \sum_{k=1}^{N} M_k/(1+i_L)^k \\
&+ S/(1+i_L)^N \qquad (B.1)
\end{aligned}
$$

Y	=	Purchase price of AVM/C system
L	=	Lease payment
T	=	Tax Rate
i_N	=	Lessor's nominal MARR
N	=	Term of lease in years
D_j	=	Depreciation in year j ($j = 1 \ldots R$,, R = depreciable life)
i_L	=	Lessor's effective MARR ($= (1 + i_N/12)^{12}) - 1$)
M_k	=	Administrative expense in year k ($k = 1 \ldots N$)
S	=	Salvage value of AVM/C system

Setting $NPV_L = 0$, and solving for L:

$$
\begin{aligned}
0 &= -Y + L(P|A, i_N/12, N \times 12)(1-T) + \sum_j D_j/(1+i_L)^j \times T \\
&+ \sum_k M_k/(1+i_L)^k + S/(1+i_L)^N
\end{aligned}
$$

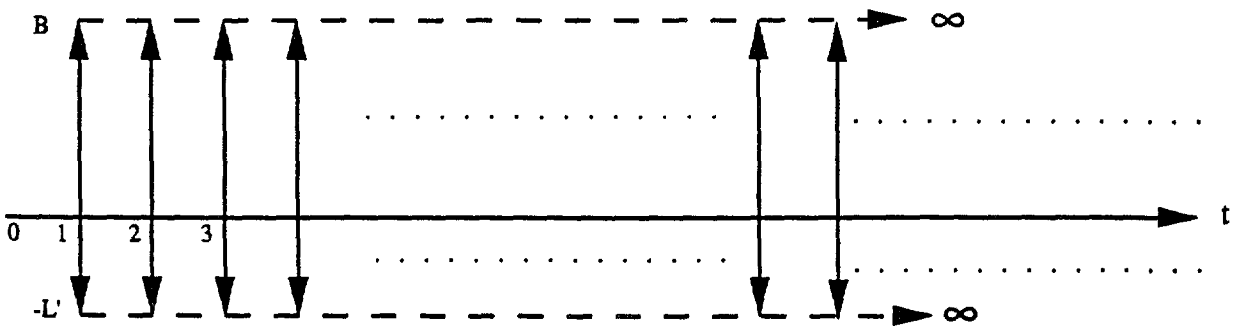
$$
\begin{aligned}
L(P|A, i_N/12, N \times 12)(1-T) &= Y - \sum_j D_j/(1+i_L)^j \times T - \sum_k M_k/(1+i_L)^k \\
&- S/(1+i_L)^N
\end{aligned}
$$

$$
L = \frac{Y - \sum_j D_j/(1+i_L)^j \times T - \sum_k M_k/(1+i_L)^k - S/(1+i_L)^N}{(1-T)(P|A, I_N/12, N \times 12)} \qquad (B.2)
$$

Appendix C: Derivation of Breakeven Years for Lease vs. Postponed Purchase

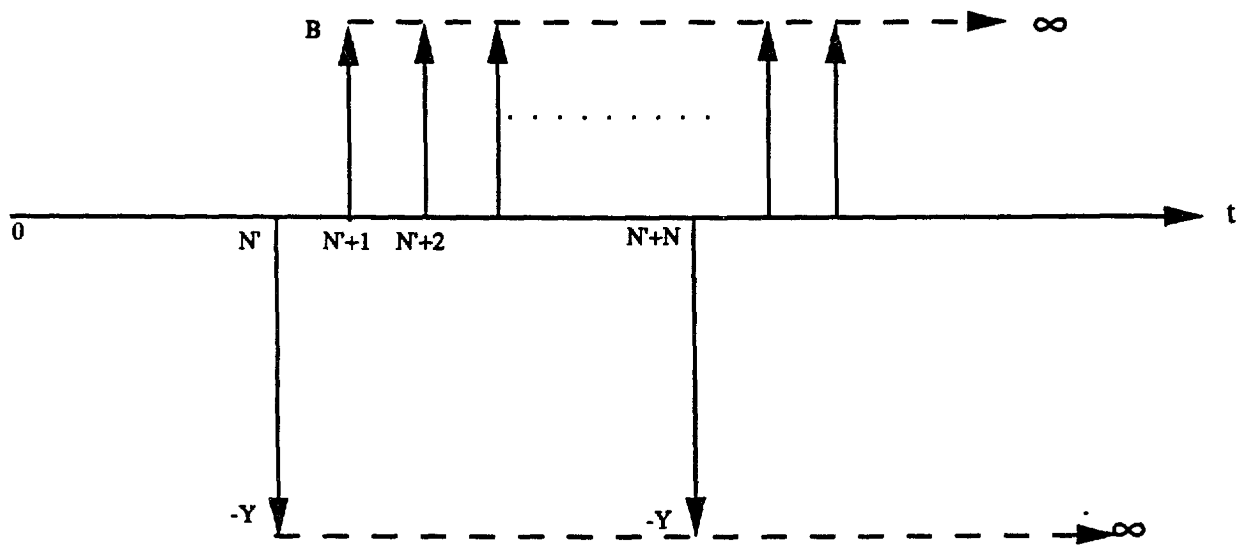
Lease Option: Agency cash flow

A

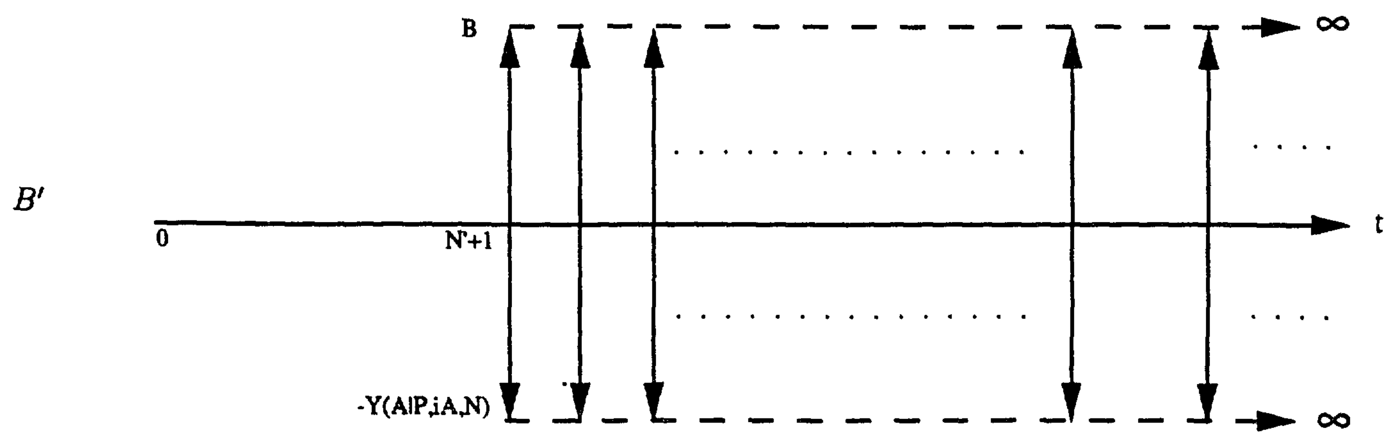


Purchase Option: Agency cash flow

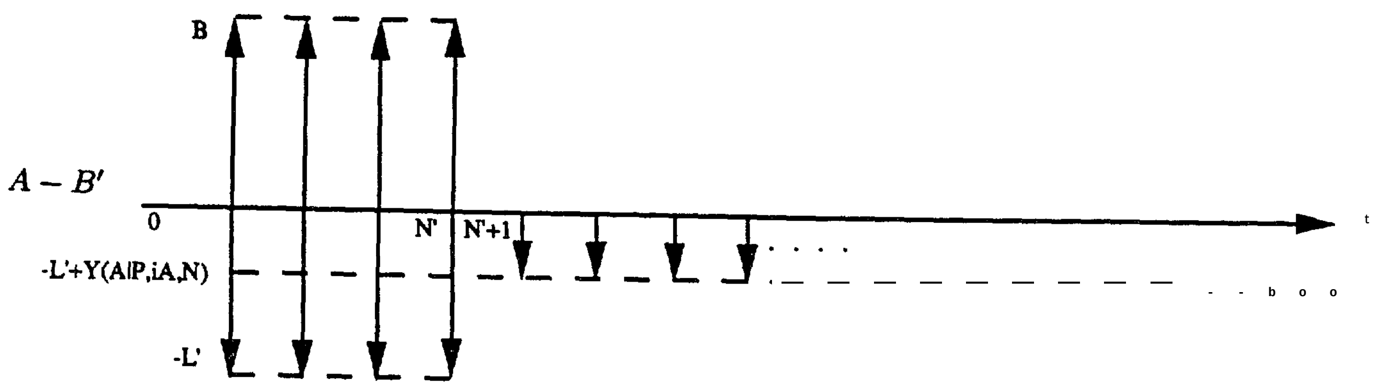
B



Pattern repeats every N years, where
N is the life of the investment



L' = Annual lease cost
N' = Year of postponed purchase
N = Life of the AVM/C equipment
i_A = Agency's effective annual MARR
B = Annual benefits



Note: for simplicity we will use i for the Agency's effective annual MARR

$$NPV_A = B/i - L'/i \text{ effective annual MARR} \quad (C.1)$$

$$NPV_{B'} = (B/i)/(1+i)^{N'} - (Y(A|P,i,N)/i)/(1+i)^{N'} \quad (C.2)$$

$$\begin{aligned} NPV_{A-B'} &= B(P|A,i,N') - L(P|A,i,N') + ((-L' + Y(A|P,i,N))/i)/(1+i)^{N'} \\ &= B/i - L'/i - (B/i)/(1+i)^{N'} + (Y(A|P,i,N)/i)(1+i)^{N'} \quad (C.3) \end{aligned}$$

Setting $NPV_{A-B'} = 0$ and collecting terms:

$$\begin{aligned} 0 &= \frac{B - L'}{i} + \frac{-B + Y(A|P,i,N)}{i(1+i)^{N'}} \\ \frac{B - L'}{i} &= \frac{B - Y(A|P,i,N)}{i(1+i)^{N'}} \\ (B - L')(1+i)^{N'} &= (B - Y(A|P,i,N)) \\ (1+i)^{N'} &= B - Y(A|P,i,N)/(B - L') \end{aligned}$$

Taking the natural logarithm of both sides and solving for N':

$$\begin{aligned} N' &= \ell n(B - Y(A|P,i,N)/(B - L'))/\ell n(1+i) \\ &= (\ell n(B - Y(A|P,i,N)) - \ell n(B - L'))/\ell n(1+i) \end{aligned}$$

For example with $N = 12$ years and $i = 10\%$ per year $(A|P,i,12) = .1468$. Note again that L' is the annual lease payment. If the actual lease payment is monthly, then L' must be the annual economic equivalent from the standpoint of the agency. The correct formula to use, where L is the monthly lease, and is the <u>end</u> of year equivalent:

$$L' = L(F|A, i_M, 12) = L((1+i_M)^{12} - 1)/i_M$$

with $i_M = (1+i_A)^{1/12} - 1$. For the typical case of $i = 10\%$ (per year), $i_M = 0.00797$ we have:

$$L' = 12.547L.$$

Note that this is significantly different from 12 times L, an approach that ignores the time value of money (to the transit agency).

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