Development of A Real-Time and Geographical Information System-Based Transit Management Information System

by

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(ABSTRACT)

The Tidewater Regional Transit (TRT) in Virginia has implemented an Automatic Vehicle Location (AVL) system into their bus system. However, there are some problems with the system that TRT is endeavoring to resolve in order to maximize its utilization. Therefore, the main goal of this research was to develop an automated Management Information System (MIS) that processes the overwhelming real-time incoming data from the AVL system in TRT, and to present it promptly in an easy-to-access, easy-to-understand, and easy-to-use format. In order to meet this goal, development of a graphics- and Geographical Information System (GIS)-based display system is essential.

Classification of data from the AVL system according to its priority, relevancy, and demand level was the first step in achieving the goal of this research. The second step was to develop a user-friendly, menu-option display system. This step mainly focuses on the structured computer model construction so that its future potential for expansion and modification is easily accommodated. The last step of the research was to develop a GIS-based display system. For this task, the TIGER/Line Census file is utilized as the data file for map display.

Since the topic of this research - MIS development - is a part of a proposed Advanced Public Transportation System (APTS) research project, its future research
direction is also identified. One of the most important recommendations for the future research is the real-time operational application of the developed MIS model.
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1.0 INTRODUCTION

1.1 BACKGROUND

In recent years, there has been a growing awareness of the need to increase patronage of public transportation systems. This has led to efforts of improving the level of service in transit and developing a positive public perceptions toward the transit system.

The Advanced Public Transportation System (APTS), a component of Intelligent Vehicle/Highway System (IVHS), is established to revitalize and expand the use of public transit systems. The main goal of APTS is to increase ridership and to improve the level of service through advanced electronic and telecommunication technologies.

The APTS consists of three Federal Transit Administration (FTA)-defined major functional areas, Customer-Based Systems, Vehicle-and-System-Based Systems, and Smart Intermodal. The ultimate goal of the customer-based system is the implementation of the "Smart Traveler" technology. The aim of Smart Traveler is to aid potential and regular transit users before they make personal decisions on how to
travel. The real-time transportation information will be provided through advanced computer and communications technology.

The second functional area of APTS is the vehicle-and-system-based system, in which implementation of the "Smart Vehicle" technology is the main goal. The aim of the Smart Vehicle is to improve the transit planning, scheduling and operations. Vehicle to vehicle and vehicle to control center communications are the most fundamental elements in this functional area. Based on an advanced communication technologies, monitoring the location of vehicles is feasible through an Automatic Vehicle Location (AVL) system, and advanced demand-respond dispatching can be also achieved. High Occupancy Vehicle (HOV) facility operation issues are also a part of the Smart Vehicle technology issue.

The other FTA-defined functional area of APTS is the "Smart Intermodal" which links APTS-related information and non-APTS IVHS. This area identifies and facilitates the information flow among APTS and other IVHS components. Figure 1.1.1 illustrates the APTS functional layout.

The Tidewater Regional Transit in Norfolk, Virginia has implemented an AVL system into their bus system to increase the reliability of its timed transfer and improve customer service level. TRT joined forces with the University Center for Transportation Research (UCTR) at Virginia Tech in an effort to expand its AVL system.

In terms of the project, it has been divided into four modules: Management Information System (MIS), Decision Support System (DSS), Look-ahead functions, and Passenger Information System (PAXIS).

The development of the MIS module, which is the main topic of this thesis, leads to a better human/computer interface and a significant improvement in data processing and information management over the current TRT system. Graphics, Geographical
Figure 1.1.1 APTS Functional Layout
Information System (GIS), and other user-friendly interfaces are incorporated in the MIS development and enhance the system's efficiency.

With the real-time data from the MIS, the DSS is an essential for the control center controllers when making decisions concerning transit operations, including: scheduling, long- and/or short-term planning, on-line ride matching, carpooling, vanpooling, and maintenance.

Look-ahead functions estimate operational characteristics, including: travel time, arrival time, and bus stop dwelling time as a function of route, time-of-day.

The travel-time-related information is then relayed to both the MIS for management and operational purposes, and to the PAXIS for passenger convenience. This information may include predicted bus arrival time at stops, transfer strategies, alternative routing information for any origin-destination (O-D) pairs, and estimated travel time for O-D pairs at a given time-of-day. Ultimately, research related to the Smart Traveler, Smart Vehicle, and Smart Intermodal concepts will be addressed in the completed APTS research project. Figure 1.1.2 illustrates the framework of the planned APTS research.

In simple terms, the goals of APTS research projects are:

1) TRT will implement an automated MIS system, which optimizes the use of the real-time operating data obtained from the current AVL system and incorporates the DSS and Look-ahead functions.

2) TRT will implement the PAXIS, which informs transit passengers the status of the transit system. This information will make the system more reliable, remove uncertainty, and eventually lead to increased ridership.

3) All travelers in the TRT area will receive complete information on entire road network system.
Figure 1.1.2 Framework of APTS Research
While this APTS project is directed at the TRT system in the Norfolk area, the technology developed can easily be transferred to other transit organizations.

1.2 GOALS AND OBJECTIVES - MIS Module

Development of a timely, reliable, safe, and easily accessible information system for riders concerning transit routing, scheduling, and expected delays in service is one strategy of the transit industries to improve their level of service. Recent advances in electronics and telecommunication technologies have made it possible to provide real-time information to transit riders addressing the service conditions of transit systems. Specifically, organizations that have already implemented the AVL system into their bus networks are capable of providing such information to their customers. These transit agencies have the opportunity to make significant improvements in their systems in terms of on-time performance, customer satisfaction and optimal use of the equipment.

Since the APTS project requires tremendous amount of manpower and time-consuming research, this thesis mainly focuses on the development of the first module, MIS module. Therefore, the goal of this thesis is to develop an automated MIS that processes the large amount of real-time data and promptly processes it into an easy-to-access, easy-to-understand, and easy-to-use format.

In order to meet this goal, the following two objectives are identified:

- develop a graphics-based user interface, and
- develop a GIS-based display system for the TRT controller.
The MIS development is crucial. A MIS enhances the managerial efficiency associated with the current AVL system in the TRT, and lays the foundation for the processed real-time information to be made available to transit passenger.

1.3 OUTLINE OF THE REMAINING CHAPTERS

The general background of the APTS functional areas, a macroscopic view of the entire APTS research, the goals and objectives of this thesis were discussed in this chapter. The next chapter, 2.0, is focused on the extensive review of transit MIS and the AVL literature. The MIS literature review consists of fundamental concepts of MIS, MIS in small and large transit systems, and review of seven case studies. The AVL literature research includes discussion of AVL objectives and benefits, system components, location detection technology assessment, and the AVL system in TRT. Chapter 3.0 describes the development of the MIS computer model, focusing on the graphics-based and GIS-based modules. Chapter 4.0 explains the computer program subroutines. A total of 24 subroutines are addressed in this chapter. The last chapter, 5.0, presents conclusions and the recommendations for future research into a complete APTS system.
2.0 LITERATURE REVIEW

2.1 INTRODUCTION

In order to meet research objectives, two topics related to the public transportation need to be thoroughly reviewed. The first topic is automation of transit management information systems (MIS). Since MIS data is mainly collected through an Automatic Vehicle Location (AVL) system, a broad literature review of AVL systems is the essential next step.

The transit MIS literature review includes historical background of MIS, its concept, definition, and brief description of seven case studies. The AVL systems section includes technology assessment of vehicle location detection, accuracy of AVL systems, currently in place, and a look at AVL system in Tidewater Regional Transit. This comprehensive review of the literature will be useful for future studies in MIS and AVL applications.
2.2 TRANSIT MANAGEMENT INFORMATION SYSTEM

2.2.1 Introduction

The conventional fixed-route bus system is the most predominant form of public transportation. In United States, it provides 83 percent of the revenue service hours and accommodates 72 percent of passenger trips [USDOT, 1983]. Twenty large cities, which comprise 49 percent of the total population of U.S., cater to 85 percent of transit service [Fielding, 1987]. This type of service is used predominantly for short trips averaging 3.6 miles.

Providing accurate, easily accessible transit route and schedule information in a cost-effective manner has long been a problem in the transit industry. This problem can be addressed by effective management of information regarding user needs. Thus, the concept of MIS is becoming more popular. Transit MIS is defined as a system that collects and uses information for the benefit of public transportation. Therefore, MIS can be a tool to make smarter and better transit management decisions.

In the late 1950's automated management information systems, which were mainly dealt with accounting applications, were first introduced to industry. In the mid-1960's the need for broad information was first recognized. Then, in the mid-1970's the microcomputers were unveiled. The importance of various microcomputer applications in transit management was recognized in the early and mid-1980's, and the implementation of this new technology was given a serious thought by transit authorities.

The change from manual to computerized data processing is a complex process and must be thoroughly planned. This transition is a continuous process rather than a
discrete one. In other words, even though in the short run there will be some
disappointments, most user expectations can be met after a certain period of time. In
1984, a workshop conducted for the purpose of exposing the staff of the Urban Mass
Transportation Administration (UMTA) to microcomputer applications, addressed these
questions: Where can computers be used productively? What type of problems are
most likely to occur? Which new technology is on the horizon? How can it be applied to
the transit industry? What role should federal, state, and local government play?

The major benefits of MIS were seen as reduced delays in bus departure, and
reduced paper work. Using present technology, an automated MIS enables monitoring
of the system more accurately. It is also noticed that automated MIS can improve the
capacity for evaluating services through cost comparison and service levels using data
from the past month/year's operations as well as from other transit systems. Another
advantage of the system is the availability and inexpensiveness of off-the-shelf
software which makes centralized MIS functions more efficient and cost-effective. The
transitional elements for an automated MIS includes the actual users, software
developer, information flow, information needs, and hardware specification.

2.2.2 Background

At 1982 Conference on Future Direction of Urban Public Transportation in
Massachusetts participants reviewed current problems in transit industries: 1) inefficient
management in the transit industry; 2) ineffective federal policy that contributes to
transit problems, and; 3) social conditions and trends that are largely beyond the
control of the transit industry or transportation policy makers. The participants also
identified future applications of computers in public transportation: inventory control, maintenance record keeping and analysis, bus performance monitoring, route and schedule planning, and other operations planning functions.

The requirements in constructing an automated MIS identified at the conference were as follows: 1) MIS should meet philosophy of management; 2) it should perform existing function of paper information system; 3) it should be fast; 4) it should be capable of examining more varied information; 5) it should provide better information than the current system, and; 6) it should be designed to help management to make decision. Automated MIS should be devised with user-friendly software so that staff with little or no computer experience can operate it.

Maze [1987] identified management information principles and techniques in his final report prepared for UMTA. The main purpose of this report is to demonstrate methods that permit better management of bus fleets through the systematic use of maintenance records and data procedures. He proposed this procedure for MIS automation: 1) identification of goals and objectives; 2) identification of performance indicator to measure objectives; 3) development of performance standards and performance indicator data support; 4) identification of the data flow, and; 5) determination of methods of converting data into management information and knowledge.

He also states in his report that without knowledge of management theory and a performance indicator, administrators have to have luck, intuition, or experience. With knowledge, the manager has a better chance to design and solve managerial problems. He quoted Koontz and O'Donnel's definition of "management" and emphasized the importance of management theory. Koontz and O'Donnel's definition of management is "design or creation and maintenance of an internal environment in
an enterprise where individuals, working together in groups, can perform efficiently and effectively towards the attainment of a group goal." However, it is an inexact science and management actions do not always achieve the objectives desired. Management principles can be used to improve the management efficiency by providing a procedure which will move the organization toward its objective.

The most basic function of management is planning. Maze defined the term "planning", as the determining objectives, policies, procedures and strategy for achieving objectives. Planning reduces the uncertainty involved in the decision making process and provides for consistency in choices. It helps to focus the attention of management on achieving the transit agency's objectives. It establishes the objectives of the agency. It delineates the steps to be taken to achieve these objectives. The first step of planning is to develop objectives.

Maze identified the next step of automated MIS procedure as "control". Where "control" guides the implementation of the plan. Controlling is the function which measures the agency's progress towards its planned objective. The details of the control process are: 1) establishing performance indicators which are attributes of applicability, promptness, critical exceptions, objectivity, clear definition, economy, and understandability; 2) establishing a performance standard, and; 3) correcting deviations from the standard. Figure 2.2.1 is a flow chart of the control process.

Maze examined Matthews' information system procedure. Information system development goes through five stages: 1) conceptualization, where an objective is determined; 2) planning, where information needs, functional specification, input/output process, and evaluation methods are determined via data flow diagrams; 3) designing, where determination of the actual system to be used to collect information, and hardware and software will be determined; 4) Implementation, where installation and
Figure 2.2.1 Flow Chart of the Controlling Process

Source: Bus Fleet Management Principles and Techniques, Final Report
evaluation will be performed; and 5) maintenance. Maze emphasized the importance of the beginning stage of automation in terms of cost. Figure 2.2.2 illustrates the relative cost to fix an error at each stage.

He quoted Horton's classification on "data", "information", and "knowledge". These definitions are: **Data** are simply the relationship between some measurable attribute and a specific event. **Information** is processed data to reduce the uncertainty of future events. If, for example, statistical analysis is performed on component failure data, information reduces uncertainty because it aids in the forecasting of future failures. **Knowledge** is highly processed data. The creation of knowledge from data requires independent judgment and interpretation.

Hardcastle [1985] identified the design and implementation issues of a personnel management system (PMS) at small and medium-sized transit agencies. He described a project to assist public transit operators in the successful incorporation of microcomputer technology to improve transit performance in which classic top-down/requirement analysis was applied. Personnel management refers to areas such as daily time-keeping, attendance recording, and payroll. The characteristics of transit personnel management, according to Hardcastle, are: 1) complicated work rules; 2) different employee categories, and; 3) high level of absenteeism, e.g., New Orleans, and Chicago has 30 day/yr of absenteeism.

He performed a case study for Sun-Trans in New Mexico, and reported the procedure of PMS implementation. The first step was to perform requirements analysis and to choose system hardware and software. The duration of this stage was two months, and 15 percent of project resources was consumed. In this stage the "top-down" approach was applied. The goal of the top-down approach is to simplify a problem by breaking it down into logical segments or modules. These modules are
Figure 2.2.2 The Relative Cost to Fix an Error at each Stage

Source: Bus Fleet Management Principles and Techniques, Final Report
further divided until the problem is simple and specific enough to permit design of a data base. Figure 2.2.3 illustrates the top-down approach for Sun-Tran PMS. The second step was to design the system and coding. The duration of this stage was eight months and 65 percent of the project resources was consumed. The last step was to implement and refine the system. In this stage, installation and off-line testing using real data was performed. The duration was six months and 20 percent of the project resources was absorbed. After reviewed the case study, Hardcastle concluded that, "the top-down approach has limitations. Hence, a new approach has surfaced in the software in the software development arena". This approach is called "prototyping". Prototyping claims to solve several problems that are not adequately addressed by the top-down approach, such as user difficulty in specifying the exact nature of their final requirements; flow charts that inadequately communicate the dynamics and acceptability of the proposed application, and; miscommunication between project members is often the rule rather than the exception.

Another consideration identified by Hardcastle was that the speed/time requirement must be balanced against development/maintenance considerations in selecting software. Dbase II was selected for the project in SUN-TRANS. However, it was too slow. Making more project resources available for the implementation and testing phase - as much as 40 to 50 percent - was another need identified. The last requirement was a necessity of efficiency and effectiveness analysis.

Koffman and Gault [1987] outlined an approach for determining data requirements of managers and planners under an Automatic Vehicle Location and Control (AVLC) system. They identified some important management-related issues, such as: 1) management is interested in information which provides an overview of the system; 2) performance indicators are needed for the entire system; 3) the best system

LITERATURE REVIEW
Figure 2.2.3 Top-Down Approach for Sun-Trans PMS

Source: Transit Personnel Management Using a Microcomputer: Issues and Lessons, Microcomputer Applications within the Urban Transportation Environment
performance within financial constraints can be acquired by knowing strengths and weakness of services, and; 4) cost efficiency, service effectiveness, and cost effectiveness are essential.

Collura et al. [1983] identified a variety of computerized MIS presently used by transit authorities and operators, and developed and applied an evaluation framework to compare and contrast these MIS. They defined transit MIS as "new and improved methods of gathering, processing, reporting, and analyzing management information". Transit management information includes financial, service delivery, capital, maintenance, personnel, and service-user data.

Management information needs often vary with the mode of transportation service provided. For example, demand-responsive service requires more information than the fixed route, subscription services. They also identified three MIS functional areas. These are: 1) operations and administrative -- scheduling passenger trips, dispatching, maintenance operations (preventive schedules, parts inventory, and repair schedule), trip booking for paratransit, word processing, mailing-lists filing, and report generation; 2) planning, monitoring, and evaluation -- ridership analysis, vehicle performance, system productivity, routing analysis, revenue generation, fuel consumption, tire wear, breakdown frequency, and comparing cost and service levels, and; 3) billing and accounting -- reports generation, issue checking, invoices, and cost allocation among different agencies.

Collura and McOwen [1984] proposed six groups of management-related functions for small, fixed-schedule transit operators. The six functional groups are: 1) administrative; 2) planning, monitoring, and evaluation; 3) operations management; 4) materials and equipment ordering and inventory; 5) maintenance, and; 6) financial management. This categorizing effort involved not only a synthesis of existing
literature on transit management and operations, but also a number of meetings with the managers of transit system. The implementation of comprehensive, affordable, and easy-to-use automated MIS should serve to simplify billing and accounting procedures and aid transit officials in complying with local, state, and federal reporting requirements (Section 15 report).

The Section 15 Program [Lyons, 1992] is a uniform system of accounts and records reporting. It was authorized in 1974 under Section 15 of the UMTA Act of 1964. It requires collection and dissemination of public mass transportation financial and operating data. Nationwide, more than 500 operators use the Section 15 program to summarize information in their annual reports to the Federal Transit Administration. It is the sole source of standardized and comprehensive data for use by all constituencies of the transit industry. It is used for management and planning by transit systems and for policy analysis and investment decision-making at all levels of government. It is a resource for consultants, researchers, and industry suppliers. No grant may be made under Section 9 unless the applicant and beneficiaries of the grant are subject to both the reporting system and the uniform system of accounts and records prescribed by Section 15.

Modeling System Inc. [1990] prepared a report for UMTA describing the implementation of a computerized trip management system to support the operation of paratransit services provided by The County of Rockland. The goal of the project was to continue high quality service, reduce the cost, provide benefits on on-time performance, reduce administrative burden, promote organizational accountability, and improve reliability. Five modules were identified for automation: transit routing, scheduling, dispatching, complaint management, and vehicle maintenance.
2.2.3 Computerized Transit Management Information System in United States

Gitten et al. [1985] researched development history of computerized management information systems (MIS). Computerized MIS were first introduced to industry in the late 1950’s. During that period most of the activities involved vehicle parts inventory tracking, and labor and payroll reports. Computer technology had evolved rapidly so that many industries recognized the need for and value of processed information in a broader sense.

In 1970's and early 1980's text file utilizing mainframe computers were used to produce paper copies of work history. Since none of the stored data was processed in the MIS, computer was used only in narrow concept as a kind of "electronic file cabinet".

Matthews [1976] differentiated an information system and record-keeping system by defining information as "part of the data which can be used to increase knowledge of that which is unexpected. Conversely, if a message is completely predictable no information is gained by receiving it". According to this definition, the transit industry had a very low use rate of computerized information systems.

He also identified five logical steps for system's planning. They are: 1) synthesis, in which brainstorming is required, and objectives are set; 2) planning, in which information needs and evaluation methods are determined; 3) design, in which specific equipment, procedures, and training are determined; 4) implementation, in which new data collection systems are introduced, and; 5) maintenance, in which maintenance, modification, and improvements to the system are performed.
Defining the information flow which meets the organizational objectives is the most important aspect to consider in planning physical and functional limitations, because functional goals of division within the organization systems are different. Hence, the decision that has to be made at each step in the organization's hierarchy must be examined by the planner. Information flow can be structured as a diagram composed of links and nodes. Links represent data flow and nodes represent processes, data records, and external entities. Other important issues of information system design are: decision on inexisting information flow that should be automated, identification in new information that should be available for decision-making, identification in new data flow that caused by conversion from paper records to automation.

Since the behavior of users is not predictable, the human-machine interface stage of planning is the most complex aspect of system planning. Accordingly, data entry should have a user-friendly input format and self-checking ability. The data entry screen should be similar to the source document, field-by-field input validation, and error messages function. Output reports should be concise and informative, and it should have uniformity, readability, and report accessibility.

One advantage of computerized MIS is reduced operating cost. Price reduction of MIS packages, and capability and flexibility enhancement of software have made computerization attractive. There is a disadvantage, too. Transit operators who lack experience with computer environments are confused about choosing and using this software.

The main barriers identified by Metthews in evolving the automated MIS are lack of computer understanding and insufficient R&D effort. These barriers are difficult to
overcome because transit industry staffs tend to be conservative. Hence, changing staff perception of computers through seminars and workshops is recommended.

In 1984, the Transportation Research Board (TRB) conducted a workshop at the request of the Urban Mass Transportation Administration (UMTA), now the Federal Transit Administration (FTA), and U.S. Department of Transportation (USDOT) to determine the role that UMTA should play and to provide information to states and local bodies about MIS. The objectives of the workshop were: 1) to exchange information on the latest developments; 2) to determine good and bad practices; and 3) to guide implementation of microcomputers in transit-related organization. At the workshop, three patterns for implementing microcomputer technology have identified: 1) limited idea of the specific benefits (in the case of in-house development); 2) used for application beyond the demonstration, e.g., depending on the abilities and initiative of agency staff, and the flexibility and suitability of the machine involved (turnkey system development), and; 3) need identification, then hardware, software selection, design, implementation when state DOT is involved in development.

Three types of microcomputer application in transit operations were also identified on the proceedings. These were: 1) in-house automation in existing procedures that were previously performed manually (e.g., financial application); 2) applications addressing problems in the organization where better organized and more accessible information is perceived as a solution (e.g., inventory-control system), and; 3) adoption of new techniques and most of these applications are developed by external agencies (e.g., planning models).

An interesting survey performed in the southwestern United States in 1983 reveals that 81 percent of transit systems did not have a computer in their organization. Transit managers without microcomputers perceived them as being most useful for
inventory control (48%), word processing (41%), accounting (33%), runcutting and scheduling (19%), preventive maintenance (17%), and fare change analysis (15%).

Frustrating factors that affected development of transit specific microcomputers technologies are identified by Cypher's workshop background paper. Transit is a labor-intensive industry, and computers are often viewed by unions as a threat to their jobs. Management may believe that a computer cannot do the work and productivity will suffer. These attitudes have signaled vendors to avoid spending time and money developing transit-specific microcomputer technology.

Cypher also discussed the reasons why transit-specific software were not provided by private software companies. The reasons include: the limited size of the transit market, competition from inexpensive commercial software, rapid technology development, the possibility of government sponsorship of similar software, and ease of duplication of existing software. The workshop participants also suggested reasons for the slowness in adopting microcomputers in transit industries compared with other industries. These were lack of productivity incentives, data system managers' fears for job security, caution in procuring technology, and relatively high total costs.

The paper also shows that computerized MIS can increase transit productivity through better tailoring of capacity to demand, better utilization of vehicles due to improved maintenance, better off-peak utilization as result of improved consumer communication, better cash-handling, better personnel management, and improved working conditions. Yet, there are factors slowing interest in implementing automation in transit systems. Unfamiliarity (e.g., fear of computer in general) with the computer is the main reason. This barrier can be overcome by education and training. Organizational barriers in large transit system is another important issue. Because well-established data processing departments are already exist and members view
microcomputers as threats. Lack of standardization in implementation and the small and fragmented transit market size are the other constraints.

2.2.3.1. Computerized MIS Implementation in Small Transit [TRB Workshop, 1984]

For small transit system (that is, one with less than 100 vehicles), budget development and monitoring, vehicle-history record keeping, financial accounting and payroll, parts inventory management, revenue and ridership accounting, vehicle servicing, vehicle maintenance management, and word processing are the feasible computerized MIS application areas. All of these applications utilize existing the data base.

There are four areas where additional attention could yield large payoffs in implementing automated MIS in small transit organizations. These areas are: 1) better matching of expectations of automated systems with their actual performance; 2) improved in planning for system installation; 3) reducing the trauma in the installation of system, and; 4) improved project management and control.

A common difficulty in the system planning stage lies on computerizing poorly documented, and loosely controlled manual systems. Hence, a management-improvement study would be a good first step in advance of computer installation study. Data acquisition and transcription, paper flow, and the summarizing and distribution of data would be essential components of such a study.

Reilly [1985] identified benefits of implementing computers in small properties. Microcomputers allow easy access to data, and give management information to improve operating efficiency and service effectiveness at reasonable cost. He classified these benefits as "perceived", because these are not quantifiable. If benefits
could be quantified in dollar amounts, managers would have less difficulty persuading city management to fund microcomputers. He identified the seven feasible automation application fields and potential benefits. MIS application fields are shown on Table 2.2.1. Potential benefits are illustrated on Table 2.2.2. The degree of benefits depend on the level of computer utilization and the application used. Reilly identified the three levels of computer utilization in transit organizations: 1) off-line (budgeting and route-planning purpose); 2) on-line (maintenance, inventory, and ridership and revenue analysis), and; 3) real-time, and on-line (hourly, and daily decisions based on the incoming information). He defined the latter one as the highest level in utilization.

Reilly also identified the procedure for the implementation of computer in small transit organizations. Planning is the first step. At this stage identification of current and future needs for automation, examination of paper flows and defining current information void, and site-visit issues would be performed. The next step is procurement. In this stage, expandability of the computerized system, cost, and external guidelines would be set. The next stage is the designing stage, in which managers should work with the software developer, and designing software should be menu-driven. Good document preparation is an important issue in designing stage. The last step would be installation. At this stage training is a key to reducing computer anxiety and lessening resistance to the computerized application.

2.2.3.2 Computerized MIS Implementation in Large Transit

A discussion group paper on workshop describes the benefits and implementation issues facing large transit systems adopting MIS. The larger the property, the worse are the consequences of non-standardized of microcomputers and
Table 2.2.1 Transit Automation Application Fields

Source: Proceedings of the Workshop on Microcomputers in Transit, 1985

<table>
<thead>
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<tr>
<td>• Inventory control</td>
<td>• Preventive-maintenance scheduling</td>
<td>• General ledger asset control</td>
<td>• Daily operations assignment</td>
<td>• Telephone information: teledrive</td>
<td>• Time records/reporting</td>
<td>• Ride check</td>
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<tr>
<td>• Parts tracking</td>
<td>• Vehicle history</td>
<td>• Accounts payable</td>
<td>• Scheduling</td>
<td>• Customer-inquiries schedule info</td>
<td>• Fringe-benefit administration</td>
<td>• Forecast</td>
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<tr>
<td>• Parts reordering</td>
<td>• Daily servicing</td>
<td>• Accounts receivable</td>
<td>• Run-cutting</td>
<td>• Trip planning</td>
<td>• Word processing</td>
<td>• service</td>
</tr>
<tr>
<td>• Parts costing</td>
<td>• Payroll</td>
<td>• Driver record keeping</td>
<td>• Dispatch</td>
<td>• Data transfer</td>
<td>• Personnel management</td>
<td>• ridership</td>
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<tr>
<td>• Parts location identification</td>
<td>• Budget</td>
<td>• Dispatch</td>
<td>• Route selection</td>
<td>• Transfer of financial activities</td>
<td>• Special project management</td>
<td>• revenue</td>
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<tr>
<td></td>
<td>• Revenues/expenses</td>
<td>• and driver bids</td>
<td>• and accident reports</td>
<td>• Electronic mail</td>
<td>• Grants management</td>
<td>• cost</td>
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<tr>
<td></td>
<td>• Cost allocation</td>
<td>• Daily ridership and revenue recording</td>
<td>• Electronic bulletin board</td>
<td>• Risk management</td>
<td>• Ticket and pass record keeping</td>
<td>• Market research</td>
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<td></td>
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<td></td>
<td>• Call management</td>
<td>• Ticket sales accounting</td>
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<td>• Performance measures</td>
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<td>• Mailing list</td>
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<td>• Socioeconomic data</td>
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<td>• Pricing policy</td>
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<td></td>
<td>• Alternatives analysis</td>
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<td>• Ridership survey analysis</td>
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</table>
Table 2.2.2 Potential Benefits of Automated Management Information System

*Source: Proceedings of the Workshop on Microcomputers in Transit, 1985*

<table>
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<tr>
<td>• No stock out/reduce vehicle downtime</td>
<td>• Reduced downtime with better utilization of vehicle</td>
<td>• Provides timely management control</td>
<td>• Improves ridership and revenue</td>
<td>• Facilitates access to benefits information</td>
<td>• Facilitates alternatives analysis</td>
<td>• Facilitates operating efficiencies</td>
</tr>
<tr>
<td>• Reduced inventory/stock, resulting in reduced inventory cost</td>
<td>• Better interface with parts inventory</td>
<td>• Allows single entry versus multiple data entry</td>
<td>• Reduces quality of service</td>
<td>• Helps assess personnel performance</td>
<td>• Reduces unproductive services</td>
<td>• Provides support for alternative service modes</td>
</tr>
<tr>
<td>• Supports purchasing/man-power savings</td>
<td>• Better use of maintenance resources</td>
<td>• Promotes better cash management</td>
<td>• Improves customer communications</td>
<td>• Can result in reduced risk coverage costs based on experience rating</td>
<td>• Improves service effectiveness</td>
<td>• Allows efficient evaluation of numerous system operations</td>
</tr>
<tr>
<td>• May reduce theft</td>
<td>• Support decision making on vehicle replacement</td>
<td>• Generates scenarios in contract negotiations</td>
<td>• Improves awareness of customers' desires</td>
<td>• Improves clerical productivity</td>
<td>• Improves operating efficiencies</td>
<td>• Increases ridership and operations</td>
</tr>
<tr>
<td>• Optimizes purchasing</td>
<td>• Assists in quality control</td>
<td>• Aids in personnel planning</td>
<td>• Improves accuracy of info.</td>
<td>• Supports collective bargaining process</td>
<td>• Supports service planning</td>
<td>• Decreases ridership and deficit</td>
</tr>
<tr>
<td>• Supports annual physical inventories</td>
<td>• Supports equipment scheduling decision</td>
<td>• Optimizes extra board</td>
<td>• Support service planning</td>
<td>• Supports accounting and budgeting</td>
<td>• Improves performance</td>
<td>• Supports ridership analysis</td>
</tr>
<tr>
<td>• Supports budgeting functions</td>
<td>• Assists in tracking warranty work</td>
<td>• Reduces accidents</td>
<td>• Improves paratransit system productivity</td>
<td>• Provides farebox control</td>
<td>• Improves wayside info.</td>
<td>• Supports ridership analysis</td>
</tr>
<tr>
<td>• Reduces time required for physical inventory</td>
<td>• Supports parts management</td>
<td>• Improves internal and external reporting</td>
<td>• Provides ability to respond quickly to operational change</td>
<td>• Provides access to historical databases</td>
<td>• Provides access to information</td>
<td>• Reduces deficit</td>
</tr>
<tr>
<td></td>
<td>• Flags immediate problems with fluid use</td>
<td>• Support adult function</td>
<td>• Provides interface with service planning</td>
<td>• Supports marketing activities</td>
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</tbody>
</table>
their software. These problems are addressed by the current advancement in hardware and software market.

Microcomputer can be used by large transit systems in two ways: 1) to enhance personal productivity, and; 2) to automate functional areas. Reduced manpower cost, shorter turnaround time, and increased availability of what are the major benefits of microcomputer implementation in large transit systems. The best area to begin computerization is where personnel appears most receptive. Discussion group found using microcomputers in operations has a considerable impact on organizational structure and may create jurisdictional conflicts between microcomputer users and the central data processing department. Therefore, implementation of MIS in large transit system needs to be carefully planned and designed.

2.2.4 Management Information System Case Study

2.2.4.1. Greater Bridgeport Transit District (GBTD), Connecticut [Final Report, 1985]

The GBTD was established in 1972. The goal of its MIS project was to maximize the effectiveness of public funds for transportation, to positively impact local community and economic development, and to provide cost-effective service to the transportation needs of residents. To achieve these goals, Integrated Management Processing System (IMPS) was implemented.

The purpose of IMPS was to provide automation of current manual administrative functions, to provide the capability to generate reports to meet both
internal as well as external reporting needs, and provide new information in support of transit management decisions.

The IMPS module consist of: a) data base management, which requires identification and storage of all data; b) information management to support transit management decisions. Main feature of this module is to take care of day-to-day, intermediate, and long-term report generation. Day-to-day reports contain daily maintenance, personnel timekeeping, and ridership reports. Intermediate reports contains weekly maintenance, operations statistics, accounting, and payroll information. Long-term reports contain longitudinal summaries over a long period of time to support route or service level changes, fleet acquisition or rehabilitation decisions, capital equipment acquisition requirements, personnel requirements, and operating budget requirements and justification, etc.; c) report generation. This module follows the FTA's Section 15 requirements; d) performance of administrative function. Functions receiving the highest priority would be those most generally common to the several users, those which readily lend themselves to automation, those for which the greatest efficiencies can be realized. Specific functional areas include account payable/receivable, general ledger posting, trial balance preparation, personnel record keeping, elderly and handicapped service subscription registration, and scheduling; e) database sharing. This module contains the information on routes and ridership; and f) performance of brokerage analytical function: The objectives of the brokerage project are to develop and implement a process to candidate, plan, implement, monitor, evaluate and improve the various series of elements, and to identify and develop the full market potential for these services.

Specifically, IMPS application areas are accounting, payroll/personnel application, budget, material management, maintenance management, scheduling,
service planning, general administration, ridesharing, elderly and handicapped transportation administration.

Functional requirement analysis was performed to provide basis for detailed design of the IMPS system, and to provide a basis for evaluation of candidate applications software. This analysis includes a flow chart which describes the application, a list of inputs, an outline of the processing function, and list of outputs and comments.

An applications software telephone survey was performed by GBTD. Objectives of the survey is to determine what functions have been computerized, to determine which operator has what application, to screen applications software for potential adaptability, to determine developmental methods, problems and success in installation, and to select software for site-visit research. Other information obtained from this survey are application capability, developer/installer, installation cost, language, special features, data input/output, transferability, documentation, and comments/evaluation. Based on the telephone survey, three transit operators were visited, AC transit in California, Denver transit in Colorado, Orange County transit in California. Yet, telephone survey has its own limitations such as not all application can be discussed with a given operator, and not all questions can be asked for a given application.

2.2.4.2. VIA Metropolitan Transit, San Antonio, Texas [VIA, 1985]

The purpose of this project was to automate VIA’s main source of information, runcutting, roistering, timeroll, and all systems that are dependent on the information
supplied by these major systems. The automation functional areas include: a) runcutting system; b) scheduling system; and c) timeroll system (timekeeping system).

The goal of runcutting system development is to switch and shift pieces of work to produce the lowest cost solution. It optimizes pay to platform hours, creates more regular work schedules for bus operators, and creates reduced the time and personnel required to make changes to the system. Parameters in this system are actual work time, the break between pieces of work, the type of transit run, and the starting and ending time.

The goal of scheduling system development was to maximize the generation, verification, and computerization of huge amounts of schedule-related data. This system increased system productivity and information flow significantly. It increased the productivity tenfold with 30 percent less schedule-related personnel, and generated schedule-related reports. This was a dynamic system. It was easy to change the data when service changes were made. It also provided easy data-handling.

The goal of the timeroll system was implementation of an automated financial MIS. Five modules are identified in this system. These are: 1) operators' name, seniority, vacation week, and calendar module; 2), sign-up module which includes scheduled run, scheduled weekly combinations of runs, driverbids, and scheduled bus pullouts; 3) dispatch module which defines given day's dispatching of work, buses, and drivers; 4) payroll module which provides operators' daily, weekly, and biweekly payroll records, and; 5) performance module which documents variances between actual dispatched work and scheduled work.

New features in VIA system include: 1) demand forecasting system which provided tools for making long-range forecasts for system-wide service planning. Its features are transit and highway network building, minimum path findings and
skimming, spreadsheet-type transit trip generation, modal choice module, total and transit trip distribution utilizing gravity and FRATAR model, total and transit trip assignment, and matrix mathematics; 2) timetable typesetting system; 3) geo-coding database system which integrated information from various data bases, and a single unified data base that is accessed by all departments; 4) general financial accounting with to functions of general ledger/management reporting, accounts payable, accounts receivable, fixed assets, grant management, payroll/personnel, accident/claims administration, and worker's compensation claims, and; 5) rostering system which utilizes the weekday, Saturday, and Sunday runs and produces weekly runs, or five days of work for each operator.

2.2.4.3 TRANSMiS, Los Angeles, California [Seagraves, 1985]

TRANSMiS is an operations planning and support system. It provides management tools to ensure that vehicles will be provided to the public in good condition and on time. It covers bus-system planning, scheduling, and bus-operator bidding and assignment.

TRANSMiS is composed of vehicle management system, material management, production control system, financial management system, and a capital project control system. Benefits of the TRANSMiS are: a) increased productivity, reduced inventory efforts, and improved project control and scheduling capabilities; b) increased reliability in scheduled departures; c) better utilization of manpower and equipment, and; d) improved decision-making, reduced paperwork, and improved budgetary control.
2.2.4.4 Brockton Area Transit Authority (BATA), Massachusetts [Beagan, 1985]

BATA was established in 1975. It currently utilizes 45 buses on 18 different routes. Its ridership is 4,000,000 passengers/yr. Originally, it was planned to develop some programs to assist in what was a completely manual method of processing ridership information. Eventually, automated functional areas included ridership, revenue, and service were developed.

2.2.4.5 Duluth Transit Authority (DTA), Duluth, Minnesota [Turnbull, 1985]

The goal of this project was to apply state-of-the-art microcomputer technology to solve some of the multi-modal information on schedule and routing problems, and to enhance and expand its availability. The objective of the automation project was to reduce the cost of maintaining a staffed information center, to provide information about expended time and locations, and to integrate transit, rideshare, taxi, AMTRAK and other transportation information. This procedure was adapted, namely, identification of design and development criteria, and designing the system elements and a system flow diagram.

2.2.4.6 IOWA DOT, IOWA [McOwen, 1986]

Iowa DOT and its five transit properties were examined by McOwen for computerized MIS design and implementation process. Identification between data processing and respective information management was an important issue. Who completes the forms, who uses them, how often they are completed, what information
is included, what additional reports are produced from the data, and what purpose is served by the form or report were crucial issues addressed by McOwen.

McOwen identified more than sixty software evaluation criteria. Some of these are reliability, back-up data system, user-friendliness, cost, warranties and service, capacity limit, speed of program, flexibility, security data, program language or languages, and interfacing needs. In order to achieve compatibility among main office and its branches, standardization of software packages, operating system, application programs, attribute-record-file structure were important factors of the designing stage.

Hardware assessment must be made for optimal design specification and selection. Hardware evaluation criteria include the degree to which the system is capable of efficient exchange of information, and reduces the time and expense involved with manual information exchange. These are able to be obtained by effective communication link between site and other divisions. Divisions can receive data automatically from the various transit systems. Software and hardware selection should consider their compatibility's in a coordinated system. Communication makes it possible to share the data and programs between computers so that any site can take advantage of the efforts of the other site to solve common management information needs without having to start from scratch.

Some design specifications of Iowa DOT are: a) system provided a multiple-user environment and comprehensive concurrence, and; b) software was menu-driven and included a help-screen. In terms of hardware, Multi-user, multitasking hardware, and multitasking operating systems were required to meet the agency's MIS demands.
2.2.4.7 Metropolitan Transit Authority (MTA), Harris County, Texas [Crew, 1987]

The duration of this project was five years and its estimated cost was $4.7 million in 1979. Two research tasks were identified in this process. The first task is "process analysis" which deals with MIS implementation procedures. This task describes how MIS was implemented in MTA. The second task is the productivity measurement in which the impact of automation is assessed. This follow-up study shows the things that are improved after MIS implementation.

Strategy of development was designed in three phases. In the first phase, parameter identification of management information needs were performed. This step became the basis for the development of conceptual definition of each system component, manpower and costs for each system component, computer hardware, and cost/benefit analysis. During the second phase, a development plan was proposed. Subsequently, in the third phase, the overall cost of the project was estimated.

The schematic representation of MIS in MTA consisted of five modules. These modules were: 1) service development (ridership survey system, customer information system, and carshare); 2) transportation (scheduling, control, and operator time keeping); 3) maintenance management system; 4) finance and administration (revenue/accounts receivable, purchasing/contract administration, accounts payable, claims and safety, payroll/labor distribution, personnel, general ledger financial reporting, property accounting, capital project management, and administrative control), and; 5) executive management reporting (performance indicator reporting).

The importance of including a decision support system in MIS was identified. MTA's decision support system is an interactive computer-based system. It is structured around analytical decision models and a specialized database directly
accessible to managers that can be used to address decisions about unstructured and non-routinized problems. Most of the transit-related data in a DSS address unstructured and non-routinized problems.

Crew and Weiher noted that there are arguments on the definition of information system development. Information system development requires a higher degree of management attention than, for example, the construction of apartment complex, "because the building materials of an information system... are often based on abstractions." Morgan and Sodan [1973] emphasized the importance of good project management because "most failures in the implementation of management information systems are managerial rather than technical failures."

After the implementation of the automated MIS, qualitative and quantitative analysis was performed to measure the improved productivity. The qualitative aspect involved: a) improved analytical capability such as scheduling and budgeting; b) enhanced capability to retrieve data and answer questions such as average peak bus pullout increased by 70 percent, on time performance increased 96 percent, miles between mechanical roadcalls dropped from 513 to 6538, accident per 1000 miles decreased from 9.2 to 2.7, and operating cost reduced to 24 percent, and; c) increased ability to monitor agency operations in the areas of capital project management and accounts payable. Since MIS deals with non-procedural or unstructured problems, it is often difficult to quantify productivity. Hence, "time series" analysis using the Box-Jenkins model was applied. This model combines ARIMA models with impact models. The ARIMA model characterizes an overall process realized through time as opposed to the impact model, which describes the way in which the process changes due to specific intervention. Specific quantifiable improvements noted were: a) bus miles service ridership and number of buses in service during peak demand; b) van share,
transport expenditure, transport personnel, and maintenance personnel; and; d) human concern for the welfare of employees as well as for the morale of work force, but it makes the size of the work force in sensitive to changes in productivity. Yet, there was little indication that immediate cash savings or personnel reductions resulted from automated MIS.

2.2.5 Summary of MIS Literature Review

Even though there has not been much activity in transit MIS since 1985, recent advances in computer-related technologies will attract more resources to transit automation. Thus, highly sophisticated MIS software can be developed. Broadening the applicable transit market or offering a stronger profit incentive to developer can be achieved by standardization of procedures. Some of these are hardware/software format standardization, and operating system standardization. Adequate support for microcomputer users is one of the recommendations for the application towards the development or improvement of the current transit systems.

Computers in transit organization can improve the quality of both individual and collaborative managerial work. But, the greatest drawback is in its higher startup cost. However, current information systems, which use real-time and easily accessible data, are now available at a much lower cost. As a result, transit system can be operated at greater savings to the government at all levels. Therefore, it makes sense for FTA to encourage microcomputer use in the transit industries.
2.3 AUTOMATIC VEHICLE LOCATION SYSTEM

2.3.1 Introduction

The concept of Automatic Vehicle Location (AVL) system has been discussed in the transit industry since the early 1970's. AVL system is defined by the Federal Transit Administration (FTA) as a "means of monitoring the movement of a fleet of vehicles". Knowledge of a vehicle's current position makes it easier to control the vehicle. Because of technological immaturity, some of these systems were abandoned. However, current technology in communications and electronics enable them to flourish. AVL application fields are broad. Currently AVL technology is utilized in the areas of police car fleets, ambulance services, taxi companies, paratransit, and extensively in trucking companies.

A successful AVL system has specific design criteria. Some of these are:

1) it should generate and transmit data so as to provide as comprehensive a picture of the system's status as possible;
2) it should examine all the components of a problem in the quest for a solution;
3) it should reduce response time between the occurrence of a problem and the implementation of a solution;
4) it should collect and process data and make it possible to implement a solution.

The ultimate operational goal [Hetl, 1988] of an AVL system is good service to the public at the low cost. Short travel times, minimum waiting time at stops and transfer points, reliable schedules, clean, safe, uncrowded vehicles, and courteous service will improve level of service in public transportation. Hetl segregated AVL's operational
goal according to peak and non-peak demand time. The goal in peak periods deals with maximizing capacity using a limited number of vehicles and schedule adherence. The goal in non-peak periods deals with infrequency of service, service predictability, and waiting time at transfer points.

There are three major vehicle detection technologies: radio-navigation systems, proximity systems, and dead reckoning systems.

2.3.2 Objective and Benefits of Automatic Vehicle Location system

Four AVL system objectives are identified from the literature:
1) to give passengers more regular traffic information and to reduce the effect of disturbances;
2) to give traffic controllers better information about the actual situation as a tool for handling traffic disturbances;
3) to improve working conditions for vehicle operators, and;
4) to make operation more effective.

AVL systems benefit passengers, vehicle operators, and controllers. The advantages of AVL system are shown on Table 2.3.1. Some disadvantages exist as well. These are also shown on Table 2.3.1.

A cost-benefit analysis was performed in Ottawa, Canada [The International Conference on AVL in Urban Transit System, 1988]. The objective of this analysis was to compare a route with an AVL system to one without one. Quantifiable and non-quantifiable benefits were identified. Quantifiable benefits were: 1) improved vehicle
Table 2.3.1 Advantages and Disadvantages of Automatic Vehicle Location system

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
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<tr>
<td>• improving regularity of service</td>
<td>• expansive in installation</td>
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<tr>
<td>• collecting real-time user data</td>
<td>• hard to quantify in terms of efficiency and effectiveness</td>
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<tr>
<td>• improving user service</td>
<td>• accuracy/cost trade-off</td>
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<tr>
<td>• improving vehicle operators' working condition</td>
<td>• vehicle operators' hesitance</td>
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<td>• generating information for planning and statistics</td>
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<td>• increasing on-time-schedule bus</td>
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<td>• reducing waiting time</td>
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<td>• monitoring and tracking the location of all buses</td>
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<td>at all times</td>
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<td>• displaying the schedule adherence status of a route</td>
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<td>• reacting immediately to service problems</td>
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<tr>
<td>• proving data collection for management decision making</td>
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<tr>
<td>• improving the information available to passenger</td>
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</tbody>
</table>
and manpower utilization saving from 5.9 to $8.2 million/yr; 2) a 5.3 percent absolute increase in ridership (from 1.7 to 3.5 million passenger/yr), obtained from a time series analysis and a before- and after-passenger survey; and 3) improved supervisory staff utilization, from 7.6 to $13.1 million/yr.

Due to the difficulties in defining and measuring the relevant key-factor and putting a specific price on improved service, benefits are hard to quantify. However, some of the non-quantifiable benefits were: 1) improved schedule adherence/service regularity; 2) reduced complaints with respect to delay and schedule adherence; 3) improved inspectors' work environment; 4) improved operators' work environment; 5) improved neighborhood-watch concept; 6) improved passenger and vehicle operator security, and; 7) reduced running time.

2.3.3 Automatic Vehicle Location System Components [FTA '90]

AVL systems have three main components: 1) vehicle location - This component measures the position of each vehicle within a certain error range. This range depends on location technologies, how they are implemented, and the systems operating environment. Location information is then either stored in on-board device or transmitted to a control center. 2) real-time information communication - For this component real-time and two-way communication are essential. Transmitted data must contain both voice data and location subsystem data. 3) capability of storing and analyzing the information in a central processor - Transmitted data must be processed in order to be used effectively. If any of these three components are missing, the AVL system will not perform optimally. Figure 2.3.1 illustrates AVL system components.
Figure 2.3.1 Automatic Vehicle Location System Component

- Processor
  - Vehicle Location Data
- Communication
  - Real-Time Two-Way Data Communication
- Location
  - Detection Technologies
2.3.4 Vehicle Location Detection Technologies

Currently three major vehicle location detection technologies are available. These are radio navigation systems, proximity systems, and dead reckoning systems. A detailed description follows.

2.3.4.1 Radio Navigation Systems

2.3.4.1.1 LORAN

Long Range Aid to Navigation (LORAN) is a hyperbolic radio-navigation system that uses low frequency ground waves to provide useful operating ranges on land from 690 to 940 miles independent of line of sight. It provides absolute position determination with 500 meter accuracy or better within its defined areas of coverage [Sypher Mueller International/Polhemus Associates, 1987]. Coverage is provided by a chain of transmitters. One station in the chain is designated as the master, and the remaining two to four stations are identified as secondaries. Typically, stations are spaced 700 miles apart. The user receiver measures the time difference between reception of the signal from the master station and each of two or more secondary stations. The concept is analogous to triangulation. The time difference between the master and the secondary station X defines a hyperbolic line of position; the time difference between the master and secondary station Y defines the second contour line. The intersection of these lines defines the receiver location. An updated signal is provided every 1/20 to 1/10 seconds so that receiver sets can calculate not only latitude and longitude but also speed of vehicle.
2.3.4.1.2 Global Positioning System (GPS)

GPS is a satellite-based navigation system that will ultimately provide accurate three-dimensional navigation throughout the world. With GPS, satellites are known points. Their positions in space are precisely monitored. By measuring the travel time of a signal transmitted from a satellite, a receiver on the ground can compute its distance from that satellite. With distance measurement from four satellites, the receiver can compute its exact latitude, longitude, and altitude. Currently, a total of 24 satellites (21 primary, 3 for backup) are in operation. This number guarantees that there will always be at least four satellites above the horizon for every point on earth. GPS, initially developed by the US Department of Defense, is global, all weather, and available 24 hours a day.

2.3.4.1.3 OMEGA

This is a very low frequency radio-navigation system (10-13 kHz). It utilizes eight transmitting stations which are located 8000 km apart and cover 90 percent of the earth's surface. Position information is obtained by measuring the relative phase of received signals. Position update is performed once every 10 seconds. A good dead reckoning system should be included for accuracy in urban transit application.

2.3.4.2 Proximity System

This system locates vehicles by determining the relationship between the vehicle and fixed locations at key points throughout the road network. A signpost periodically
transmits a digital message containing a unique signpost ID. The signpost receiver on
the bus receives a ID, and transmits it to the control center through a data/voice radio.
The vehicle is regularly polled to transfer this information to the control center. An
odometer reading is usually employed to determine the location between signposts.

2.3.4.2.1 Inverted Proximity System

This system is operated by an inverted way of proximity system. The vehicle is
equipped with a transmitter. Signposts along the road function as receivers.

2.3.4.3 Dead Reckoning System

Unlike other technologies, a dead reckoning system designates location at any
point in the service area without reference to external signals. In this system distance
traveled and heading are continuously integrated to determine relative position from a
known starting point. Differential odometers, magnetic compasses (direction
measuring), accelerometers, gyroscopes, and digital odometers (distance measuring)
are used to measure the distance and direction of travel.

2.3.5 Vehicle Location Detection Technology Assessment

Factors such as accuracy, flexibility, coverage area and cost should be considered
in performing system assessment of these location detection technologies. Table 2.3.2
illustrates the advantages and disadvantages of each location detection system and

LITERATURE REVIEW
Table 2.3.3 identifies the system selection criteria. There is big trade-off between accuracy and cost. A great amount of money will need to be invested to increase the error range from 20 meters to 10 meters. Figure 2.3.2 illustrates the relationship between cost and absolute accuracy.

2.3.6 Automatic Vehicle Location System at Tidewater Regional Transit

2.3.6.1 Overview

In April 1987, the Tidewater Transportation District Commission (TTDC) awarded Fishbache & Moor Global Communication (F&M) a contract for the development and installation of an AVL system. The TTDC operates 160 buses on 30 routes in the areas of Hampton, Norfolk, Virginia Beach, Portsmouth, and Chesapeake, Virginia. On a daily basis, Tidewater Regional Transit (TRT) buses cover a distance of 12,800 miles and transport 25,000 passengers. The TRT system also operates demand responsive systems such as Maxi-Ride for low-demand density service areas and Handy-Ride for elderly and handicapped passengers.

2.3.6.2 How Does It Work?

The TRT system consists of four major components: 1) the bus operator; 2) a bus equipped with on-board micro computer, mobile radio communication system, and signpost receiver; 3) the radio transmitters mounted on signposts at fixed locations, and; 4) the central computer at the TRT control center.
Table 2.3.2 Advantages and Disadvantages of Location Detection Systems

<table>
<thead>
<tr>
<th></th>
<th>ADVANTAGE</th>
<th>DISADVANTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROXIMITY</td>
<td>• Simple to understand</td>
<td>• large number of signposts required</td>
</tr>
<tr>
<td></td>
<td>• relatively inexpensive</td>
<td>• frequent signpost maintenance</td>
</tr>
<tr>
<td></td>
<td>• high reliability</td>
<td>• not suitable for small fleet of vehicle</td>
</tr>
<tr>
<td>INVERTED PROX.</td>
<td>• no location computation required</td>
<td>• applied only on fixed route</td>
</tr>
<tr>
<td></td>
<td>• cheaper than other system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• no spectrum space required</td>
<td></td>
</tr>
<tr>
<td>LORAN C</td>
<td>• short signal update period</td>
<td>• signal interference in area with high structures</td>
</tr>
<tr>
<td></td>
<td>• speed detection available</td>
<td>• noise or other radio signal interference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• impossible to be stand alone system</td>
</tr>
<tr>
<td>GPS</td>
<td>• most accurate location capability</td>
<td>• accuracy problem in urban area</td>
</tr>
<tr>
<td></td>
<td>• weather proof</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• available 24 hours a day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• global coverage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• three dimensional location detection</td>
<td></td>
</tr>
<tr>
<td>OMEGA</td>
<td>• appropriate for urban environment</td>
<td>• low location update rate (1/10 sec)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• high receiver cost</td>
</tr>
<tr>
<td>DEAD RECKONING</td>
<td>• available for unfixed route</td>
<td>• inaccuracy caused by cross winds,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>differences in wheel size, tire pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• error accumulation</td>
</tr>
</tbody>
</table>
### Table 2.3.3. Location Detection System Selection Criteria

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Cost</th>
<th>Coverage Area</th>
<th>Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROXIMITY</strong></td>
<td>• depends on number of signposts</td>
<td>• depends on number of signposts ($1000/ea.)</td>
<td>• depends on number of signposts</td>
<td>• fair</td>
</tr>
<tr>
<td></td>
<td>• $900 for vehicle unit</td>
<td>• $900 for vehicle unit</td>
<td></td>
<td>• fixed route</td>
</tr>
<tr>
<td><strong>INVERTED PROX.</strong></td>
<td>• depends on number of signposts</td>
<td>• $14500 (total)</td>
<td>• depends on number of signposts</td>
<td>• fair</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• fixed route</td>
</tr>
<tr>
<td><strong>LORAN C</strong></td>
<td>• average 500 meter</td>
<td>• $1200 to $1500 for vehicle unit</td>
<td>• worldwide</td>
<td>• good</td>
</tr>
<tr>
<td></td>
<td>• 60 to 200 meter with correction factors for local signal variation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GPS</strong></td>
<td>• 5 meter with differential adjustment</td>
<td>• $1500 for vehicle unit</td>
<td>• global</td>
<td>• excellent</td>
</tr>
<tr>
<td><strong>OMEGA</strong></td>
<td>• 300 meters 95% of time</td>
<td>• $3000</td>
<td>• worldwide (90%)</td>
<td>• good</td>
</tr>
<tr>
<td><strong>DEAD RECKONING</strong></td>
<td>• errors are time-dependent</td>
<td>• $3200</td>
<td>• no limit</td>
<td>• good</td>
</tr>
</tbody>
</table>
Figure 2.3.2 Cost/Accuracy Trade-Off

Source: Hamilton, G.B., 1988
To initiate the system, vehicle operators enter their employee identification number and the scheduled route for the bus into an on-board micro-computer before the leaving the bus depot. This information is immediately sent to a control center computer, then begins monitoring the bus.

The odometer reading of each bus is transmitted once every 40 seconds to the control center throughout its service period, allowing the center computer to track the movement of each bus. In addition, each bus route is equipped with radio transmitters that are mounted on signposts at suitable locations. There are 55 signposts located throughout the transit network. The transmitters are low-energy, short-range (approximately 100 feet radius) beacons that detect a bus coming into range. Each transmitter notifies the control center as each bus reaches a particular location. The computer at the control center acts in coordination with the odometer readings and transmitters to correct and minimize the mileage differential between a bus' actual location and its computer-estimated location. With information about the location and movement of all buses in service at any given time, the computer calculates each bus' adherence to its schedule. TRT system configuration is illustrated on Figure 2.3.3.

2.3.6.3 System Features

If a vehicle encounters a signpost that is not on its route or detects one on its route that it has passed, the bus will be flagged as uncorrelated and a message will be transmitted to the dispatcher's systems message queue alerting the controller to the fact that the bus is off-route. If a signpost is missed by five consecutive buses, it is declared to be inoperative.
Figure 2.3.3 Tidewater Regional Transit AVL System Configuration
The predicted arrival time of a vehicle is computed by dividing the distance to the next scheduled destination by the schedule speed for the route segment. This value is calculated each time a location message is received from a vehicle. The value is transmitted to the vehicle, displayed on the mobile data unit and if it is out of the range of allowable early/late parameters, this information is announced to the dispatcher. Vehicle operators can monitor their own performance and make corrections, independent of the dispatcher.

Another feature of the system is the inclusion of an emergency alarm system on each bus. This system consists of three remote mechanical alarms: engine temperature, low air pressure, and oil pressure. In case of mechanical failure, the dispatcher is automatically notified through this emergency system. Also, the bus operator can use a microphone handset or special push-buttons to notify the control center of an emergency, such as passenger health problem or a bus-jacking. The operator can communicate with the control center by pressing a request to talk button, which causes a message to be sent to the dispatcher requesting direct communication. This emergency system enhances vehicle performance in real-time.

There is also a system reports generation function in the TRT AVL system. Management personnel can get the reports from the controller's keyboard for multiple days including the current operational day. Log files are created at the beginning of each operational day and closed at the end of operational day. Closed files are transferred to magnetic tape for archival purposes using standard console operator commands. The system reports include: daily pull-in report, daily pull-out report, schedule adherence by TTDC route report, schedule adherence by route/block report, schedule adherence by operator report, and schedule adherence by vehicle report.
The system has the capacity to store up to 1000 incident reports on-line. When a new incident report is created, the oldest closed incident report is over-written.

2.3.6.4 Cost

The overall cost for equipping a fleet of 92 buses was $2 million. It included the AVL computer hardware, software, base station, power supplies, signposts, two-way radio system, training, installation, and documentation to make the system. Costs are itemized in Table 2.3.4.

2.3.6.5 Summary

The current TRT’s AVL system is a fixed route location system utilizing signpost and odometer reading technology for its data collection. The AVL system is responsible for tracking and collecting data for all buses on their assigned routes. TRT controllers are able to analyze this data to improve daily and long-term operational service of the TRT transit system. Additional features of the TRT’s AVL system include forecasting capabilities, and generation of reports on schedule adherence and incidents.

The major drawbacks of the TRT’s AVL system is:

1) lack of information processing capability;
2) limited to fixed-route vehicle performance monitoring;
3) user-unfriendly screen information display;
4) inefficient manual;
Table 2.3.4 Tidewater Regional Transit Automatic Vehicle Location system Cost

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QUANTITY</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit data/radio units (per spec.)</td>
<td>155</td>
<td>622,325</td>
</tr>
<tr>
<td>Van mobil radio equipment</td>
<td>70</td>
<td>210,000</td>
</tr>
<tr>
<td>Trolley radio equipment</td>
<td>26</td>
<td>78,000</td>
</tr>
<tr>
<td>Portable radio equipment</td>
<td>20</td>
<td>60,000</td>
</tr>
<tr>
<td>Signpost</td>
<td>55</td>
<td>44,000</td>
</tr>
<tr>
<td>Base station equipment</td>
<td>1</td>
<td>91,000</td>
</tr>
<tr>
<td>Computer software (installed)</td>
<td>lot</td>
<td>94,000</td>
</tr>
<tr>
<td>Control processing equipment</td>
<td>1</td>
<td>90,000</td>
</tr>
<tr>
<td>Control console and associate equipment</td>
<td>1</td>
<td>65,000</td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td>Miscellaneous item</td>
<td></td>
<td>640,153</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>2,000,000</strong></td>
</tr>
</tbody>
</table>
5) inaccurate location information provided by signpost with electronic odometer detection technology;
6) lack of AVL information dissemination device to passengers, and;
7) not enough knowledge on the system.

This research is directed to relieving and improving these deficiencies.

2.3.7 Automatic Vehicle Location System Future Research Needs

At the International Conference on AVL in Urban Transit Systems, the panel of experts presented their thoughts about research needs for future AVL system. These needs were:
1) exploring the possibility of artificial intelligence application to enhance the service control function;
2) developing new operating control strategies;
3) further exploring in planning and management information needs, and;
4) developing a passenger information system based on AVL data.

2.3.8 Summary of Automatic Vehicle Location System Literature Review

AVL has the potential to collect large quantities of data for use in the planning and management of public transit [Koffman, 1987]. Careful consideration needs to be given to the reporting systems associated with AVL precisely because there is so much data available. Certainly, having too much data is sometimes as bad as having too little.
The AVL system constitutes a technological leap for public transit networks because it is the only way to take data into processing. AVL system is simply one component of transit management information system and it must, therefore, tie into and provide information to other systems [Caruso, 1988].
3.0 MODEL DESCRIPTION

3.1 INTRODUCTION

The Tidewater Regional Transit (TRT) operates an AVL system on their 30 bus routes. Every 40 seconds, the current location of each bus, its status, and adherence to schedule, etc. are transmitted to the control center. Since information-management philosophy was not defined thoroughly at the early planning and designing stage of AVL system, so much incoming data is somewhat of a headache for the TRT. Hence, this research is focused on the development and improvement of their managerial working environment.

A computer model to address the improvements in the current AVL-based management information system in TRT was constructed in two modules. The first module is a graphics-based display system. Because of its user-friendly interface, graphics-based MIS leads to significant improvements in data processing and information management of the TRT transit system.
In the second display module, the TIGER/Line Census File, 1990 is used for the GIS-based screen display. The bus-route map is superimposed over the area map, and then the buses are shown as small isosceles triangles on their respective routes. Multiple program codes are written to utilize the TIGER/Line data file. Combining graphics-based and GIS-based display system will provide an improved presentation and a better management mechanism than the existing TRT system.

3.2 GRAPHICS-BASED DISPLAY SYSTEM

3.2.1 System Design

The development of a graphics-based MIS for the TRT begins with identification of data in the current AVL transit management and operation system. This data includes: vehicle location, vehicle ID, vehicle operator ID, route/run ID, schedule adherence, headway, incident report, mechanical alarm, and emergency alarm. Relevancy level, priority level, and demand intensity levels were evaluated in order to select the most informative data set. According to these levels, the most relevant, high-priority, and high-demand information is consistently displayed and updated on the computer at the MIS control center in TRT. Lower priority information is updated less frequently and only made available upon the user’s request. Differentiated levels of data are shown on Table 3.2.1, Information Intensity Level. Also, it is important to determine a consistent format in which this information will be disseminated.
Table 3.2.1 Information Intensity Level

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>DYNAMIC (Higher)</td>
<td>• Incident report</td>
</tr>
<tr>
<td></td>
<td>- time and date of receipt</td>
</tr>
<tr>
<td></td>
<td>- incident type</td>
</tr>
<tr>
<td></td>
<td>- location</td>
</tr>
<tr>
<td></td>
<td>- report number</td>
</tr>
<tr>
<td></td>
<td>• Emergency alarm report</td>
</tr>
<tr>
<td></td>
<td>• Mechanical alarm report</td>
</tr>
<tr>
<td></td>
<td>• System message report</td>
</tr>
<tr>
<td></td>
<td>• Request to talk</td>
</tr>
<tr>
<td>STATIC (High)</td>
<td>• Vehicle ID</td>
</tr>
<tr>
<td></td>
<td>• Operator ID</td>
</tr>
<tr>
<td></td>
<td>• Route ID</td>
</tr>
<tr>
<td></td>
<td>• Run ID</td>
</tr>
<tr>
<td></td>
<td>• Pull-out time</td>
</tr>
<tr>
<td></td>
<td>• Pull-in time</td>
</tr>
<tr>
<td></td>
<td>• Schedule adherence status</td>
</tr>
<tr>
<td></td>
<td>• Look-ahead function</td>
</tr>
<tr>
<td></td>
<td>- travel time on each link</td>
</tr>
<tr>
<td></td>
<td>- dwelling time on each stop</td>
</tr>
<tr>
<td></td>
<td>- expected arrival time on each stop</td>
</tr>
<tr>
<td></td>
<td>- passenger demand pattern</td>
</tr>
<tr>
<td></td>
<td>- bus route traffic pattern</td>
</tr>
</tbody>
</table>
The MIS computer hardware involved needs to be economical to install and maintain, compatible with existing equipment, user-friendly, and to have multi-user capability. The software functions designed are simpler to use than the current AVL system and are also user-friendly. Additional benefits of the software include: fast execution time (for the purpose of real-time on-line operation), low-maintenance, expansion ability, and multi-tasking. The MIS design flow chart is shown in Figure 3.2.1.

3.2.2 Screen Display Structure

The computer screen of the software package developed consists of five windows, namely, the title and clock window, the main menu window, the display window, the information window, and the on-line help window. Description of these windows follows:

- **Title and Clock Window**

  This window is located at the top of the screen, and displays the name of the software and current clock time. Figure 3.2.2 illustrates screen window division.

- **Main Menu Window**

  This window is right below the title and clock window, and displays the main menu functions. The main menu is composed of *File*, *Log*, *Info*, *Analysis*, *Look-Head*, and *Options* functions. These functions can, however, be expanded or changed as
Figure 3.2.1 Management Information System Design Flow Chart
Figure 3.2.2 Screen Window Division
needed. Further down, each of this main menu has a pull-down sub-menu. The details of these sub-menu modules are described in the following section 3.2.3.

• **Display Window**

  This window covers the largest area in the computer screen, and displays maps, text reports and graphical representations. In addition, any result of data analysis will also be displayed in this window.

• **Information Window**

  This window is located on the right hand side of the screen. When the user selects specific bus on the map, additional information is displayed, such as bus number, and the vehicle operator's name. The color legend of the map is also displayed in this window. Two frequently using functional keys such as print and quit options can be incorporated here for users' convenience.

• **On-line Help Window**

  This window is located at the bottom of the screen, and serves as a quick reference to users about the functions of the main menu and the sub-menu.

3.2.3 Menu Description

The menus are designed to provide efficient and effective managerial work for the controller and the planner in a transit organization. These include file, log, info, analysis, look ahead, and options. Specific descriptions follow:
• File

This menu consists of open, save, print, and quit sub-menus. The open module can be designed for file management purposes. For instance, a saved data file can be retrieved for playback purpose in this module. This module also facilitates downloading of files from the mainframe computer in TRT. The function of the save module is to save the analyzed data results. The results can be saved either on a floppy disk, or on the hard disk. The save module can also uploading data to the mainframe computer. The print module provides hard copy of reports, maps, and data analysis results. A screen capturing-package will be incorporated into the print function module. Any printed copy should follow the current paper format. The quit module exits the current display window and returns the cursor to the operating system prompt. Then, users can utilize the computer as word processors or spreadsheets.

• Log

The pop-up real-time information on incidents, emergencies, mechanical alarms, and request-to-talk can be stored as reports in the log file. These reports can be retrieved in this module and used as a data base for future uses such as maintenance purposes. A maximum of 1000 reports can be stored under this module in the hardware, after that, the oldest report will be overwritten.

• Info

This menu consists of bus location and zoomed area functions. This menu displays the area map, bus route map, and bus movement. See Section 3.3 for more detailed description. In this menu function, the zoomed area sub-menu function displays zoomed downtown areas in Norfolk.
• **Analysis**

This function has a *delay* and a *schedule* sub-module. These sub-modules are to be used for future applications.

• **Look-ahead**

The *bus number* is sub-module of this menu. When the controller either selects a certain bus on the screen by using the mouse, or selects this sub-menu and types the bus identification number, the computer program calculates the arrival time of its next stop. This module will be used for the future applications.

• **Options**

This menu offers a selection of *screen colors* and a *clock on/off* sub-module. The screen color module allows users to select any screen background color according to user preferences. The clock on/off module allows the clock display on the window to be on or off.

Schematic display of menus and sub-menus are illustrated in Figure 3.2.3. Computer screen format of the main menu is illustrated in Figure 3.2.4. An example of *Log* pull-down menu is illustrated in Figure 3.2.5.
Figure 3.2.3 Schematic Display of Menus and Sub-menus
<table>
<thead>
<tr>
<th>File</th>
<th>Log</th>
<th>Info</th>
<th>Analysis</th>
<th>Look-ahead</th>
<th>Options</th>
</tr>
</thead>
</table>

Use the arrow-keys to select the pull-down menus!

Figure 3.2.4 Main Menu Screen
| Incident report | Emergency alarm | Mechanical alarm | Request to talk |

Reveal the Incident Reports

Figure 3.2.5 Log Pull-Down Menu Display
3.3 GIS-BASED DISPLAY SYSTEM

3.3.1 TIGER File and Area Map Display

In order to display GIS-based MIS, the TIGER/Line Census Files, 1990 was used. TIGER file is a computer readable map database that automates mapping. It is composed of 1990 census map features (roads, rivers, and railroads), feature names, and classification codes, and FIPS codes (zip codes, cities, and township, etc.). An average file size for a state requires 400 megabytes of computer memory. TIGER file is available from computer tapes or CD-ROMS with ASCII or EBCDIC format.

The TIGER/Line file is an extract of selected information from the TIGER database. It is organized as a topologically consistent line network. Specifically, Record type 1 and 2 of the TIGER/Line files were used to develop maps in this research. Straight road segments have their coordinates stored in record type 1 whereas curved road segments have theirs in record type 2. If the Record Type 1 is a straight line, then there will not be a record type 2. Record type 1 provides a single record for a unique line segment whereas record type 2 provides an additional series of latitude and longitude coordinate values.

The study areas of Norfolk, Virginia Beach, Hampton, Portsmouth, Newport News, and Chesapeake, Virginia were extracted from the TIGER/Line file. These files were obtained from Mr. Stowe at Anderson and Associates, Inc. at Blacksburg. Originally, these files were stored in the CD-ROM and had to be downloaded to floppy diskettes. Since the file size of each city is huge (normally 10 megabytes), it was zipped. Zipping is a process by which the data is compressed and stored in diskettes.
The first task was to unzip the files. Then a program, which reads and plots record type 1 and record type 2, was written. When this program is executed, primary, secondary, connecting, and neighborhood roads are displayed using different colors to represent each road classification, e.g., interstate is displayed in white, state highway in magenta, neighborhood road in brown, etc. Detailed programs and subroutines are explained in the next chapter. Figure 3.3.1 illustrates the area map plotting of Norfolk, Virginia.

Some advantages of using TIGER files are:

- **time savings in map display** -- Originally, digitizing the map was attempted, but it has many difficulties in terms of accuracy and time consumption.
- **ability to easily display important locations on the electronic map** -- Since all these features are already built in the TIGER file, a computer code can be written and important locations such as hospitals, and police stations can be added to the map.
- **cost effectiveness** -- The cost for entire Virginia area is $3475.

Some disadvantages found were:

- **coding errors** -- Since a mis-coding error was found during the extraction of bus route in city of Norfolk, there are probably more mis-coding errors in the TIGER file.
- **data intensive** -- Much unnecessary information is contained in the TIGER file. Sometimes too much data is worse than too little.
- **inaccuracy** -- Differences were found between plotted map and real topology of the region.
3.3.2 Bus Route Map Display

The bus route map was constructed based on the data file of the area map (Record Type 1 and 2). This was time-consuming manual work. Since no specific data for bus route is prepared in the TIGER/Line file, all the street names which contain bus routes in the study area were extracted from the map and stored in a file. Then, a program was written to compare extracted bus route names and all the street names in record type 1 and 2. If these two names were the same, then the record which contains line segment coordination was saved to a file. Later the saved file was used to plot and overlay it on the area map. In the model, the bus route map was given a different color than the roads. Currently, a bus route (route number 1 in Norfolk) is overlaid. The same and time consuming methodology can be applied to the other bus routes. Figure 3.3.2 illustrates the zoomed area map and bus route 1 in Norfolk.

3.3.3 Bus Display

The direction of bus movement was depicted with isosceles triangle. Since bus can move any directions, it was not easy to find and display the right direction of bus movement. Thus, this task required the most complicated programming work in order to calculate the direction of each bus. The algorithm for development of this task is as follows. Whenever buses are plotted on the bus route, a program checks whether the tangent of the line segment in a bus route is different than the former one. According to the tangent value, the bus direction can be decided. The procedure for displaying bus direction is: 1) read line segment of bus route; 2) calculate the tangent of the line

MODEL DESCRIPTION
Figure 3.3.2 Zoomed Area Map and Bus Route
segment; and 3) draw the isosceles triangle. There are eight possible bus directions and these are illustrated in Figure 3.3.3. Whenever a bus moves from one position to next, the program repeats the above direction decision procedure. Each bus is colored red so that it can be easily identified.

3.3.4 Features of the Model

There are some unique advantages to this model. These are:

- It has menu pull-down capability for high user-friendliness environment.
- Each routine is well modularized so that it can be expanded easily.
- Graphic-based menu display screen can be applied development of other software packages.
- It is PC-based software so that it is cost-effective for the transit organization.
- Operation is similar to the commercial software so that a new user becomes accustomed to it easily.
- On-line help function provides quick reference for the new user.
- A warning sound alerts users who type the incorrect keyboard.
- A faster map display.
- It provides 256 color applications.
- All codes are written in C language.
Figure 3.3.3 Possible Bus Direction
3.3.5 Current Status of the Model

As it was pointed out in the literature review chapter, overall MIS automation in transit organization is a very complicated and labor-intensive project, and requires long periods of time to plan, design, and implement. For these reasons, the majority of function descriptions, which were made in the preceding section, are not yet incorporated into this model.

The functions currently implemented in this model are maps and zoomed area map display functions in info menu, one module in option, which changes screen background color, and quit function in file menu. All these functions are trouble-free.

Currently, bus location display is performed in the simulation mode. Various speeds are assigned to corresponding bus identification number for this purpose. Hence, faster buses can overtake the slower buses. Ultimately, this program should be run under with real-time bus location data from the AVL system at TRT. Hence, another algorithm to test the feasibility of running under the real-time situation is needed. This algorithm would require two personal computers to operate. The first computer performs the MIS function with simulation data as it was stated in the paragraph above, and then this information is transferred to the second computer via cable. The second computer interprets this data as if it were real-time data and performs the MIS functions with it. This algorithm should be thoroughly tested before implementation.
4.0 PROGRAM STRUCTURE

4.1 INTRODUCTION

Since the size of computer source codes were expected to be huge, the computer model programming philosophy was based on the more organized and more modularized code generation. In accordance with this philosophy, the computer model consists of three program modules and a header file.

The three computer program modules are composed of menu, busroute, grafutil module. The menu module addresses subroutine programs related to menu screen design. The busroute module is composed of the TIGER/Line-file-related subroutine programs and bus display simulation subroutines. The grafutil module consists of more detailed and technical subroutines.

The purpose of the header file is to avoid repetitive typing of the code, such as type definition and declarations. Since there is a preprocessor phase in C language, the programmer can direct the compiler in various ways. Inclusion of customized
header files is an example to save programmer's time and allow them to have more organized computer program structure.

The remaining sections in this chapter consists of descriptions of subroutines on each module. Figure 4.1.1 illustrates the program structure for the model.

4.2 MENU MODULE

The purpose of this module is to construct the user interface environment through the graphics-based menu screen.

4.2.1 sclayout () Subroutine

The main function of this subroutine is to divide computer screen into five windows and draw rectangular outlines in each window. This subroutine calls bar_menu() in the Grafutil module.

4.2.2 message_5 () Subroutine

The main function of this subroutine is to represent the on-line help message at the initial screen stage. It calls the bar_new() in the Grafutil module.
Figure 4.1.1 Program Structure
4.2.3 `topmenu()` Subroutine

The main function of this subroutine is to design the main menu options. The procedure for this task is to, first, allocate memory for `getimage` and `putimage` functions, which are built-in C library functions; then, to write the menu items.

This subroutine executes selected menu options through returned value from the sub-menu selection. The main-menu selection is operated either by moving the arrow keys of the keyboard or by holding the ALT key and pressing the first letter in each menu option. In arrow-key operation, after it reaches the last menu option, it is programmed to go back to the first menu option. Pressing ALT key with the first letter of main-menu key operation provides more convenient menu selection to users experienced with commercial software packages. When the user presses a key other than the designated the first letter of main-menu option, program generates warning sound. This subroutine calls other subroutines - `bar_new()`, `message_5()`, `submenu()`, `out_of_here()`, and `nfmap()`.

4.2.4 `submenu()` Subroutine

The main function of this subroutine is to operate the pull-down sub-menu display. The ESC key deselects the selected menu option and returns the screen to the initial display format. Users can operate the sub-menu selection either by using arrow keys or by typing the first letter (colored as red). When users want to see another sub-menu in other menu option, they use left and right arrow keys. Top-down operation is also designed for the user convenience. When the sub-menu reaches the
end of selection options, the program returns the selection to the first selection option. When users select a certain sub-menu option, the program returns the value to the top-menu and executes the further function. This subroutine calls other subroutines -opttime() and message_5().

4.3 Busroute Module

The purpose of this module is to plot the area map, bus route map, and bus.

4.3.1 nfmap() Subroutine

The main function of this subroutine is to plot the area map of Norfolk, Virginia. Two files must be opened. One file is opened for reading the binary screen image file, and the other file is opened for reading the minimum and maximum coordinate values of the Norfolk area. Various other programs, which deal with the TIGER/Line fire, were written to produce the screen image file. The followings procedure briefly describes the binary-screen-image file construction methodology; 1) read all the line segment coordinates in the TIGER/Line file; 2) find the minimum and maximum coordinates; 3) read again the line segment coordinates and plot them; 4) check if they have curved line segments. If they have them, go to the curve file whose extension file name is .f42. Then, open this file and keep plotting road segments; 5) during the plot of the road segments, check the road classification (interstate, state highway, neighborhood, etc.).
Then, assign different colors to each line segment, and; 6) check if file point reaches the end of the file. If so, then stop the execution. Otherwise, repeat the procedure. Figure 4.3.1 illustrates the flow chart of the TIGER/Line file plotting algorithm.

After area map plotting is complete, the computer screen itself is saved and written as a binary file. In order to achieve this, getimage and putimage functions in C library are employed. Since the memory size of the PC is limited, small pieces of the screen (2 by 430) are consecutively saved into a file. Hence, whenever program needs to display the area map, the program just reads a saved-file instead of reading the TIGER/Line file and re-plotting. This technique greatly alleviates time-consuming area map plotting. Formerly, it took about two minutes to plot two megabytes of data on a IBM 80386 compatible machine, now it takes only three seconds. Since a minute of waiting time in front of computer is long enough, saving two minutes is a big achievement. This image file saving technique can be applied to any other similar tasks, such as retrieving complicated drawings, plotting time saving, etc. This subroutine calls bus_on rt1() subroutines.

4.3.2 get_or_not() Subroutine

The main function of this subroutine is to assign new location of the bus movement to the array as memory allocation so that it can be used in the getimage and putimage functions. No other subroutines are called.
Figure 4.3.1 Area Map Plotting Algorithm
4.3.3 draw_route() Subroutine

The main function of this subroutine is to draw the bus route. Before the TIGER/Line file is utilized in this model, this subroutine was to demonstrate imaginary bus routes. Each route can be plotted in 16 different colors. The number of nodes in a route is unlimited.

Now, the TIGER/Line file is utilized and specific bus route is extracted from this file. The bus route extraction procedure is: 1) take the bus route names from the map and store those names into a file, 2) read the TIGER/Line file and compare the name, 3) if the name is the same, then save the coordinates of that link into another file. Figure 4.3.2 is the flow chart of the bus route extraction algorithm. This subroutine calls another subroutine - bar_new().

4.3.4 bus_on Rt1() Subroutine

The main function of this subroutine is to plot buses on the bus route. This subroutine requires the most complicated programming works. Three read-only files are opened. These are: 1) nfroute.tmp -- All the coordinates for bus route and assigned speeds is stored in this file, 2) mnmxnxrd.dat -- The minimum and maximum coordinates values of the city of Norfolk are stored in this data file. The purpose of this file is to map the plotted area map into the allocated information window in the computer screen. 3) mnmxnfdt.dat -- The maximum and minimum coordinates for downtown Norfolk are stored in this file for the purpose of plotting the zoomed area of downtown Norfolk.
Figure 4.3.2 Bus Route Extraction Algorithm

PROGRAM STRUCTURE
The procedure for developing this subroutines is as follows: 1) draw the bus route first, 2) initialize bus characteristics according to speed, starting link, tangent value, etc. 3) calculate the tangent value, considering the eight possible directions. The detailed description about bus direction was made in former section 3.3.3. 4) since the real-time application is not implemented yet, bus location determination on each road segment is conducted by the calculation of link tangent value, link length calculation, and assigning the speeds on each bus.

This subroutine calls other subroutines - map_r2w(), draw_route(), get_or_not(), pt(), zoom_a, map_route(), and draw_route().

4.3.5 dt_nfmap() Subroutine

The main function of this subroutine is to plot the zoomed downtown Norfolk. Two files are opened. These files are the screen image file of downtown Norfolk, and its minimum and maximum data file. The plotting procedure is the same as nfmap() subroutine. No other subroutine is called.

4.3.6 getminmax() Subroutine

The main function of this subroutine is to obtain the minimum and maximum coordinates of the TIGER/Line file. The algorithm is: 1) initially assign a very small value, such as 0, to maximum and a very large value, such as 1000000000, to
minimum, 2) compare each x and y coordinate with the minimum and maximum values, 3) if maximum value is less a certain value, then assign that value as the maximum value. Otherwise, move on to the next coordinate value. 4) repeats until the file point reaches the end of file. Determining a minimum value follows the same procedure except: If minimum value is greater than a certain coordination value, then assign that value as the minimum value. Figure 4.3.3 is the flow chart of the minimum and maximum value obtaining algorithm. No other subroutines are called.

4.3.7 selection() Subroutine

The main function of this subroutine is to select the different road classification. Switch-Case clause is mainly utilized in this subroutine. No other subroutines are called.

4.3.8 dt_plotting() Subroutine

The main function of this subroutine is to plot the pre-defined zoomed downtown area of Norfolk. Since the mouse function is not incorporated into the model, only the pre-defined area can be zoomed. The procedure for this task is: 1) find the minimum and maximum coordinate values of downtown Norfolk, 2) plot the area based on the minimum and maximum coordination values. The coordinates that locate the outside of the minimum and maximum will not be plotted. Basically, this subroutine follows the same procedure as the subroutine nfrmap() excepting the minimum and
Assign Small Value to Initial Maximum Value

Read Coordinate Value in TIGER/Line file

coordinate value > max

No

Yes

Assign Coordination Value to Maximum Value

Keep the Original Maximum Value

EOF?

Write the Current Maximum Value to a File

Stop

Figure 4.3.3 Minimum and Maximum Algorithm
maximum coordination values. Two data files, nfroute.f41 and nmnxnfdt.dat, are opened for read-only purposes. No other subroutines are called.

4.4. **GRAFUTIL MODULE**

The purpose of this module is to provide utility functions for the graphics display.

4.4.1 rect() Subroutine

The main function of this subroutine is to draw the rectangle. No other subroutines are called.

4.4.2 menu_edit() Subroutine

The main function of this subroutine is to perform the background color change in the computer screen window. This subroutine calls menu_e(), which performs the actual window background color editing.
4.4.3 menu_e() Subroutine

The main function of this subroutine is to edit the background color of the computer screen window, when the user selects screen color sub-menu under the option menu. When the user presses the TAB key, it switches the window to select. Then, arrow keys are used to see the color. Whenever they press the arrow key, it changes its color and let the user to select any color background. When the user presses the ENTER key, it saves that color. As long as a computer is not re-booted, screen color remains the same. When a computer is re-booted, it goes back to the original color background. This subroutine calls other subroutines - rect(), bar_new(), menu_e(), and sclayout().

4.4.4 zoom_a() Subroutine

The main function of this subroutine was to zoom the area map. When the user presses the 'z' character in keyboard, it zoomed in. The zooming operation was based on the center of the map. Since screen image file is utilized, this subroutine is not included in the model.
4.4.5 map_r2w() Subroutine

The main function of this subroutine is to match the TiGER/Line file coordinate values and computer screen size. The size of this subroutine is small but it is a very important subroutine. No other subroutines are called.

4.4.6 map_route() Subroutine

The main function of this subroutine is to match the bus route file coordination values and computer screen size. This subroutine calls the map_r2w().

4.4.7 bar_new() Subroutine

The main function of this subroutine is to provide the window background colors other than basic 16 colors. Expanded 256 (16 by 16) colors are possible from this subroutine. No other subroutines are called.

4.4.8 setport() Subroutine

The main function of this subroutine is to set the window size so that outside of window size will be eliminated. No other subroutines are called.
4.4.9 ptime() Subroutine

The main function of this subroutine is to incorporate the clock time into the window. No other subroutines are called.

4.4.10 pt() Subroutine

The main function of this subroutine is to ensure clock keeps running while some other routines are being executed.

4.4.11 out_of_here() Subroutine

The main function of this subroutine is to quit the model and return the cursor back to the c> prompt.

4.4.12 color_table() Subroutine

The main function of this subroutine is to mix the colors and provide 256 colors to the application. This subroutine calls bar_new().
5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The goal of this research was to develop an automated MIS that processes a large amount of real-time data into an easy to access, easy to understand, easy to use format in order to maximize the capability of the current AVL system at TRT. The development of a graphics and GIS-based model will improve controllers working environment due to a user-friendly interface and interactive screen display. In this way, the model makes manageable the tremendous amount of real-time information available to the controller by making it much easier for controllers to visualize the system. The model developed affords TRT the opportunity to make significant improvement in their AVL system in terms of on-time performance, customer satisfaction and optimal use of the equipment.

In turn, maximum use of AVL system has application to other aspects of APTS in the area of Smart vehicle, Smart Travel and Smart Intermodel concepts. The major components of AVL --operations plus communication -are basic to smart vehicles in
general. In the area of Smart Travel, trip planning will be made easier with when AVL system is used to its full potential. Dependable transit AVL system has smart intermodal implications as well. For instance, buses on a road system can act as a vehicle probe sending non-transit related data as well to traffic control for access by private vehicles.

5.2 RECOMMENDATIONS

To complete an APTS project, several opportunities for expanding this MIS model are identified. These include real-time operation, analysis function expansion, mouse integration, program conversion to C++, GIS capability expansion, scheduling, routing, DSS development, look-ahead functions development, and PAXIS integration.

Since the development of MIS model was based on the simulated data, real-time application is the core ingredient for effective system. The first step toward implementing a real-time MIS is to identify the data flow (input/output) of the current TRT's AVL system. To complete this, interviews and meetings with operational personnel at TRT are necessary.
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**GLOSSARY OF ACRONYMS**

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<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>APTS</td>
<td>Advanced Public Transportation System</td>
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<tr>
<td>AVL</td>
<td>Automatic Vehicle Location</td>
</tr>
<tr>
<td>AVLC</td>
<td>Automatic Vehicle Location and Control</td>
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<td>BATA</td>
<td>Brockton Area Transit District</td>
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<tr>
<td>CD-ROM</td>
<td>Compact Disk-Read Only Memory</td>
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<td>DOT</td>
<td>Department of Transportation</td>
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<tr>
<td>DSS</td>
<td>Decision Support System</td>
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<td>DTA</td>
<td>Duluth Transit Authority</td>
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<tr>
<td>EBCDIC</td>
<td>Extended Binary-Coded Decimal Interchange Code</td>
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<tr>
<td>F&amp;M</td>
<td>Fishbache and Moor Global Communication</td>
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<td>FIPS</td>
<td>Federal Information Processing Standard</td>
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<td>GIS</td>
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<tr>
<td>IMPS</td>
<td>Integrated Management Processing System</td>
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<td>IVHS</td>
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<td>LORAN</td>
<td>Long Range Aid to Navigation</td>
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<tr>
<td>MIS</td>
<td>Management Information System</td>
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<td>MTA</td>
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<td>O-D</td>
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<td>Passenger Information System</td>
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<tr>
<td>PMS</td>
<td>Personnel Management System</td>
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<tr>
<td>TIGER</td>
<td>Topologically Integrated Geographic Encoding and Referencing System</td>
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VITA

Sanghoon Bae was born on August 27, 1964 in Pusan, the second largest city in Korea. He enrolled the Pusan National University (PNU) with a full scholarship in the fall of 1983. After his sophomore year in the university, he joined United States Army in Korea as Korean Augmentation Troops to the U.S. Army. During his service in the Army, he received an Army Commendational Medal, and two Army Achievement Medals. He was discharged in 1988, and resumed his study at the university. He received B.S. degree in civil engineering from PNU in 1990.

In the summer of 1990, he came to United States for graduate study. He enrolled the department of civil engineering (transportation division), University of Florida (UF). After a year of study in UF, he transferred to the Virginia Polytechnic Institute and State University (VPI&SU).

After his M.S. degree, he plans to study for a Ph.D. at the VPI&SU. Bae is versed in transit management information systems, automatic vehicle location systems, and computer applications in transportation. He is also interested in IVHS-related research area, specifically in advanced transportation management system.

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