NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Report 9

Modular Approach to On-Board Automatic Data Collection Systems

TRANSPORTATION RESEARCH BOARD
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Modular Approach to On-Board Automatic Data Collection Systems

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AREAS OF INTEREST

- Administration
- Planning
- Forecasting
- User Needs
- Operations and Traffic Control
- (Public Transit)

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TRANSPORTATION RESEARCH BOARD
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Administrators, engineers, and many others in the transit industry are faced with a multitude of complex problems that range between local, regional, and national in their prevalence. How they might be solved is open to a variety of approaches; however, it is an established fact that a highly effective approach to problems of widespread commonality is one is which operating agencies join cooperatively to support, both in financial and other participatory respects, systematic research that is well designed, practically oriented, and carried out by highly competent researchers. As problems grow rapidly in number and escalate in complexity, the value of an orderly, high-quality cooperative endeavor likewise escalates.

Recognizing this in light of the many needs of the transit industry at large, the Urban Mass Transportation Administration, U.S. Department of Transportation, got under way in 1980 the National Cooperative Transit Research & Development Program (NCTRP). This is an objective national program that provides a mechanism by which UMTA's principal client groups across the nation can join cooperatively in an attempt to solve near-term public transportation problems through applied research, development, test, and evaluation. The client groups thereby have a channel through which they can directly influence a portion of UMTA's annual activities in transit technology development and deployment. Although present funding of the NCTRP is entirely from UMTA's Section 6 funds, the planning leading to inception of the Program envisioned that UMTA's client groups would join ultimately in providing additional support, thereby enabling the Program to address a large number of problems each year.

The NCTRP operates by means of agreements between UMTA as the sponsor and (1) the National Research Council as the Primary Technical Contractor (PTC) responsible for administrative and technical services and (2) the American Public Transit Association, responsible for operation of a Technical Steering Group (TSG) comprised of representatives of transit operators, local government officials, State DOT officials, and officials from UMTA's Office of Technical Assistance.

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Research projects addressing the problems referred from UMTA are defined by panels of experts established by the Board to provide technical guidance and counsel in the problem areas. The projects are advertised widely for proposals, and qualified agencies are selected on the basis of research plans offering the greatest probabilities of success. The research is carried out by these agencies under contract to the National Reserch Council, and administration and surveillance of the contract work are the responsibilities of the National Research Council and Board.

The needs for transit research are many, and the National Cooperative Transit Research & Development Program is a mechanism for deriving timely solutions for transportation problems of mutual concern to many responsible groups. In doing so, the Program operates complementary to, rather than as a substitute for or duplicate of, other transit research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, or the Urban Mass Transportation Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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FOREWORD

By Staff
Transportation Research Board

This report addresses the potential for using a modular approach to automatically collect data on board transit buses. Recommended technical specifications for various modular units, such as passenger counters and fare collectors, and for the totally configured system are provided. Guidelines are included to aid the practitioner in evaluating the utility of automating data collection activities and to assist in the design and implementation of an automatic data collection system based on transit agency needs. These guidelines are applicable with or without the use of separate modular components. The modular approach, however, will permit step-by-step implementation and ease in tailoring a system to an agency's present needs without greatly limiting future options. A greater degree of flexibility to update systems because of improvements in individual components is also provided through the modular approach. The report will benefit transit agency personnel concerned with the collection and use of bus passenger and fare data, and those involved with the physical implementation and procurement of equipment. Manufacturers and suppliers will benefit by considering the recommended specifications for the modular approach and individual components in the development of data collection equipment.

Current economic conditions coupled with a continuing need to provide operational efficiency require that a transit system improve productivity while making the best use of limited resources. Emphasis on improving route productivity places an increasing importance on good ridership and schedule adherence data so that responsible decisions on routing and scheduling can be made. In addition, because farebox revenue is important to the stability of transit systems, accurate fare payment information by fare category is needed to calculate the effects of alternative fare adjustment proposals, including an analysis of the equity of fare structures.

Currently the most predominant form of gathering ridership information is collecting data manually. Data gathered in this manner are expensive to collect and process, limited in scope, and usually infrequent. Fare and revenue data are generally available only on a systemwide basis, and special efforts that usually rely on driver participation or cumbersome fare-box handling are required to collect route-level, fare-payment information.

In recent years, a few transit systems have turned to automated methods. Although, in general, transit properties that have used these automated systems have been satisfied, widespread use has not occurred. Some reasons why many transit systems have not implemented automated technology include: (1) a general lack of understanding of the options available in terms of hardware to provide the information; (2) an uncertainty as to how much of what type of hardware and software is needed; (3) the lack of commitment by transit management to implement the technology; (4) the difficulty in quantifying benefits, together with costs, and in determining the net benefits to the transit system; and (5) the lack of standardization of functional requirements of the technologies, which, in turn, dampens the availability of hardware and discourages manufacturer participation.

Under NCTRP Project 39-1, "A Modular Approach to On-Board, Automatic Data Collection Systems," The MITRE Corporation investigated and developed requirements and implementation guidelines for an automated on-board passenger/fare data collection system using a modular equipment configuration. The guidelines detailed in Appendix I for evaluating the utility of automating a data collection system and for designing and implementing such a system, however, are applicable with or without the modular concept. Recommended specifications, especially performance specifications, for individual hardware components found in Appendix II will also be of benefit with or without the modular concept. The use of the report will greatly assist transit properties in the various aspects of collecting and using passenger/fare type data obtained from either a totally automated or a partially automated system installed on-board transit buses.

The modular configuration that has been investigated and suggested in this report is intended to provide flexibility to transit agencies and encourage competition in the marketplace. A truly modular system permits step-by-step implementation, which may be required by budget constraints or perceived present needs, together with the capability to accommodate unforeseen future data requirements or to update modules without the need to redesign or purchase an entirely new system. However, because a universally applicable modular approach is not now standardized, implementation of the concept will require agreement among at least several transit agencies or manufacturers, or preferably both. Specific agreement will also be necessary on a standard interface to allow the greatest degree of flexibility in the selection of various modules. Recommendations for the technical requirements of individual units and the adoption of a suggested interfacing connection are set forth in the report with the intent to provide a basis for such agreement.

CONTENTS

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The research reported herein was performed under NCTRP Project 39-1 by the Transportation Systems Development Department, The MITRE Corporation.

Mr. Lawrence E. Deibel, Group Leader of the Management and Operations Group, was the principal investigator. The other author of this report is Ms. Barbara Zumwalt, Member of the Technical Staff.

The work was performed under the direction of Mr. Deibel with the assistance of Ms. Zumwalt. Mr. George Kachadourian, Member of the Technical Staff, Mr. Rex Klopfenstein, Member of the Technical Staff, and Mr. Peter Wood, Department Head, also contributed to the work. A software cost analysis was performed by Ms. Margaret Bisignani, Member of the Technical Staff, and Mr. John Seminerio, Technical Associate of the Economic Analysis Group, The MITRE Corporation.

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MODULAR APPROACH TO ON-BOARD AUTOMATIC DATA COLLECTION SYSTEMS

SUMMARY

During the past decade, several North American transit agencies have implemented automated data collection systems to gather ridership, fare revenue, and schedule adherence statistics necessary for effective operations management. The experiences of these transit agencies have shown that on-board automatic data collection systems can meet transit management information needs, improve data accuracy and availability, and reduce data collection costs.

The research conducted under NCTRP Project 39-1 investigated three critical aspects related to future widespread implementation of automatic data collection systems:

1. The potential for standardizing system requirements for automatic data collection system hardware and software.
2. Transit agency requirements for designing, selecting, and implementing a cost-effective automated data collection system.
3. Constraints to successful implementation of automated data collection systems.

This report documents in Chapters One through Four the activities and findings of the research regarding a standardized modular system and the deployment/application constraints. Appendix I contains an implementation manual that serves as a practitioner's guide to procedures for designing, selecting, and implementing an automated data collection system. Appendix II contains detailed technical specifications that may be used to assist in the procurement process.

In general, the research found that despite reliability and delivery problems encountered with early installations of automatic data collection systems, transit agencies and manufacturers show more interest in on-board automatic data collection systems than is generally perceived. The research also confirmed that automated data collection systems offer advantages over manual data collection systems in many transit applications. These advantages include (1) improved data turnaround time, (2) lower data collection costs, and (3) better quality data. At larger transit agencies, the annualized cost of an automated system approximates the cost of checker salaries alone.

The following summarizes the findings according to the three critical areas associated with implementing automatic data collection systems.

Standardized System Requirements

The research presumed a modular approach to the design of an automated data collection that is intended to standardize the various functional units of the system so that each unit (or module) is fully compatible with other units regardless of the manufacturer.

It was established that such a system is feasible based on the similarity of management information data requirements among transit agencies, the penetration of microprocessor technology in the transit industry, and the availability of standardized electrical and mechanical interfaces to link the modules. A computer bus (a set of address, data, control, and power circuits arranged in a standardized manner and operating under a strict set of data communication rules) known as STD BUS was chosen as the standardized link for the system because it is well established, widely recognized, and supported by many suppliers. (The STD BUS is supported by multiple sources including the STD Manufacturers Group (STDMG). STDMG has prepared and makes available to interested parties, a document titled, "STD BUS, Specification and Practice." STD BUS is recognized as a defacto industry standard without any trademarks, copyrights, or patents restricting its use. STD BUS also provides the foundation for a proposed Institute of Electrical and Electronics Engineers (IEEE) Standard P961. The STD BUS term is used throughout the report because this term will remain more widely recognized, at least, until the IEEE standard is fully developed and adopted.) Technical specifications based on this standard were developed. Developments in data communications standards, such as the Digital Data Bus (D^2B), were examined and found to be suitable to the data collection functions addressed in this research. As emerging standards become accepted and hardware incorporating them is available, a reassessment of the standards underlying this research should be undertaken.

The standardized data collection system consists of 13 modules. The modules provide the electronic means to gather passenger, fare, and schedule data, to obtain the information required to define and identify data records, and to provide information storage, control, and retrieval functions. The nucleus of the modular system is a microprocessor based unit called a system controller. Each module located on the vehicle is plugged into the system controller via the STD BUS and is required to communicate specified data. Provided these conditions are met, a transit agency may choose to implement any variation of the individual modules.

System Design and Implementation Issues

The research examined the cost impacts of alternative automatic data collection system configurations representing several significant system design and implementation issues including:

- *Signposts*—A comparison of a data collection system with two signposts per route to a system without signposts revealed that costs were nearly equivalent. The choice between the two alternatives depends largely on the reliability of dispatching procedures and driver involvement to provide data identification functions.
- *Fare data collection equipment*—The cost of adding an electronic registering farebox roughly approximates the unit cost of the on-board equipment associated with passenger counting equipment. Only the incremental cost for upgrading electronic fareboxes (about $500 per farebox) on buses instrumented with data collection equipment should be attributable to the data collection system. Purchases of electronic fareboxes must be justified on grounds other than data collection benefits.
- *Standardized software*—Standardized, user friendly software offers the potential for reducing the initial investment costs for an automated data collection system and the labor costs associated with data analysis. Standardized software would be most beneficial to small transit agencies because software development and processing costs represent a sizable burden in these applications.
- *Dedicated computers for data processing*—The analysis indicated processing costs are sensitive to the type of computer facilities used and that dedicated computer

facilities may be cost-effective. An in-house mainframe is likely to reduce costs at large transit agencies compared to time-share arrangements. Medium-size systems can achieve savings with microcomputer or minicomputers.

Step-by-step guidelines for selecting and implementing an automatic data collection system were developed in this research project. Two activities in the evaluation process merit careful consideration because the results can influence the outcome of the cost-effectiveness evaluation. These activities are (1) estimating equipped bus requirements and (2) estimating the potential benefits of automatic data collection systems.

The number of equipped buses required by a transit agency depends on its sampling strategy for data collection, cost considerations, dispatching procedures, and implementation plans. Although valid approaches for estimating equipped bus requirements range in complexity, simplified approaches are recommended for system sizing. The two techniques included in the implementation manual generated equipped bus requirements close to 10 percent of the fleet for a typical transit agency.

The potential benefits of automated data collection systems—cost savings in data collection functions as well as indirect benefits from improved and more timely data—can be significant, but are difficult to estimate. Comparisons of automated data collection systems with a manual system should be based on similar data collection activities for both systems, not the current level of effort. The indirect benefits such as productivity and efficiency improvements and enhanced management decision-making are very difficult to monetize. A qualitative assessment of the potential for achieving these benefits is recommended.

Barriers to Implementation

This research identified numerous labor, management, and institutional issues that can hinder successful implementation of automated data collection systems. Because transit agencies with automated data collection systems have not experienced significant problems, it appears that the barriers can be minimized by comprehensive planning to include training, coordination, negotiation, etc. The most important step is early involvement of all departments and personnel who would assume the functions and responsibilities. Serious consideration should also be given to phased implementation. Given the learning and start-up problems inherent in implementing a complete system, any inefficiencies associated with a phased implementation are deemed justified.

The most critical element in successful implementation will be coordinating equipped bus assignments with current dispatching operations. The cooperation of dispatchers, bus hostlers, and drivers is essential. Modifications to current dispatching and hosteling practices may be required.

Conclusions and Suggested Research

This research shows that hardware standardization is technically feasible and can produce significant benefits. It also indicates that substantial benefits can be obtained for standardized software and the application of dedicated computer facilities. Ultimately greater reductions in the overall cost of automated data collection may be achieved through software improvements and changes in data processing functions than through hardware improvements (cost and otherwise).

Efforts to standardize equipment and improve data analysis functions should proceed simultaneously. Software development efforts should be directed at small and medium-sized transit systems because these systems are most affected by the cost of software, and the potential benefit of reduced costs appears to offer the best opportunity for improving the economics of automated systems at these sites.

CHAPTER ONE

INTRODUCTION

PROBLEM STATEMENT

During the past decade several North American transit agencies have implemented automated data collection systems to gather the passenger and schedule adherence statistics necessary for effective operations management. While the data collection systems in use today are experimental in nature, operator experiences have shown that on-boad automatic data collection systems have significant potential. They can meet transit management information needs, improve data accuracy and availability, and reduce data collection costs.

Many transit agencies in the United States are looking for cost-effective means to collect data, but automated data collection systems have not been used extensively. Transit agencies have been reluctant to make a commitment to automated data collection technology for several reasons:

1. The basic building blocks for automated data collection systems are available, but purchasers face a confusing array of options with varying costs and disparate capabilities that often are incompatible with one another.
2. The type and amount of hardware and software necessary to provide different levels of management information are not well understood.
3. Many of the benefits are intangible or difficult to quantify and it is difficult to determine the net benefit or cost of automated data collection systems.
4. Equipment reliability and accuracy improvements have been hindered by the lack of standardized functional requirements.

Each transit agency pursuing an automated data collection system has developed its own specifications. As a result, each data collection system has unique technical features, data formats, or recording requirements for performing essentially the same functions. The number of passenger counter system designs nearly equals the number of systems implemented. The systems currently in use lack one or more of the elements necessary for a comprehensive data collection system. In fact, no transit agency has yet incorporated both a fare and revenue data collection component and a passenger counting component into its system. However, efforts to develop an integrated fare and passenger counting system are under way at Metropolitan Atlanta Rapid Transit Authority and Kalamazoo Metro Transit System.

RESEARCH OBJECTIVES

The general objectives of this research are to develop modular requirements for an automated, on-board passenger/fare information collection system and develop a set of practical guidelines that transit agency managers could follow in selecting and implementing the system. An ancillary objective of the project is to stimulate the implementation of automated data collection systems by providing a single-source and easy-to-use guide for selecting and implementing automated data collection systems.

RESEARCH APPROACH

The research to meet these objectives comprised three major activities:

1. *Determining modular requirements of on-board automatic data collection systems.* A review of transit agency data needs and the state of the art of automated data collection technology was completed using various information sources, including published technical reports and manufacturer specifications. Based on this review, the modular hardware requirements to provide information for various levels of decision-making were determined. Draft functional specifications were developed and reviewed by transit agency experts and equipment suppliers. Technical specifications were also prepared. An ancillary effort defined a modular approach to software requirements.
2. *Developing implementation guidelines.* This research activity included a review of current practices and potential new approaches for selecting hardware modules, determining software needs, determining the amount of equipment required, and estimating the costs and benefits of automated data collection systems. A draft implementation manual outlining step-by-step procedures for undertaking these functions was prepared. Transit agencies in Seattle and Norfolk tested the validity and usability of the procedures. The manual was revised based on the results of the site validations.
3. *Identifying deployment/application constraints.* Institutional barriers to successful implementation of automated data collection systems were identified and possible ways to overcome the problems were documented. An electronic spreadsheet was used to investigate the cost sensitivity of unit cost assumptions, key transit agency characteristics, and data collection system configurations.

SCOPE OF RESEARCH

Much of the information resulting from this research is presented in the framework of the modular, on-board automatic data collection system defined during the research effort. However, transit agencies need not adopt a modular design in order to apply the results. The functional capabilities of the modular system are similar to those of existing hardware. The modular approach is a new concept in assembling available hardware rather than a new hardware development.

This research project does not explicitly address data collection for real-time vehicle dispatching, revenue and fiscal auditing, and special user analysis. Those applications would require customized management information systems to meet site-specific needs. The data needed for the applications could, however, be provided by an appropriately configured automated data collection system.

The implementation manual and technical specifications developed in this research are intended to assist transit agencies in evaluating the feasibility of automated data collection systems and to encourage development of an industry standard for these systems. The procedures and specifications do not represent policies of the Urban Mass Transportation Administration.

SUMMARY OF PROJECT DOCUMENTATION

The body of this report provides an overview of the proposed modular data collection system, the benefits and costs of automated data collection, and the implementation issues associated with the installation of these systems. Key findings of the research are described in Chapter Two. Major issues related to the application of automated technology are described in Chapter Three. Chapter Four contains conclusions and suggests future research.

Appendix I contains an implementation manual designed to assist transit agency personnel in the design, selection, and implementation of an on-board, automatic passenger/fare data collection system. It includes an overview of the activities necessary to assess the potential application of automated data collection at a bus transit agency. Worksheets provide a step-by-step guide for the following major activities:

- Establishing transit agency goals and objectives for automated systems.
- Selecting system hardware components.
- Determining software requirements.
- Estimating the amount of equipment required.
- Estimating the costs of the system.
- Determining the net benefits of the system.
- Assessing institutional barriers.

Practical implementation procedures are discussed in the concluding chapter of Appendix I. The appendix also contains a tutorial on the functional requirements of individual components and typical system configurations as background information for transit personnel not familiar with the technology.

Appendix II provides technical information regarding the hardware for on-board, automatic data collection systems. The functional requirements for a modular system are described. Detailed technical specifications for each module are presented to assist in the procurement process. Data format and storage requirements associated with the system are also presented.

CHAPTER TWO

FINDINGS

This chapter reviews the current status of automated data collection system applications in the United States, Canada, and Europe, and discusses the general benefits of automated methods of data collection. The modular system developed as part of the research effort is defined, and the cost, benefits, and limitations of this approach are presented.

STATE OF THE ART

Despite reliability and delivery problems encountered with early installations, transit agencies and manufacturers continue to show interest in on-board automatic data collection systems. The state-of-the-art review in this research found the industry to be healthier than is generally perceived.

Current Installations

In recent years eight North American transit agencies have successfully implemented on-board automated data collection systems (*1*). A brief description of these installations is provided in Table 1. At least five new U.S. systems are being considered—in Jacksonville, Denver, Tucson, Atlanta, and Chicago. Passenger counting technology has also been implemented in conjunction with comprehensive automatic vehicle monitoring systems at several other transit agencies—in Cincinnati and Los Angeles (inactive); in Windsor, Ontario, and Toronto (active); and in Hull, Quebec, and Rochester, New York (being installed).

The systems are not limited to North America. Several major European cities have installed stand-alone passenger counting systems or incorporated the technology into automated vehicle monitoring systems. Appendix I provides a compendium of installation sites and of the equipment installed at these sites.

Equipment Suppliers

During the 1970's many firms entered the market for automated data collection equipment. Some companies, unable to

Table 1. North American automated data collection systems.

Transit Agency and Implementation Date	Number of Units	Sensors	Storage and Transmission	Identification Data	Agency Contact
Calgary Transit Alberta, Canada 1982	5 Counters (Demonstration)	Photoelectric Beam	Solid-State to Portable Unit	No bus stop referencing	Keith West 403-268-1625
COTA Columbus, OH 1982	6 Counters 8 Signposts	Photoelectric Beam	Magnetic Tape Cassette	Match distance and signpost files	Bruce Bowles 614-275-5800
Kalamazoo Metro Transit System Kalamazoo, MI 1982	20 Counters 30 Signposts	Photoelectric Beam	Magnetic Tape Cassette	Match distance and signpost files	Charles Richards 517-322-1090
MTC Minneapolis/St. Paul 1979	44 Counters	Photoelectric Beam	None	Drivers manually record counts from display	Ray Neetzel 612-221-0930
OC Transpo Ottawa, Ontario 1978	65 Counters	Photoelectric Beam	Solid-State to Portable Unit	Schedule files matched with counts	Joel Koffman 613-741-6440
Quebec City Quebec City, Quebec 1980-1982	13 Counters	Photoelectric Beam	Solid-State to Portable Unit	No stop referencing	Pierrie Bouvier 418-627-2351
Seattle Metro Seattle, WA 1978-1983	56 Counters 250 Signposts 50 New Counters to be Purchased	Switch Mat	Solid-State to Portable Unit	Match distance and signpost files	Thomas Friedman 206-223-4705
TRI-MET Portland, Oregon 1983	50 Counters	Photoelectric Beam	Solid-State to Infrared Buffer	Match distance and signpost file; backtagging of time from receiver clock	Douglas Allen 503-238-5831

Reference: "An Assessment of Automatic Passenger Counters," Multisystems, Inc., DOT-I-82-43, September 1982.

develop an adequate market for their product despite extensive research and development, are no longer supplying equipment (*2*). Firms that have withdrawn from the North American market include General Motors, AB Almex, Dyniman, and Prodata.

Numerous domestic and foreign firms still supply equipment that can be used for automated data collection in transit applications. The available products fall into one of four groups:

1. Complete passenger counter systems.
2. Automated vehicle monitoring systems.
3. Electronic fareboxes.
4. Self-service fare equipment.

These remaining firms have focused their efforts on technology improvements. Counter accuracy and reliability have been improved with new sensor designs. New technology options have been introduced, such as bubble memory for data storage and infrared data retrieval. Fare collection equipment improvements based on microprocessor technology have been introduced by U.S. and European firms.

In addition to technology improvements, many firms have begun to adopt a modular approach in their own designs. These firms offer a menu of data collection subsystems that can be integrated into an individually tailored on-board system. Other firms offer technology options for various components.

A list of current equipment suppliers is provided in Table 2. More detailed information on product characteristics is contained in Appendix I.

BENEFITS OF AUTOMATED DATA COLLECTION

Significant management benefits can result from introducing an automated data collection system—either the modular system proposed here or a commercially available system. The major benefits of automated data collection are described in the following sections.

Improved Data Turnaround

Data from an automated system will generally be available sooner than the data from a manual data collection system and as a result transit decision-making can be more timely. Data collected from an automated system are available for immediate processing, while data collected manually (e.g., traffic checker forms) frequently require considerable preprocessing (keypunching or optical character scanning) that can delay processing by

Table 2. Automated data collection equipment suppliers.

Automated Passenger Counting Systems	Key Product Features
Dynamic Controls Corporation South Windsor, Connecticut	Switch mat sensors, signpost interface, solid state memory, umbilical data transfer.
Etrometa BV* Gorredijk, The Netherlands	Inductive loop mat sensors, signpost interface buble memory.
London Mat Industries London, Ontario	Switch mat sensors.
Pacena* Burnaby, British Columbia	Switch mat sensors, signpost interface, solid state memory, portable disk unit.
Red Pine Instruments, Ltd. Denbigh, Ontario	Infrared beam sensors, solid state memory, portable disk or infrared data transfer.
Urban Transportation Associates Cincinnati, Ohio	Leases equipment and provides processing and analysis support.
AVM Equipment and Signposts	
AVM Systems, Inc. Fort Worth, Texas	Switch mat sensors, signpost transmitters, radio data transmission.
General Railway Signal Rochester, New York	Switch mat sensors, wayside transponders with on-board interrogators, real time radio communications.
Electronic Farebox Systems	
General Farebox, Inc. Chicago, Illinois	Electronic registering farebox, solid state memory, infrared data transmission.
Cubic Western San Diego, California	Electronic registering farebox w/electronic pass reader.
Self-Service Components	
AB Almex* Stockholm, Sweden	Ticket Issuing and Cancelling Equipment, cassette storage.
Associated Electronics* Morley, Western Australia	Ticket Issuing and Cancelling Equipment, Drop Type Farebox, solid state memory, portable or radio data retrieval.
Control Systems, Ltd.* Middlesex, England	Ticket Issuing and Cancelling Equipment, solid state memory, umbilical or radio data retrieval
Micro System Design, Ltd.* Dorset, England	Ticket issuing and cancelling equipment, pass readers, solid state memory, or radio data retrieval.
Ticket Equipment, Ltd.* Cirencester, England	Ticket issuing and cancelling equipment, solid state memory.

*No operational U.S. systems.

the host computer. For example, data are typically available from Seattle's automated system within one week from the date of collection from the on-board system. In contrast, delays up to one year have been reported in the manual system in Los Angeles (*1*, p. 38).

Lower Data Collection Costs

Given a comparable data collection effort, the annual cost of an automated system will generally be less than that for a manual system. Figure 1 compares the annual cost of a representative automatic data collection system (consisting of a passenger counter and employing on the average two signposts per route) with the annual costs associated with a manual system. Previous research concluded that on a strict economic basis, automated systems may not be cost effective for small transit agencies with less than 100 peak hour vehicles (*1*, p. 53). The costs shown in Figure 1 show that the annual cost of an automated system for the small transit agency would be comparable to the total cost for an equivalent manually supported information system. However, small systems frequently require little or no information processing to make limited use of the data. The fact that the automated cost significantly exceeds the wages of manual checkers at agencies with fewer than 100 peak buses makes it difficult to justify an automated system on strict economic terms in these size systems; other factors must enter into the decision process to justify automation. Appendix I provides additional information on cost sensitivity analysis and evaluation of other factors such as operating efficiency improvements. At larger transit agencies, the total annual cost of the automated system approximates the cost of checker salaries alone and can be significantly lower than the total costs of manual data collection.

Better Quality Data

Tests have shown that the accuracy of data obtained from a well-designed automated system is comparable to the data accuracy obtained from manual counts (*3*). Compared to on-board ridership counts taken manually, many automated systems have equaled or bettered the accuracies obtained in the manual process. Compared to manual street-side checkers, on-board automated systems perform considerably better. Manual checkers face a number of problems in estimating ridership accurately. These include overcrowding conditions, uneven distribution of passengers on the bus (e.g., standees at the front and empty seats at the back), and increasing number of buses with smoked windows that make it difficult for checkers to obtain accurate counts. Automated systems, on the other hand, while not completely accurate, have a good probability of producing very accurate results—especially where special algorithms are used to screen and correct the data.

THE MODULAR APPROACH TO AUTOMATED DATA COLLECTION

A significant part of the research effort was directed at defining and developing the specifications for a modular data collection system. The modular system is intended to standardize various functional units within the overall system so that each unit (or module) is fully compatible with other units regardless of the manufacturer. Rather than forcing the redesign of the data collection system for each custom application, the modular system would permit each transit agency to tailor its system to its individual information needs by selectively choosing from a range of standardized modules.

The modular approach was adopted to ease development and

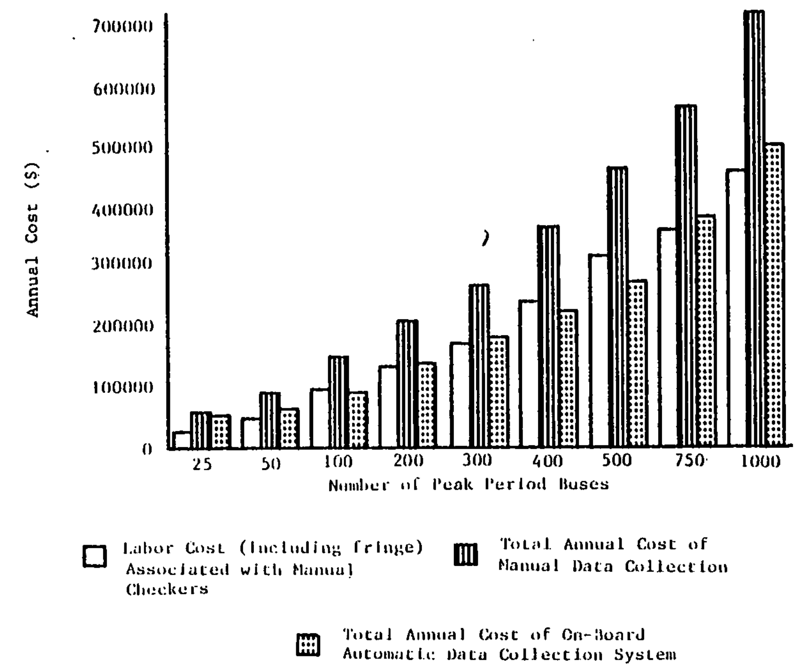

Figure 1. Comparison of manual and automated data collection costs.

implementation requirements for both the operator and supplier. The primary goal of the modularity is to permit transit agencies to select the type of information and the levels of capability (and cost) suitable to their needs. In that it encourages system suppliers to develop standard products, transit agencies would be able to modify their system as technology improves or data needs change. It is also possible that a modular approach would foster improved equipment by allowing manufacturers to concentrate on developing, improving, and producing specific modules and/or systems. Ultimately, the module system might permit the transit agency to select specific modules from various suppliers rather than to rely on one manufacturer to develop a total system. This degree of standardization is viewed as a long-term secondary goal.

PROSPECTS FOR ACHIEVING A MODULAR SYSTEM

The research effort examined the feasibility of developing uniform modular requirements based on the experiences of those transit properties which have implemented automated data collection systems, and the penetration of microprocessor technology in the transit industry.

Current applications of automated data collection systems have shown that management information data requirements of individual transit operators are similar. Most differences in the data collection systems developed to date are based on individual preferences in format, sequence, or types of records produced. Successful testing and operation of these systems have reduced early skepticism about the ability of microprocessors and sophisticated electronic equipment to function reliably in a hostile transit environment.

The low cost and increased computing power of microprocessors and the penetration of automated data collection devices into the transit industry have provided the fundamental building blocks for the modular system. Microprocessor-based technology allows for modular design in which individual data collection units can be integrated with standardized input/output devices and interfaces. Microprocessors can be easily reprogrammed to include customized algorithms, allowing a uniform approach to automated data collection system development that still has sufficient flexibility to accommodate most transit data collection schemes.

Microprocessor technology alone is not sufficient to support the overall objectives of a modular system. Most automated data collection systems on the current market are microprocessor-based and therefore allow some customization to take place by simple reprogramming. However, the systems continue to lack flexibility. It is difficult to tailor them to fit new applications or to accept new or different data collection devices. Often, the present systems do not provide for expanded functions, or if they do, the systems incorporate nonstandard interfaces and proprietary programs that make it difficult for any modifications to be made except by the original manufacturer.

A successful modular system must conform to recognized and widely supported standards in a number of key areas. Electrical and mechanical interfaces between modules must be specified to the extent that modules manufactured by different suppliers will be compatible. Similarly, individual module and system packaging should be such that individual suppliers have a certain amount of flexibility in their own designs while conforming to a general but standard package concept.

The research examined several alternative approaches to providing the uniform interfaces, connections, and packaging required by the modular system. Approaches based on the use of standard computer buses (bus refers to standardized links between computer cards or communication devices; a computer bus is a set of address, data, control and power lines arranged in a standardized manner and operating under a strict set of data communication rules) and conventional card cages were compared to approaches that relied on standard communications buses and relatively relaxed packaging concepts (*4, 5*). Both were deemed practical since both provided the standards to which a modular system could be constructed while maintaining the flexibility to change, expand, and adapt the system to a variety of applications.

A computer bus approach was adopted over the more simplified communications bus approach primarily because computer bus standards are well established, are widely recognized, and are supported by a variety of suppliers. Chapter Four discusses the longer term prospects for developing and promoting a modular automatic data collection system based on emerging communications bus standards.

DEFINITION OF MODULAR DATA COLLECTION SYSTEM

The following section defines the modular system in general terms. Appendix II contains the technical specifications for the proposed system. Figure 2 shows the overall structure of the proposed modular system with its 13 modules, and Table 3 relates the modules to the functional units on which each module is based. The modules provide the electronic means to gather passenger, fare, and schedule data and the information required to define data records and identify them by time and location.

The nucleus of the proposed modular on-board, automatic data collection system is a microprocessor-based unit called a

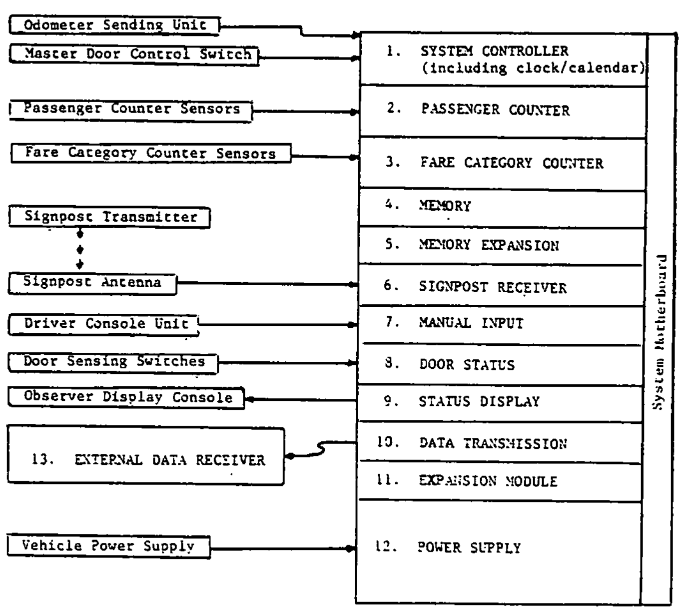

Figure 2. Structure of the modular system.

Table 3. Description of automatic data collection system modules.

MODULE DESIGNATION	FUNCTIONAL DESCRIPTION
1. System Controller	Microprocessor located on the vehicle that accepts, monitors, and controls the data collection and data transfer functions of all other modules. In addition, it includes a clock and calendar with back-up battery. Also accepts data from odometer and driver door control switches.
2. Passenger Counter	Sensors that detect the number of passengers boarding and alighting at each bus stop.
3. Fare Category Counter	Fare collection equipment that detects the number of passengers per fare category. Maintains cumulative value of revenue received.
4. Memory*	Stores data on the vehicle. At least 64K of non-volatile memory is provided.
5. Memory Expansion	Provides additional memory where needed.
6. Signpost	Signpost transmitter installed along routes transmits an encoded identification number to an antenna mounted on the bus roof.
7. Manual Input	Console for driver to enter data reference information such as bus number, farebox number, farezone identification, etc.
8. Door Status Sensors	Additional door switches that can be used to detect and count the number of passengers boarding and alighting at each door.
9. Status Display	Portable data transfer equipment that allows transit personnel to monitor counter accuracy and perform other system diagnostic checks.
10. Data Transmission	On-board data communications device for transferring data from memory to the external data receiver.
11. Expansion Module	Provides the capability to add other data collection functions. For example, the destination sign could be used to automate route/trip information.
12. Power Supply	Converts, conditions, and filters primary bus voltage to provide power to the data collection system.
13. External Data Receiver	Data retrieval unit used to receive data from the vehicle and send it to the computer for processing.

*Solid state memory is preferred method of data storage; however, this module may be changed to contain the electronics for an alternative data storage medium (e.g. cassette tape) or may be deleted entirely in specialized real-time applications.

system controller. The system controller and all circuitry to interface with other modules are contained in a single enclosure located on the vehicle.

Each module consists of appropriate sensing devices, electronic circuits to record data from the sensors, and necessary cabling connections. The design philosophy of the modular system requires each module located on the vehicle to contain an independent plug-in component that is inserted into the system controller.

Few restrictions are imposed on the design, operation, or characteristics of individual modules—other than that they interface (electrically and mechanically) with the system controller in a specified manner and communicate specified data. Providing these conditions are met, a transit agency may choose to implement any functional variation of the module it desires. For example, it may choose between photoelectric, switch-mat passenger counting, or any other sensor design or logic configuration so long as the data presented to the system are in the form of an electrical signal representing the number of passengers boarding and the number of passengers alighting. Similarly, no particular device or technology is dictated for data storage or data retrieval. Solid-state memory or magnetic tape cassettes may be used, and data retrieval may be by physical or electronic means. Table 4 presents the numerous options that may be chosen, depending on particular site circumstances.

Essential Modules

Certain modules are required for all data collection systems to provide the information storage, control, and retrieval functions. These modules are:

1. *System controller*—Required to interface and provide control of all other on-board modules.
2. *Memory*—Required to store the data on-board the vehicle. This module might be eliminated in a real-time data collection system, but in most instances some memory would be required.
3. *Data transmission*—Required to transfer data from the vehicle to the external retrieval unit.
4. *External receiver*—Required to retrieve the data.
5. *Power supply*—Required to convert, condition, and filter primary bus voltage to the data collection system.
6. *Data gathering module*—At least one of the primary data collection modules (e.g., passenger counter, fare category counter) is needed to provide the data that are the focus of the system.

The general consensus of this research project has been that even the most elementary system should incorporate information pertaining to mileage, date and time-of-day, and door openings and closings. For this reason, the system controller module has been specified to accommodate directly the traditional approaches adopted to provide these particular data elements (see App. II). A calendar/clock resides within the system controller and the controller accepts two external input signals directly: one from a standard odometer, and one from the driver door control to represent a door open/closed state. Separate additional modules are required to implement unique functions that deviate from these conventional practices—for example, to monitor door open/closed states for individual entrances and exits.

User Selected Modules

Other modules are selected to provide the data to meet particular management information needs. Example configurations for the on-board automatic data collection system are shown at the top of Table 5. The management information data provided by each configuration is shown in the lower portion of the table.

These configurations range from a basic system designed solely to obtain system-level ridership data to a comprehensive passenger and fare revenue data collection system containing

Table 4. Technology or implementation options.

Module Options	Potential Advantage
Passenger Counter	
Switch Mat Sensors	High counting accuracy
Inductive Loop Mat Sensors	Improved reliability
Photoelectric Beam	Lower cost
Fare Category Counter	
Standard & Electronic Farebox	On-board fare payment and fare categories provided.
Expanded & Multiple fare media devices	On-board and off-vehicle fare payment and fare categories provided.
Manual Input	
Minimum configuration	Minimum operator involvement
Expanded configeration	Detailed identification data generated
Memory	
Solid State	Reduced data loss from human error, mishandling, damage
Cassette	Data storage capacity reduces frequency of data transfer functions
Data Transmission and Retrieval	
Umbilical/Direct contact data extraction to intermediate storage media.	Low cost
Umbilical/direct contact extraction to host processor	Eliminates problems with intermediate data handling
Non-contacting data extraction: RF transmitters, infrared, etc.	Eliminates labor from data transfer
Real-time data transfer	Real-time schedule changes can be made

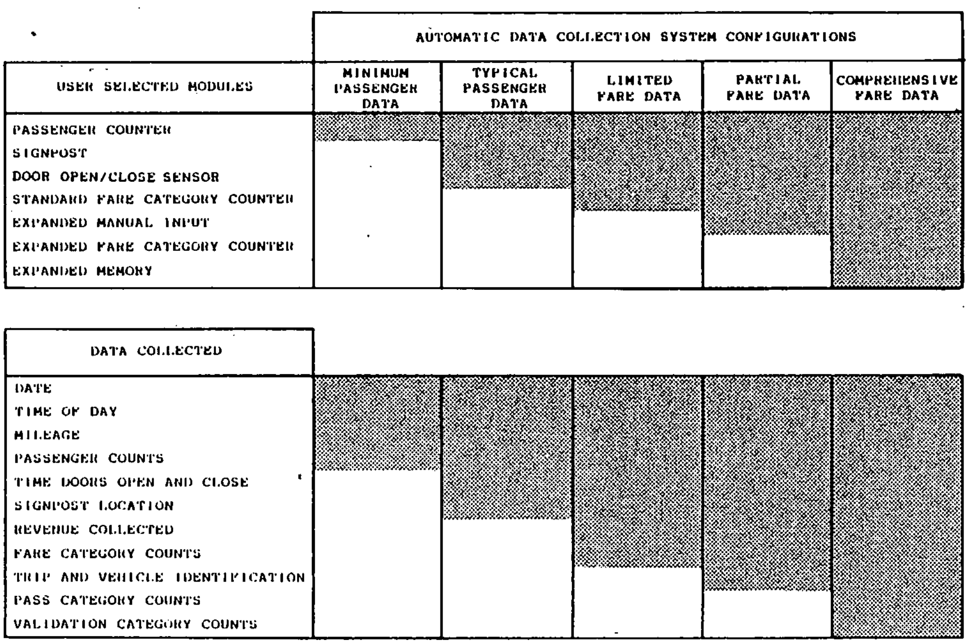

Table 5. Combining modules to collect specific information.

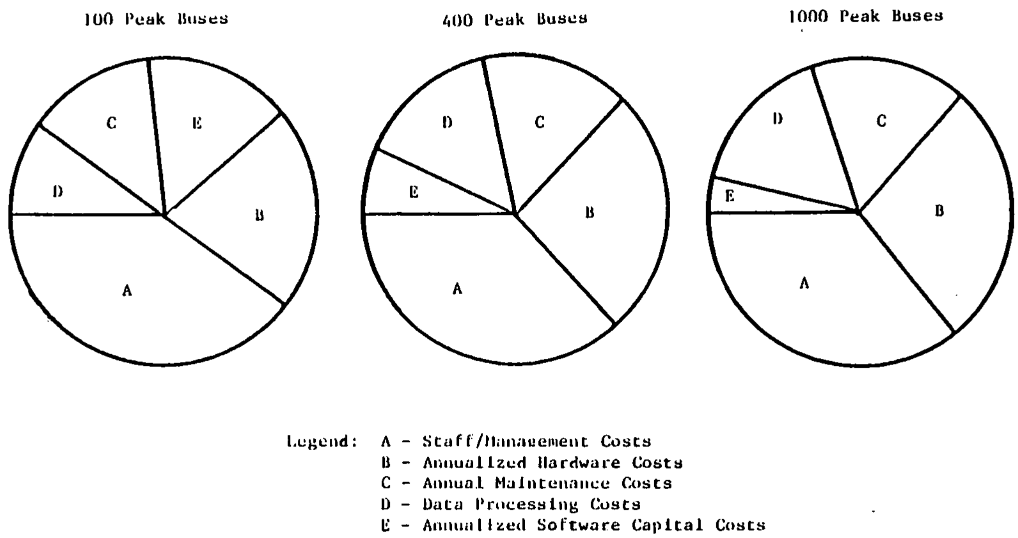

Figure 3. Relative contribution of individual cost elements to the total annual cost of automated data collection systems.

extensive manual input data. These configurations do not represent all possible combinations. They reflect common applications of the technology and illustrate how modifications would affect the data collected.

TYPICAL AUTOMATED DATA COLLECTION SYSTEM COSTS

From a practical standpoint, the cost of implementing an automated data collection system consists of two major components: (1) data gathering costs, including the capital cost for hardware procurement, and installation and annual equipment maintenance costs; and (2) data analysis costs, including software development, computer and data processing costs, and personnel costs. Figure 3 illustrates the relative contributions each of these several elements represent within a representative data collection system (excluding the revenue data collection element) for small, medium, and large transit agencies. The chart shows that even in an automated system, labor costs represent a substantial portion of the total annual costs for all transit agency fleet sizes. Annualized costs associated with the capital investment in data collection equipment, both on-board and wayside equipment, is the second largest expense. However, both maintenance and data processing costs follow closely the cost of data collection equipment in contributing to the overall cost of an automated system. Software development costs represent a significant share of total cost for the small system and decline to a small proportion of total costs for large systems.

Data Gathering Costs

Table 6 presents the unit costs for typical hardware components of the data gathering portion of the data collection system. The table also lists commonly applied and accepted factors for accounting for associated costs such as installation and maintenance. These values were based on data provided by equipment manufacturers and data from electronic trade publications. They represent the higher end of the range experienced for current data collection system components because it is expected that at least in the short term the separation of the system into modules and the special packaging required would result in prices at this end of the spectrum.

Figure 4 summarizes the capital investment associated with the data gathering equipment in a typical passenger counting system. Costs shown are for a mat-based passenger counting system incorporating a standard odometer, solid-state memory, and an average of two signposts per route.

Smaller transit agencies incur a greater incremental cost on a per unit basis than larger agencies. As indicated in Figure 4, the difference may be as much as 50 percent. The cost of all data gathering hardware exclusive of the signpost transmitters is slightly above $10,000 per equipped bus for the 25 peak bus system and declines to just over $7,000 for the large 1,000 bus system. The larger incremental cost for a small transit agency comes from the fact that it will generally have to buy supporting equipment such as data retrieval units which would not be used to their designed capacity.

Wayside signposts add approximately $3,000 to the per unit cost for the very small system but less than $1,000 per unit to the very large system. The costs associated with signposts are determined by the number of routes and not on the number of vehicles in the fleet. Typically, the number of routes operated by a transit system does not increase in proportion to fleet size.

Data Analysis Costs

Data analysis costs, which include the cost of software development, computer processing, and personnel costs, represent substantial portions of the total cost of automated systems as depicted previously in Figure 3.

Table 7 summarizes representative costs associated with the functions required to transform the raw data collected into useful

Table 6. Unit costs for data gathering functions (1983 dollars).

COST COMPONENT	UNIT COST [a]
Hardware	
Passenger Counter Sensors	
a. Photoelectric	$300 [b]
b. Switch Mats	$500 - $600 [b]
Passenger Counter Electronics	$200 [c]
Fare Category Counter	
a. Electronic Farebox	$3400 [d]
b. Farebox Upgrade	$500 [d]
c. Pass Reader	$500
d. Ticket Validator	$1200 - $1500
Odometer	$120
Signpost	
a. Wayside Transmitter	$300
b. On-Board Receiver & Antenna	$800 - $1000 [e]
Manual Input Console	
a. Minimum Version	$100
b. Expanded Version	$400
System Controller	$1200 [f]
System Memory	
a. Cassette	$300
b. Base Solid-State (to 32K)	$400
c. Expanded Solid State (to 64K)	$500
External Control	$100
Status Display Device	$1000
Data Transmission	
a. Off-Line (Physical Con.)	$50
b. Off-Line (Infrared Transc.)	$125
c. Real-Time (Radio)	$2000
External Receiver	
a. Direct Cassette Transfer	$2000
b. Interm. Storage (Cassette/ Disk)	$6000
c. Infrared Base Unit	$3900
d. Base Radio Station	$20,000 - 40,000
Implementation	
Contingency [g]	10%
Shipping and Acceptance [g]	10%
General and Administrative [g]	20%
Installation [g]	10%
Spare Parts [h]	5%
Hardware Maintenance	
Data Collection Equipment [(i)]	15%
Farebox Maintenance	1 mechanic/110 fareboxes

(a)Prices include cabling and mounting brackets or hardware where required.
(b)Unit prices for passenger counter sensors are quoted per passenger stream. Costs assume two sensors per passenger stream. Quantity value must be expressed in terms of the total number of doors on which sensors must be installed. For standard size bus, the number of sensors would be 2 x the number of buses. Double wide doors with two passenger streams should be counted as two doors.
(c)Price quoted for passenger counter electronics is for the separate logic board required in the modular system.
(d)Price quoted is for a new electronic registering farebox. Non-registering electronic fareboxes can be upgraded at a cost of $500-1,000 per unit.
(e)Price quoted includes antenna on vehicle as well as the on-board receiver required for the modular system.
(f)Price quoted for system controller does not include interface electronics for other modules or memory. These items are priced separately in the modular system.
(g)Ten percent of total hardware costs.
(h)Spare parts requirements are minimized since the sizing procedures take into account equipment reliability.
(i)Excluding electronic farebox.

Table 7. Unit costs for data analysis functions (1983 dollars).

COST COMPONENT	UNIT COST
Data Processing Equipment	
Mainframe Computer System	
a. Capital Cost	0
b. Maintenance Cost	0
Dedicated Computer System	
a. Capital Cost (including peripherials):	
Advanced Microcomputer	$10,000
Low-Range Minicomputer	30,000
Mid-Range Minicomputer	50,000
b. Annual Maintenance	12 percent of purchase price
Software and File Development	
Capital Investment to Develop Software	
a. System without Signpost Referencing	$123,000
b. System with Signpost Referencing	$ 78,000
File Construction	
a. Agency with Pre-Existing, Automated Schedule	$50 per peak vehicle
b. File Construction including Automated Schedule Files $150 per peak vehicle	
Data Processing (Annual)	
Computer Charges	
a. System without Signpost Referencing	$0.004 per input record*
b. System with Signpost Referencing	$0.0036 per input record*
Printed/Plotted Output	
a. Printed Output ($0.001 per printed line)	$2.00 per equipped bus
b. Plotted Output ($4.00 per graph generated)	$48.00 per route
Personnel Costs	
System Administration, Coordination and Support	0.50 person years (transit analyst, programmer, or equivalent wage category) plus one full-time equivalent per 300 peak-period buses in fleet
Management and Supervision	25 percent of labor costs associated with administration, coordination and support.

*Based on 200,000 records generated per bus per year, annual cost associated with data processing are $800 and $720 per equipped bus per year.

management information. Data analysis costs, particularly the costs of software development and data processing, reflect many site-specific conditions that make estimates difficult. Chapter Three discusses the sensitivity of annual cost changes to changes in data analysis costs in more detail. Appendix I contains the procedures and information that can be used to estimate these costs for a particular data collection system.

Computer hardware costs are general estimates based on typical costs of such equipment. Software development costs are based on software cost analyses undertaken by MITRE using the Constructive Cost Model (COCOMO) developed by Boehm in *Software Engineering Economics,* Prentice-Hall, Inc., 1981. The default values are based on rough estimates of the number of lines of code required and assumes that the report generator would be an off-the-shelf software package.

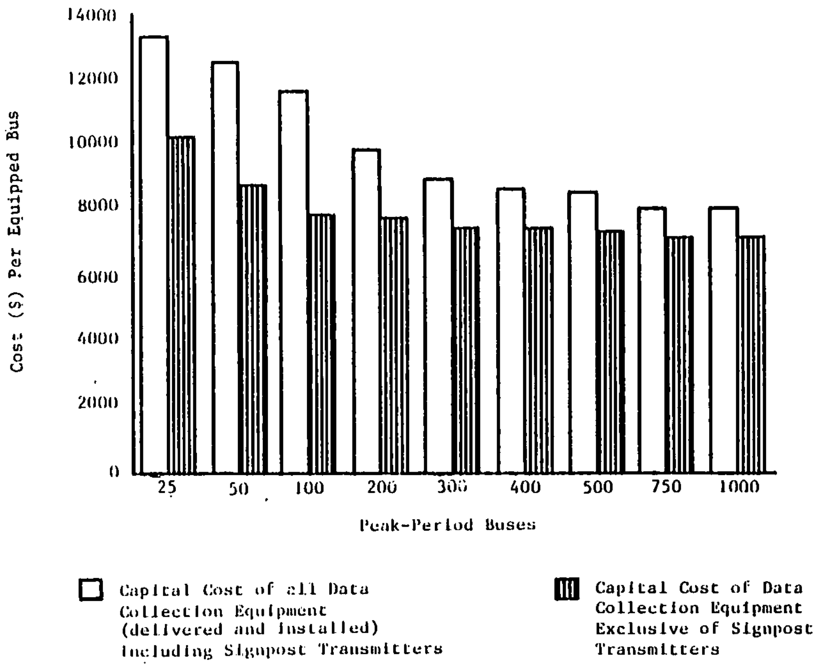

Figure 4. Capital cost of data collection hardware.

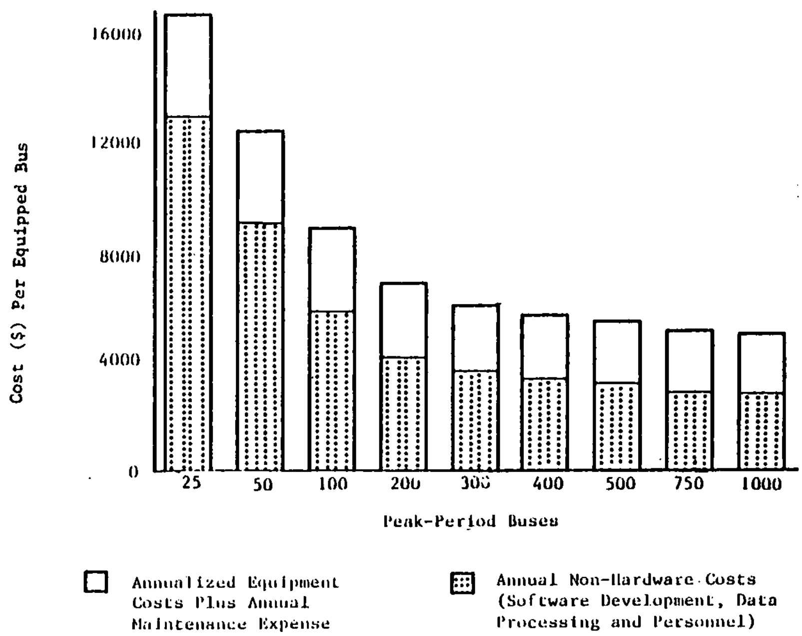

Figure 5. Total annual cost per equipped bus.

Data processing costs and personnel costs are the result of informed judgments based on the processing costs associated with large-scale data base management programs and the staffing required to support management information systems of similar magnitude. The estimates provided for these two cost elements are viewed as conservative values.

Figure 5 compares the annualized cost of the data gathering equipment, including the cost of equipment maintenance, to the annual cost of data analysis for the typical passenger counting system previously described. In all systems, the cost of data analysis is substantial. However, the annualized cost of data analysis, on a per unit basis, decreases rapidly as transit agency size increases. This is partly because the basic software to assemble, edit, analyze, and report the data is independent of the size of the data collection system. The development cost to small transit agencies will generally be equal to the cost borne by a large agency. Certain economies of scale in data processing and staffing costs are also realized by the larger systems.

ALTERNATIVE DATA COLLECTION SYSTEM COSTS

The system illustrated above incorporated modest amounts for signposts (average of two per route), assumed the availability of an appropriate mainframe computer to perform the analyses, and supposed that each agency had to undertake substantial software development efforts. Several alternative configurations based on different assumptions were examined to assess the relative costs and potential merits of such modified systems, including:

1. The installation of additional signposts at all timepoints to identify vehicle location more accurately.
2. The elimination of signposts; in other words, the reliance on distance data for vehicle stop location information.
3. The potential cost advantage of performing data analyses and information processing using an advanced microcomputer or midrange minicomputer instead of a mainframe.
4. The potential benefit of standardized software.
5. The incorporation of fare/revenue counting functions via an electronic registering farebox.

The research compared each of these alternatives to the annualized cost of the baseline system.

Signposts at Timepoints

Figure 6 compares the cost of the standard system to a system that incorporates signposts at timepoints in addition to route terminal points for a 400-peak vehicle fleet. Five signposts per route are used in this particular system modification. As expected, equipment costs increase significantly in this configuration. The advantage of such a system is more precise vehicle location. This tracking capability would theoretically reduce data collection costs by reducing the number of processing steps needed to associate individual data points with particular stop locations. It is also possible that it would drastically reduce the amount of data that had to be discarded because a location match could not be verified.

The analysis presented in Figure 6 assumed that the additional signposts would result in a 10 percent decrease in both data processing costs and staffing costs. The results show that even with these reductions, annual costs exceed those of the system with substantially fewer signposts. The cost-effectiveness of implementing significantly greater numbers of signposts has not been tested in actual operation. However, the analysis undertaken in this research indicates that in addition to decreases in data processing staff costs of approximately 10 percent, a substantial reduction in data losses would have to be realized in order to offset the additional equipment and maintenance costs associated with installing signposts at all timepoints. It is doubtful that such offsetting benefits can be realized.

Data Collection Without Signposts

Figure 6 also compares the overall costs of data collection using signposts to that without signposts. The analysis assumed

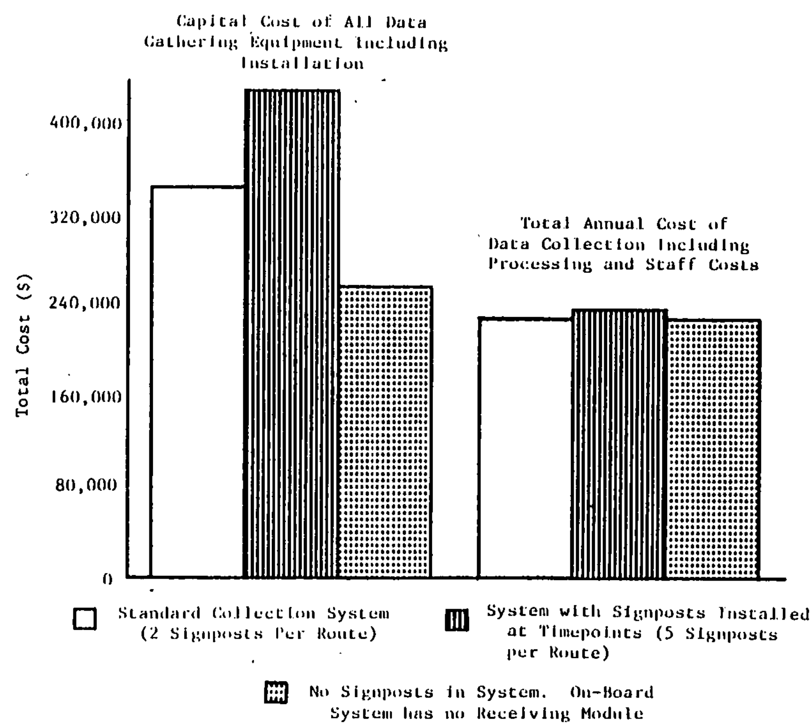

Figure 6. Capital cost and annual cost of signposts (400 peak vehicle transit fleet).

that the absence of signposts would result in less usable data and therefore would require an increase of 10 percent in the number of equipped buses. Consequently, data processing costs increase by approximately 10 percent (because of greater numbers of records being generated) and staff costs also increase by a similar amount (because dispatching is more complicated and there is greater manual intervention in the data screening process). Software is also judged to be more costly in a system without signposts. On this basis, the higher equipment costs associated with signposts are largely offset by the lower software development costs, lower processing costs, marginally lower staff costs, and lowered numbers of equipped buses.

The choice between a system with signposts and one without depends largely on the extent dispatching procedures and driver involvement can be relied on to identify data according to specific blocks of work and particular trips within the assignment. The consensus of the research is that the signpost-based system is preferred because of the inability of most systems to guarantee consistent and reliable procedures. For example, in one system, approximately 20 to 30 percent of the data had to be discarded because of counter inconsistency or the inability to adequately correlate bus stop records with specific stops prior to installation of signposts. Expert judgment suggests that where signposts are installed the proportion of usable data may improve to approximately 90 percent. The cost effectiveness of various quantities of signposts is being investigated by Seattle Metro. Results of the UMTA-funded study should be available early in 1985.

Dedicated Computers for Data Processing

Data processing costs represent a significant percentage of the total annual cost for automated systems of all sizes (see Fig. 3). The research examined the potential for using an advanced microcomputer or a midrange minicomputer for information processing and found that the processing and data base storage requirements for properties with 300 to 400 peak vehicles or less are within the capability and capacity of these relatively low cost alternatives to mainframe computers and time-share systems. On the basis of a purchase price of $50,000 for a complete computer system including data storage devices, it was found that moderately sized systems (300+ buses) might recover the investment in under 2 years, while smaller systems (100+ buses) could recover the investment within a 5-year time period. Very small systems would have to use less costly computer systems such as the latest models of extended personal computers in order to gain a significant cost advantage compared to traditional time-share or contract arrangements. Chapter Three discusses the sensitivity of annual costs to changes in data processing costs in more detail. Appendix I contains the procedures that would be followed to determine the processing and storage requirements associated with a particular data collection system and assess the efficacy of the use of such alternative computer resources.

Standardized Software

For small transit systems, the investment, both in software to process the data and in creating the supporting files for the software, represents a sizable burden. For systems with approximately 50 or fewer buses, these expenses exceed any other cost, including the capital expense associated with the purchase of the equipment. The software development costs estimated in this research effort assume that each new system benefits from the experience of previous systems, to the extent that models for the types of reports and general insights into the data processing are available. However, directly usable software would not be available and each system would have to devote substantial efforts to developing software compatible with its computer environment. Smaller systems are particularly burdened by this expense.

The research found that the single most significant activity to benefit the smaller transit systems would be the development of a standard software package that would be available through commercial sources at moderate cost. Extremely low cost software is not likely, given the limited market, but a software package costing even $10,000 would result in approximately a 17 percent decrease in total annual cost for the agency with 50 peak buses and an 8 percent decrease for a 200-bus system.

Fare/Revenue Data Collection

Adding an electronic registering farebox to collect fare and revenue data represents a significant expense. Dallas, for example, recently installed 600 fareboxes capable of collecting detailed data at a total cost of just over two million dollars or approximately 3,400 dollars per farebox (*6*). Farebox costs, thus, roughly approximate the unit cost of the on-board equipment associated with an automated passenger counting data collection system.

The cost of adding a fare/revenue element to an on-board data collection system is difficult to quantify. The costs illustrated in Figure 7 assume that only the incremental cost for upgrading electronic fareboxes on buses instrumented with data collection equipment (approximately $500 per farebox) is assignable to the data collection system. The costs do not account for additional costs that may be incurred because the nonportability of fareboxes relative to other data collection devices may require more data collecting fareboxes than data collection systems. Nor do the costs include any portion of the costs associated with equipping the entire fleet with compatible (from a passenger perspective) electronic but nondata collecting fareboxes.

Although the incremental costs assumed in Figure 7 may be justified purely on terms of the benefits derived from the data, this research indicates that the other associated costs cannot be supported by the data collection system. Purchase of electronic fareboxes must first be justified separately from the issues of data collection, that is, on the basis of revenue security, bill handling capability, fare evasion reduction, etc. Similarly, the "benefits" of additional data-collecting fare/revenue devices have to be justified based on the extent to which these additional units reduce the problems and costs associated with assigning vehicles.

BUS EQUIPMENT REQUIREMENTS

Interviews with and other information provided by transit agency experts and equipment manufacturers indicated a widespread belief that transit agencies need to equip approximately 10 percent of the fleet with the on-board modules to obtain

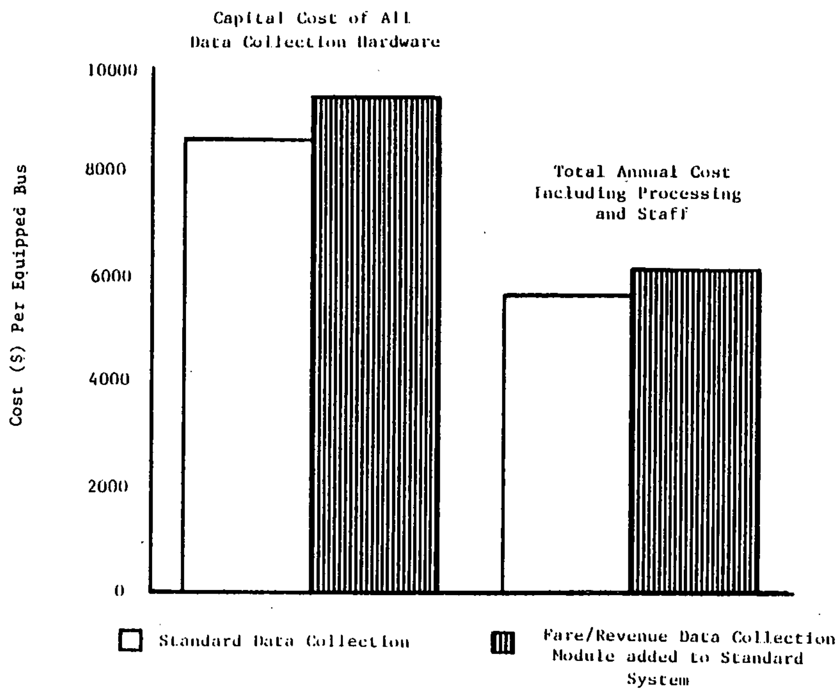

Figure 7. Capital/annual cost of fare/revenue data collection.

adequate data. The premise is that 10 percent allows for equipment availability and data accuracy constraints for the most commonly used sampling strategies.

A major concern of this research was developing a more logical method for determining the number of buses transit agencies need to equip with the on-board modules to produce the intended result—a useful, valid, and reliable data base. Two approaches for estimating equipped bus requirements based on alternative sampling strategies were developed for the implementation manual. Both sizing methodologies generated typical equipped fleet size requirements close to 10 percent. The methodologies and results are described briefly in the following discussion. More information on selecting and applying these methodologies is provided in Chapter Three and in Appendix I.

Typical Equipped Fleet Requirements for Systematic Sampling

Data sampling with automated equipment is most commonly accomplished by systematically rotating the equipped buses throughout the system during each driver signup or seasonal schedule period. Generally the goal is to obtain 3 to 5 valid data points on each vehicle trip or driver assignment during each data collection cycle (i.e., sign-up or schedule period).

A transit system with quarterly service changes will have approximately 75 days (exclusive of holidays, etc.) within each period to obtain 5 data points throughout the system. In order to complete the data survey in the specified period of time, the system must collect data at the minimum rate of 6.7 percent (5 ÷ 75) of all data per day and must therefore have at least 6.7 percent of its vehicles equipped to collect data. However, this proportion of data (and of the equipped fleet) does not account for losses due to missed assignments, vehicle servicing, data errors, special studies, etc. A 50 percent margin to account for these factors results in the requirement that exactly 10 percent of the fleet be equipped.

Typical Equipped Fleet Requirements for Statistical Sampling

UMTA-sponsored research is focusing on developing methods for designing a comprehensive statistically based data collection program that generates precise route-level sampling requirements for different time periods during the day (*7*). Once individual route sampling requirements are determined, an estimate of the number of equipped buses can be made.

An adaptation of the statistically based sampling strategy that could be used to estimate equipped vehicle requirements was developed in this research. The sample (and equipment) requirements for the average or typical route are determined and systemwide requirements are derived by simply scaling up average route requirements to cover all routes. The premise in this approach is that the resulting equipment requirement will be adequate to ensure a statistically valid sample for all routes since equipment excesses on some routes will be shifted to make up equipment deficiencies on other routes.

This particular approach to system sizing was applied to a typical transit system, where the values assumed were average values derived from various sources (*10*). The results (for the typical transit system with average route characteristics) were also close to 10 percent.

CHAPTER THREE

INTERPRETATION, APPRAISAL, AND APPLICATION

This chapter examines the major issues associated with implementing an automated data collection system.

IMPLEMENTING A DATA COLLECTION SYSTEM TODAY

For now, individual transit agencies must retrace the steps of their predecessors, and specify equipment that both meets their individual needs and does not exceed the capabilities of equipment currently on the market. Two products of this research effort are expected to ease difficulties in the selection and implementation process:

1. *Implementation Manual*—An easy-to-use guide to the selection, design, and feasibility analysis activities necessary to determine what type of data collection system is appropriate and whether it is cost-effective.
2. *Technical Specification*—A detailed technical specification that can be used by transit agencies that elect to procure an automated data collection system.

Although much of the information in these reports is presented in terms of the modular system, transit agencies need not adopt the modular design to use it effectively. The modular approach permits discussion of technology capabilities, constraints, and trade-offs without requiring reference to specific suppliers. Where transit managers prefer to consider systems available from specific manufacturers, this information will assist in evaluating alternative system capabilities and procuring the system in a cost-effective manner.

IMPLICATIONS FOR INDIVIDUAL TRANSIT AGENCIES

As discussed in the previous chapter, the costs associated with the data gathering equipment represent an increasing proportion of the total annual costs as fleet size increases. At smaller transit systems, total system costs are dominated by nonhardware costs—that is, the costs associated with software, data processing, and personnel. The implications of modifying the baseline data collection system are explored for different sizes of transit agencies.

Additional/Modified Equipment

At larger systems, data collection equipment costs represent a larger share of total system costs. Therefore, any additional equipment such as a fare/revenue module to collect fare/revenue data or of a radio to transmit data in real-time will have a greater impact on total annual costs for the larger system. Table 8 illustrates the overall effect on total system costs caused by several potential hardware changes to the baseline data collection system. Adding a fare/revenue data collection module via the upgrading of an electronic farebox results in increases in total annual cost ranging from 2.8 percent for the very small transit system to 9.6 percent for the large 1,000 bus system. Similarly, adding a radio system on-board the bus increases annual costs in the range from 4.3 percent to 14.7 percent. The (assumed) $1,500 add-on associated with the radio does not produce three times the increase associated with the $500-farebox upgrade because the radio is assumed to have lower maintenance costs than the electronic farebox.

Cost savings, such as from the substitution of less expensive photoelectric sensors for the switch mats in the passenger counter, have similar characteristics and tend to benefit the large transit system in greater proportion. Figure 8 summarizes the sensitivity of total annual costs to changes in equipment costs through several curves. For given fleet sizes, the curves indicate the amount that the cost of the data collection equipment would have to increase in order to increase annual cost by 5, 10, and 20 percent. The curves in Figure 8 reveal, for example, that a 20 percent increase (or decrease) in equipment costs would change annual costs by approximately 10 percent for the largest transit system but by only 5 percent for the smallest system.

Software Development

Figure 9 shows similar curves for changes in the cost of software development. As expected, changes in software development costs have the most significant impact on the smaller systems because these costs represent a sizable portion of the overall cost for such a system. A standardized software package that significantly reduced this cost element for the smaller system would greatly reduce overall costs. In fact, because the benefits of standardized software rapidly decline as system size increases, it appears that any effort toward such standard packages should be directed specifically at transit systems with 200 to 300 buses or less. These smaller transit systems are also the most likely to lack the programming expertise and computer resources that are available to many large systems. A standard, user-friendly system might encourage their entry into automated data collection.

Processing Costs

Figure 10 shows the sensitivity of total annual cost to changes in data processing costs. It shows that the larger systems have relatively more to gain from a reduction in the computer and input/output costs associated with the information processing tasks. For large systems, it means that an in-house mainframe

Table 8. Annual cost of additonal/modified equipment.

Peak-Period Fleet Size	Percent Change In Total Annual Cost Compared to Base System: Fare/Revenue Module (Farebox Upgrade)	Real-Time Data (Radio)	Photoelectric Passenger Counter
25	2.8	4.3	-1.8
50	3.8	5.8	-2.4
100	5.3	8.1	-3.4
200	7.0	10.7	-4.4
300	7.9	12.1	-5.0
400	8.4	12.9	-5.3
500	8.7	13.4	-5.5
750	9.4	14.3	-5.9
1000	9.6	14.7	-6.1

is likely to produce substantial benefits compared to third-party, time-share arrangements. Medium-sized systems (150 to 400 buses) are likely to benefit most from the application of an advanced microcomputer or midrange minicomputer because the purchase cost would be rapidly offset by savings in processing costs. Assuming a capital expense of approximately $50,000 for this dedicated computer system, costs would be recovered within 2 to 5 years, depending on system size. Small systems, on the other hand, appear to have little to gain from dedicated computer resources because costs savings would have to be large if they were to effect a substantial reduction in overall costs. Nevertheless, such dedicated resources might be desirable from the standpoint of the control it would provide to the user, and could be cost-effective if less costly advanced microcomputers were used, particularly if software specifically designed for the system were available commercially.

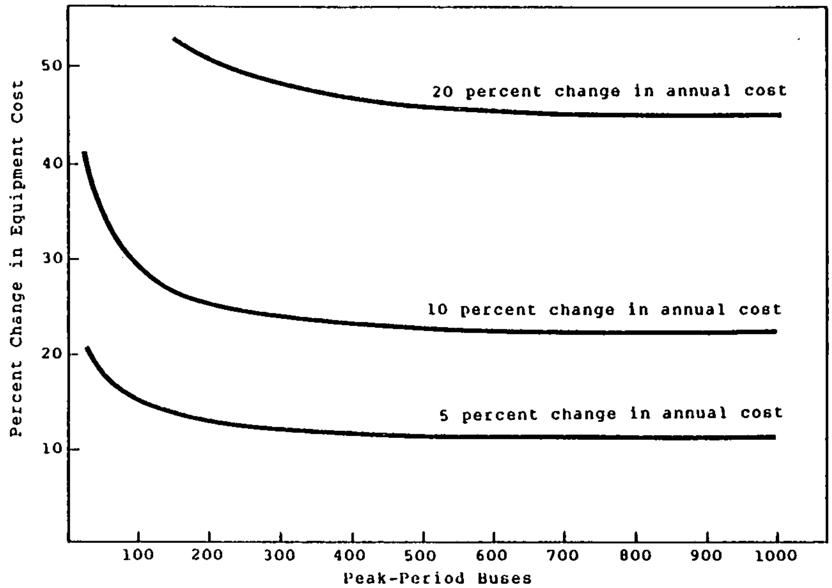

Figure 8. Sensitivity of total annual cost to changes in cost of data collection equipment.

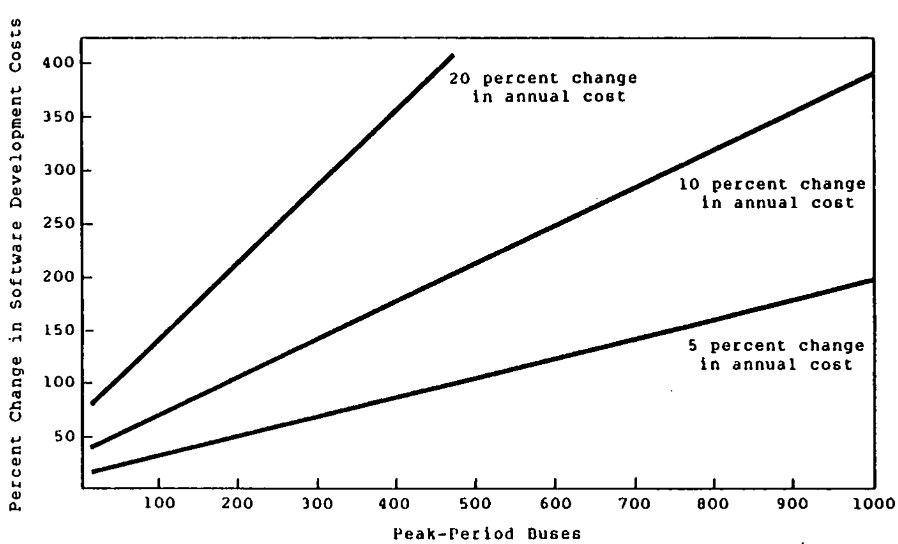

Figure 9. Sensitivity of total annual cost to changes in software development costs.

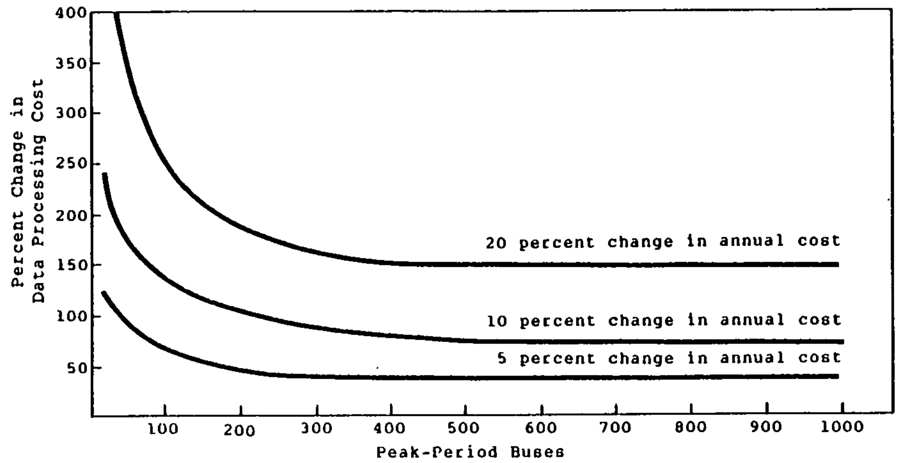

Figure 10. Sensitivity of total annual cost to changes in data processing costs.

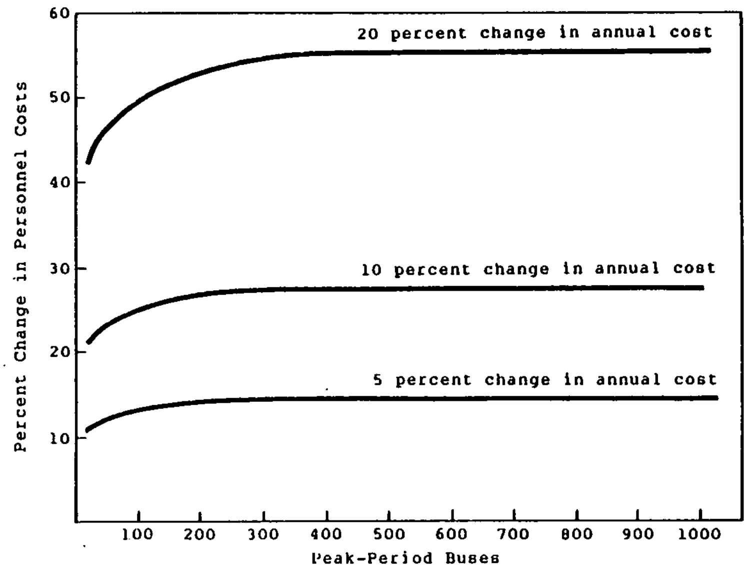

Figure 11. Sensitivity of total annual cost of changes in staff and management costs.

Labor Costs

Figure 11 examines the effects of personnel costs on total annual cost. Personnel costs—for management, administration, data input, data base maintenance and enhancement, and so on—represent the most significant cost of data collection, even in an automated system, and regardless of system size. Smaller systems are marginally more burdened with such costs than larger systems because certain economies of scale are obtainable in large systems. At the same time, these costs are perhaps the most difficult to reduce. Greater equipment reliability will tend to reduce labor costs, such as those associated with dispatching, hosteling, scheduling, but would have its greatest effects on labor costs associated with equipment maintenance.

The greatest potential for reducing the particular staff costs in Figure 11 appears to be in the software/computer area. If standardized software were available, if it resided on an in-house microcomputer or minicomputer, and if it incorporated a user-friendly data base manager, the labor costs associated with data administration, management, and maintenance could be reduced significantly. Table 9 summarizes the potential net benefit that might result if data processing became more standardized. Smaller systems would benefit more substantially from equal changes, but the benefits to moderately large agencies are nonetheless significant.

CRITICAL ISSUES IN THE EVALUATION PROCESS

Evaluation of the potential cost effectiveness of any automated data collection system requires an estimate of equipped bus requirements and should involve a comparison with a similar manual data collection system and an analysis of the potential indirect benefits. Transit agencies have the opportunity to tailor the assumptions and data input to reflect transit agency policies, system operational characteristics, and other site-specific conditions. All of these factors exert a significant influence on the outcome of a cost-effectiveness evaluation and merit careful attention. The key issues are described as follows.

Table 9. Potential effect of data processing standardization.

Peak-Period Fleet Size	Percent Cost Reduction Compared to Base System: Software Development	Data Processing	Staff	Total Annual Cost
50	50	25	10	16.0
			20	20.4
		50	10	17.4
			20	21.8
100	50	25	10	13.0
			20	16.9
		50	10	15.9
			20	18.9
300	50	25	10	10.2
			20	13.9
		50	10	13.2
			20	16.8
500	50	25	10	9.2
			20	12.8
		50	10	12.5
			20	16.1

Determining Equipped Bus Requirements

A detailed examination of the major issues and alternative approaches for estimating equipped bus requirements was undertaken in this research. The results of this analysis indicate that several valid options for estimating the number of equipped buses are available. The approach taken by an individual transit agency will depend on its sampling strategy and data accuracy requirements, cost considerations, implementation strategies, and practical aspects of vehicle dispatching. The two options provided in the Implementation Manual reflect the most commonly used approaches to sampling: systematic sampling and statistical sampling. The advantages and disadvantages of each are described below.

Systematic Sampling

Data sampling with automated equipment can be accomplished by systematically rotating the equipped buses throughout the system during each driver signup or seasonal schedule period. Generally the goal is to obtain 3 to 5 data points on each vehicle trip or driver assignment during each data collection cycle (i.e., sign-up or schedule period). The desired number of data points is based on the expert judgment and preference of transit agency staff who use the data. To estimate equipped fleet requirements, transit agencies must determine how many peak hour vehicles are needed each day to accomplish the sampling.

From a practical viewpoint, this approach is relatively simple to implement because it is compatible with typical servicing and dispatching procedures. However, this process does not guarantee that the data collection for individual routes will yield estimates at the same prescribed level of confidence. Routes with stable ridership may not need the prescribed amount of sampling, while routes with fluctuating ridership may require much more sampling. However, where the overriding concern is not statistical accuracy, but is the acceptance and use of the data by participating departments, the policy approach may be deemed the only acceptable procedure despite a certain lack of statistical "purity."

The systematic sampling approach does not preclude the possibility of obtaining statistically reliable data. The initial data collected can be used to develop individual route sampling plans as time and experience with the system progresses. Differences among routes can be accommodated by selectively changing the sampling scheme to include more data collection where necessary. As the system matures, equipped bus requirements can be modified if necessary to accommodate unique system characteristics.

Statistical Sampling

UMTA-sponsored research is focusing on developing methods for designing a comprehensive statisically based data collection program that generates precise route-level sampling requirements for different time periods during the day (*7*). For example, a stable route may require only 1 or 2 days of limited data collection, while a new route might require a 10-day sample of all trips to obtain accurate ridership forecasts. Once individual route sampling requirements are determined, an estimate of the number of equipped buses can be made.

This research has concluded that while such complex approaches are valid and may be desirable, they are not wholly appropriate for analyzing the cost-effectiveness of automated data collection systems or for determining the quantities of equipment that are required. The need for an extensive data collection effort plus the overall complexities associated with the procedures are likely to discourage most transit agencies from continuing the evaluation. The cost and effort associated with these procedures are justified only after a commitment to proceed with an automated system is made based on a more elementary feasibility analysis.

An adaptation of the comprehensive statistical sampling approach was developed in this research. In this method the peak period sampling and equipment requirements for the typical route are used to estimate systemwide requirements. The premise is that the equipment estimates will be sufficient to allow for necessary adjustments to the sampling plans for individual routes. Provided the characteristics of the system's routes do not greatly deviate from a normal distribution, equipment schedule adjustments will accommodate route sampling differences.

This approach would generate statisically reliable data for all routes that meet UMTA's Section 15 requirements and possibly reduce the number of equipped buses as compared to the systematic approach. However, there are some drawbacks in implementing it with automated data collection systems. The major difficulty with the approach is that the statistical validity is based on the assumption that all trips can be sampled randomly. This is easily accomplished with manual checkers who can move from bus to bus. With an automated system where the equipment is assigned to vehicle blocks, usually with multiple trips per route, random trip sampling can only be achieved by selecting from the trips surveyed. In general, larger samples and thus more equipment may be required than suggested by the BTM Manual (*9*).

Comparisons with Manual Data Collection Systems

Care should be taken in comparing the economics of a manual data collection program with an automated data collection system. This analysis should be based on camparable data collection activities and not on the current level of effort. Typically, manual data collection systems collect fewer data items, less frequently. In many cases, vehicle operators provide some or all of the data. A one-to-one relationship between the number of buses required and the number of checkers is unlikely. An automatic data collection system is less flexible than a manual data collection system. A manual checker can be easily moved from vehicle to vehicle and route to route. A manual checker can also be very efficient in collecting peak load data on multiple trips and multiple routes given the right conditions. In contrast, the automatic equipment remains with a single vehicle and provides all data on a ride check basis.

Quantifying Potential Indirect Benefits

The information obtained from an on-board automatic data collection system can provide the impetus for productivity and efficiency improvements. Reliable passenger and running time data can be the basis for optimizing schedules, readjusting routes, and modifying vehicle assignments (*10*). Schedule changes can be translated into cost reductions and/or improved service. Other benefits of automated data collection systems such as reduced data turnaround time and improved data accuracy can improve management decision-making.

The potential dollar value of any of these benefits is directly related to conditions of a particular transit agency, particularly the quality of each transit agency's current data collection program and schedule efficiency. It is difficult to speculate in advance what benefits may occur and the magnitude of any potential benefits. Dollar estimates should be reviewed judiciously. These difficulties should not imply that these potential benefits are insignificant and should not be considered. On the contrary, decision-makers frequently use unquantifiable benefits to justify proceeding with investments that appear to be marginal or nonproductive in financial terms. A qualitative assessment of the potential for achieving these benefits is recommended.

INSTITUTIONAL BARRIERS TO IMPLEMENTATION

Successful implementation and effective management of any automated data collection will involve overcoming a variety of real or perceived institutional barriers. Table 10 presents the major labor, management, and organizational issues that could lead to problems.

Labor

The need to convey to transit personnel that the automated system is not intended to be a monitoring device that will be used to penalize poor performance cannot be overemphasized. Although this capability is present, its function should be clarified and staff reassured that such is not the intent. Previous experience has shown that failing to alleviate this apprehension will lead to attempts to defeat the system. Trucking firms that installed tachographs, for example, have found them disconnected and/or tampered with. Even some police organizations that tried AVM systems note deliberate attempts by some officers to confuse the system so that movements could not be monitored.

The extent and type of driver involvement in the data collection process is a continuing concern. It is obviously desirable to remove the driver from the operation to the greatest extent possible. However, this is not entirely practical because in some instances, such as in the use of electronic fareboxes, this involvement is necessary. The driver is also in the best position to monitor equipment malfunctions and can be brought into that role through a careful orientation and training program.

The cost savings of an automated system might be reduced significantly if drivers and other personnel successfully use additional responsibilities and duties to justify higher wages. Similarly, cost savings could be reduced significantly if manual checkers cannot be reassigned or phased out. This may be particularly difficult at transit agencies which employ former drivers as manual checkers.

Table 10. Potential implementation barriers.

Labor
Data collection devices perceived as management surveillance of performance.
Added responsibilities used to demand wage increases.
Union perception that intent of improved performance is to eliminate jobs.
Continued compensation for manual checkers who cannot be reassigned.
Unrealistic data demands by schedulers and planners.
Management
Data collection perceived as a low priority item given funding constraints.
Apprehension about technical risk and potential for failure.
Organizational
Difficulties in assigning equipped buses to specific routes on runs due to the way buses are serviced.
Resistance to changes in organizational procedures to accommodate the system.
Low priority assigned to data collection system maintenance.
Low priority assigned to data collection system by central processing facility.
Existing management information systems may dictate the nature and form of the data collection system.

Management

Management has traditionally perceived data collection to be a low priority item compared to other projects competing for limited agency resources. Other projects may produce more visible results or generate more public interest and support. Apprehensions about the technical risks and other potential implementation problems may inhibit management approval of an automated data collection system and even support of a feasibility study.

Organizational

One element that cannot be ignored in the process of collecting data with an automated system is the role of the dispatching operation. Dispatching equipped buses to serve specified vehicle blocks is a critical human element that cannot be avoided. Efforts are required not only at the dispatcher level to orient, train, and retrain the individuals directly responsible for vehicle assignments, but also to enlist the cooperation of drivers and bus hostlers in the process. In fact, the vehicle dispatching procedure is the single most important element in achieving an effective data collection program.

Modification of current dispatching and hosteling practices is also potentially the most disruptive to traditional operating procedures. Agencies operating in cold weather accustomed to dispatching buses from a lineup in the garage will likely experience the most problems in coordinating vehicle dispatch because hostler activities the previous night determine the order of the next day's departures. A workable but simple procedure must be established to reduce the complications of dispatching even if it means more than the minimum number of buses will need to be equipped.

Adequate maintenance is critical to operating an automated data collection system. Malfunctioning of inoperable equipment can complicate dispatching and sampling procedures. Where maintenance is a centralized function, maintenance of other equipment—buses, fareboxes, radios, etc.—will frequently take precedence, and data collection system maintenance may be postponed. A similar circumstance may also arise where the data collection system is linked to a central, in-house data processing facility. Processing of data from the data collection system may have a low priority compared to payroll, budget, and the like.

Overcoming Barriers To Implementation

Transit agencies that have already implemented automated systems apparently have not experienced significant problems, perhaps because they thoroughly anticipated the problems and acted effectively to prevent them from arising. Portland, for example, specified its system to minimize driver involvement. Columbus avoids significant in-house support of its system by contracting with an outside consultant to analyze the data and make recommendations. The apparent lack of problems thus far is also likely because of the somewhat limited nature of the implementations. Fare category counters have not been implemented and a full-scale management information system has not been established.

Planning

By far, the most important step in attempting to overcome potential problems is to develop a comprehensive plan for the data collection system. The plan, which would include an overview of the purpose and functions of the system and would define the expected responsibilities of all individuals, would be circulated to the departments and the personnel who would assume the functions and responsibilities. Their feedback, including their apprehensions, estimates of the resources required, and comments on what they perceive is needed to implement the system, would be used to refine the plan and begin a broader program of dissemination and training. Table 11 enumerates activities that should be considered. More information is provided in the Implementaion Manual contained in Appendix I.

Phased System Implementation

Because of the technical risk involved with any new system, serious consideration should be given to phased implementation. Some inefficiencies will obviously be present if, for example, only a few routes are targeted. However, compared to the learning and start-up problems inherent in attempting the complete system, some inefficiency may be acceptable.

Phased system implementation can also alleviate the difficulties with system scheduling. System scheduling refers to the developing of a plan for assigning the units to vehicles and then assigning these vehicles to vehicle blocks in order to complete the data collection in an organized and efficient manner while adhering to the precepts of valid sampling. This is no trivial effort and a simple method for developing this schedule has not yet evolved. In the interim, the most straightforward course of action available is to identify the routes for which data are considered a priority and then to begin data collection on these routes based on a random selection of the vehicle blocks (including trippers) servicing these routes. In developing the data, the rules of good sampling should be observed, such as avoiding holiday periods, abnormal weather, consistent observation of the same drivers, etc. The resulting data would be examined to judge whether or not they were valid and appropriate. Scheduling would then be adjusted and, over time, a sampling scheme developed.

Table 11. Recommended alternatives for reducing institutional barriers.

<u>Comprehensive Planning</u>

- Begin with a workable implementation plan.
- Solicit input from all parties on all aspects of the plan.
- Modify plan in light of input.

<u>Information Dissemination</u>

- Inform all personnel of plans and goals.
- Inform all personnel of system status after implementation.

<u>Training and Retraining</u>

- Establish orientation program.
- Establish retraining program.
- Reward employees who keep the system working.

<u>Organizational Structure</u>

- Establish clear organizational responsibilities.
- Establish procedures for dealing with problems.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

ACHIEVING A MODULAR APPROACH

Most transit agencies and most equipment suppliers accept the goals and aspirations of modularity and of standardization. However, the transaction from the current customized systems to the commericial reality of a fully modular system will be a long and difficult process requiring numerous concessions from all parties involved before a consensus can be reached. Suppliers that are already heavily invested in their own approaches are likely to resist moves to standardization that would involve substantial redesign or modification of their systems, preferring instead to promote their approach as a de facto standard. Individual transit agencies can also be expected to espouse those particular system characteristics and features that they deem essential.

The function and configuration of the modular system developed in this research effort is intended to represent a preferred and cost-effective system that is sufficiently flexible and expandable to accommodate the vast majority of potential applications. The proposed design approach has been reviewed by a number of equipment suppliers, and many of their comments, suggestions, and insights have been incorporated into the final proposed system.

The Choice Between Established Versus Emerging Data Communications Standards

The modular system developed in this research was defined on the basis of using an established, widely recognized, and extensively supported data communications computer bus (STD-BUS) that would facilitate the integration of modules by independent suppliers while ensuring module compatibility (*4*). (It is noted that the STD-BUS is a concept conceived by the Pro-Log Corporation. There are no trademarks, copyrights, or patents restricting its use and it is supported by multiple sources.) This particular standard may be perceived as an overspecification for the proposed application since its capabilities exceed the relatively elementary data control and communications required of the system. However, this is deemed preferable to designs that appear to present a more efficient and economical structure, but risk the loss of true system modularity. The research considered the possibility of basing the system design on nonestablished standards and on nonstandard computer and communications bus structures and concluded that the perceived benefits in terms of cost and system simplicity would either not be realized or would be outweighed by the costs that would result if these were applied in a proprietary manner. The perceived excess capability residing in the STD-BUS does not result in increased cost because supporting hardware is produced by multiple vendors and in sufficient quantities to attain relatively low per-unit costs. Documentaion of the STD-BUS is extensive, and experience with this standard is sufficiently broad to encourage additional suppliers to enter the market.

One emerging contender to the STD-BUS as the basis for the modular system is a small area network (SAN) known as the Digital Data Bus (D^2B) (*5*). The D^2B is designed primarily as a box-to-box interconnect method and uses only two wires between boxes. The D^2B has been defined and used in Europe during the last 2 years as an interconnection scheme for electronic apparatus in the home. It is currently being considered for standardization in Europe and is being examined by the Society of Automotive Engineers (SAE) for application in the automotive environment.

The obvious advantage of the Digital Data Bus is that it requires only two wires. Functional units thus could be located where they fit best rather than where wiring constraints dictate or rather than in a central control box requiring multiple, multipin connectors, etc. The D^2B provides serial data communication and multimaster form of system control and is also characterized by low radiation and high noise tolerance. Therefore, it appears to be suited to the data collection functions addressed in this research.

The D^2B, however, has not yet been accepted as a standard and certain logic and interface functions are still being modified. More importantly, hardware incorporating the D^2B is not yet available from manufacturers in the United States. A recent licensing agreement between its European developers and two U.S. companies promises to result in the domestic availability of at least two microprocessors incorporating the bus, but for now the D^2B is unavailable.

The research, therefore, had to choose between an existing standard, the STD-BUS, or a future standard, the D^2B. It was concluded that the only choice was to proceed with the known and adopt the STD-BUS.

Industry Movement Toward Standardization

The first realistic step toward standardization must be a commitment by the transit industry to one or more procurements based on the modular system and the standards on which it is based. This includes the securing of funding for the initial procurement. If such can be achieved within a reasonable timeframe, the procurements should proceed on the basis of the specifications contained in Appendix II. However, there is the possibility that a new standard such as the D^2B will be officially adopted and gain user acceptance and manufacturer support. Should this occur, a reassessment of the standards underlying the specifications should be undertaken.

Irrespective of the particulars of the initial procurement of a modular system, the industry should continue to move towards a consensus on the function, configuration, and design of a transit data collection system. This need not result in total agreement in all areas. Obtaining even basic agreement on data elements, data formats, and the like will still net considerable improvement over the present circumstances. A continuing committee role with equal representation by current users, suppliers, and especially prospective entries into the field (users and suppliers) is necessary to maintain interest in modularity and to achieve the consensus on those items that will be most beneficial in terms of cost, flexibility, reliability, etc.

OTHER RESEARCH NEEDS

The research showed that hardware standardization and modularity can be expected to produce significant benefits. It also showed that substantial benefits can be obtained from improvements in other areas. In particular, standardized software and the application of dedicated computer systems could ultimately reduce the overall cost of automated data collection by even a greater amount than through hardware improvements (cost and otherwise). Developmental efforts in these areas should proceed simultaneously with efforts to promote hardware standardization and should be directed at both the small and the medium-sized transit system. Table 12 summarizes the research (and funding) needed in both hardware and nonhardware areas to achieve greater standardization.

Table 12. Future research needs.

Product Development and Demonstration
Develop formal, cooperative agreement between U.S. and Canadian research efforts to move toward a unified North American modular specification.
Establish (and fund) industry task force to develop, review, and approve "model" uniform, modular specification.
Fund demonstration of two or more different system configurations based on model specification.
Data Sampling Parameters
Fund efforts to define default values for key statistics—focusing on rules-of-thumb based on recognizable route characteristics and which do not require data collection.
Cost/Benefit Parameters
Investigate and quantify software development and data processing costs.
Vehicle Scheduling
Develop vehicle scheduling procedures for automated systems.
Information Dissemination
Fund case studies of several systems highlighting dispatching, scheduling, retrieval procedures.
Fund software documentation efforts of significant in-house routines that may be transferred to other projects.

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APPENDIX I

IMPLEMENTATION MANUAL

Contents ***Page***

CHAPTER I.1

INTRODUCTION

The on-board automatic data collection system implementation manual is designed to assist transit personnel in determining the potential utility and cost-effectiveness of automating data collection activities. It is a step-by-step reference guide for designing, selecting, and implementing on-board automatic data collection systems tailored to meet the management information requirements of individual transit agencies. It can be used for a range of bus transit applications to determine:

- The extent of automation appropriate to achieve a transit agency's data and information needs.
- The specific hardware and software components appropriate to meet a transit agency's information needs.
- The amount of equipment required to achieve a cost-effective system within the constraints posed by staff, facilities, and fiscal resources.
- Potential management and operating benefits from automation.
- Planning and implementation activities that would minimize difficulties in integrating the system into existing operations and facilitate system expansion.

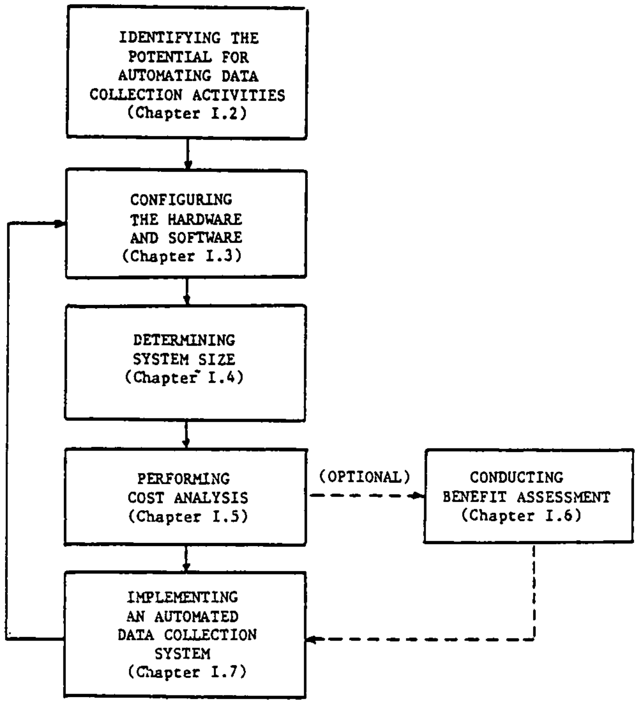


Figure I-1. Design, selection, and implementation activities.

1.1 ORGANIZATION OF THE IMPLEMENTATION MANUAL

Figure I-1 identifies the design, selection, and implementation activities discussed in subsequent sections of this report. The figure indicates the order in which the analysis should be undertaken and provides a cross-reference between the activities illustrated in the figure and the chapters containing the information relating to each activity.

The implementation manual assumes that users have knowledge of the basic hardware and software components of an on-board automatic data collection system and elementary statistical concepts related to data collection programs. A glossary of terms used in the manual is provided in Appendix I.A. Examples of reports and graphics that can be obtained from automated data collection systems are illustrated in Appendix I.B. Additional information on data collection system hardware is contained in Appendix I.C. Appendixes I.D. and I.E. provide detailed information on data processing functions and the data files to support and supplement the automated data collection system. Appendix I.F. contains a brief overview of data sampling as it relates to system sizing.

1.2 SCOPE OF THE IMPLEMENTATION MANUAL

This manual has been tested and evaluated at two transit agencies to ensure that the information and format of the manual are practical, usable, and appropriate for a range of transit applications. Every effort has been made to ensure that the manual is complete and comprehensive. However, two important aspects related to implementation of automated data collection systems are beyond the scope of this research effort.

First, the manual does not provide detailed information regarding the requirements and procedures for establishing, executing, and operating a transit data collection program. Reports sponsored by the U.S. Department of Transportation and others provide guidance on developing a comprehensive data collection program (*1, 2*). An operational data collection program is not required to use this manual; however, a detailed assessment of agency data needs is desirable. A prior determination of what data are to be collected, accuracy requirements, collection frequency, and sampling strategies would help to ensure that agency information needs are met while technology and software requirements are kept to a minimum.

Second, it is not feasible to detail all the activities for implementing a "turn-key" data collection system, because a number of site-specific issues, priorities, and procedures must be incorporated. While these aspects are discussed in subsequent chapters of the manual, additional planning is necessary prior to proceeding with procurement activities.

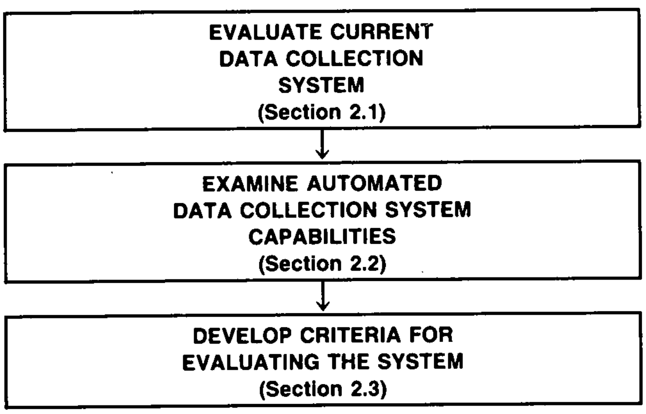
This manual does not explicitly address data collection for real-time vehicle dispatching, revenue and fiscal auditing, and special user analysis. These applications would require customized management information systems to meet site-specific needs. The data needed for these applications, however, could be provided by an appropriately configured automated data collection system.

The implementation manual was developed in conjunction with a parallel research effort to develop standardized system requirements for automatic data collection hardware and software. Much of the information provided in the implementation manual is presented in terms of the standardized, modular system that was developed and is documented in Appendix II. The advantage of this approach is that it permits discussion of technology capabilities, constraints, and trade-offs without requiring reference to a data collection system that is currently being used or provided by a supplier of these systems.

A transit agency need not adopt a modular design in order to use this manual. The functional capabilities of the modular system are similar to those of existing hardware. The modular approach is a new concept in packaging and assembling available hardware, rather than a new hardware development. Where transit managers prefer to consider systems currently available from specific manufacturers, the modular approach provides a useful tool for evaluating alternative system capabilities and ensuring that agency information needs are achieved in a cost-effective manner.

CHAPTER I.2

IDENTIFYING THE POTENTIAL FOR AUTOMATING DATA COLLECTION ACTIVITIES



■A clear understanding of current data collection problems and the capabilities and characteristics of on-board automatic data collection is essential in determining whether or not automation of these functions would benefit an individual transit agency. Information to assist transit agencies in making this determination is provided in Sections 2.1 and 2.2. Transit agencies that wish to evaluate the feasibility of automated data collection systems in more detail should first develop criteria for evaluating the system (Section 2.3). A clear understanding of management perspectives and agency resource limitations is instrumental in selecting suitable hardware and software components and in integrating the system into existing transit operations.

2.1 EVALUATE CURRENT DATA COLLECTION

All transit agencies undertake similar management functions. These functions include, for example, route planning, driver scheduling, performance evaluation, marketing, and policy development. Recent studies (*3, 4*) have shown that the data used by transit agencies to accomplish these functions are similar. Data on ridership, vehicle performance, revenue, and patron socioeconomic characteristics, travel patterns, and attitudes form the nucleus of a transit agency's management information needs. These data coupled with data from agency records (i.e., route miles, schedules, etc.) are used to construct performance measures, prepare external reports, revise schedules, and develop work assignments.

Ridership, vehicle performance, and revenue data are typically the most important, most frequently collected, and most expensive components of a transit agency's management information system. This is partially due to the inherent variability of the data caused by the large number of factors influencing passenger behavior and vehicle performance. In addition, these data are critical components of most transit agency decision-making functions. Figure I-2 shows where information on passenger counts (boarding and alighting passengers), passenger loads, time, mileage, and revenue data are applied in various transit management and operations functions.

Most transit agencies use manual data collection systems to fulfill their information needs. Typically, traffic checkers collect ridership and schedule adherence data by conducting point checks or ride checks. In some cases, the vehicle operator is responsible for recording passenger counts and schedule adherence. Fare and revenue data are most commonly acquired by requiring the vehicle operator or garage personnel to record farebox register readings (*3*, p. 42).

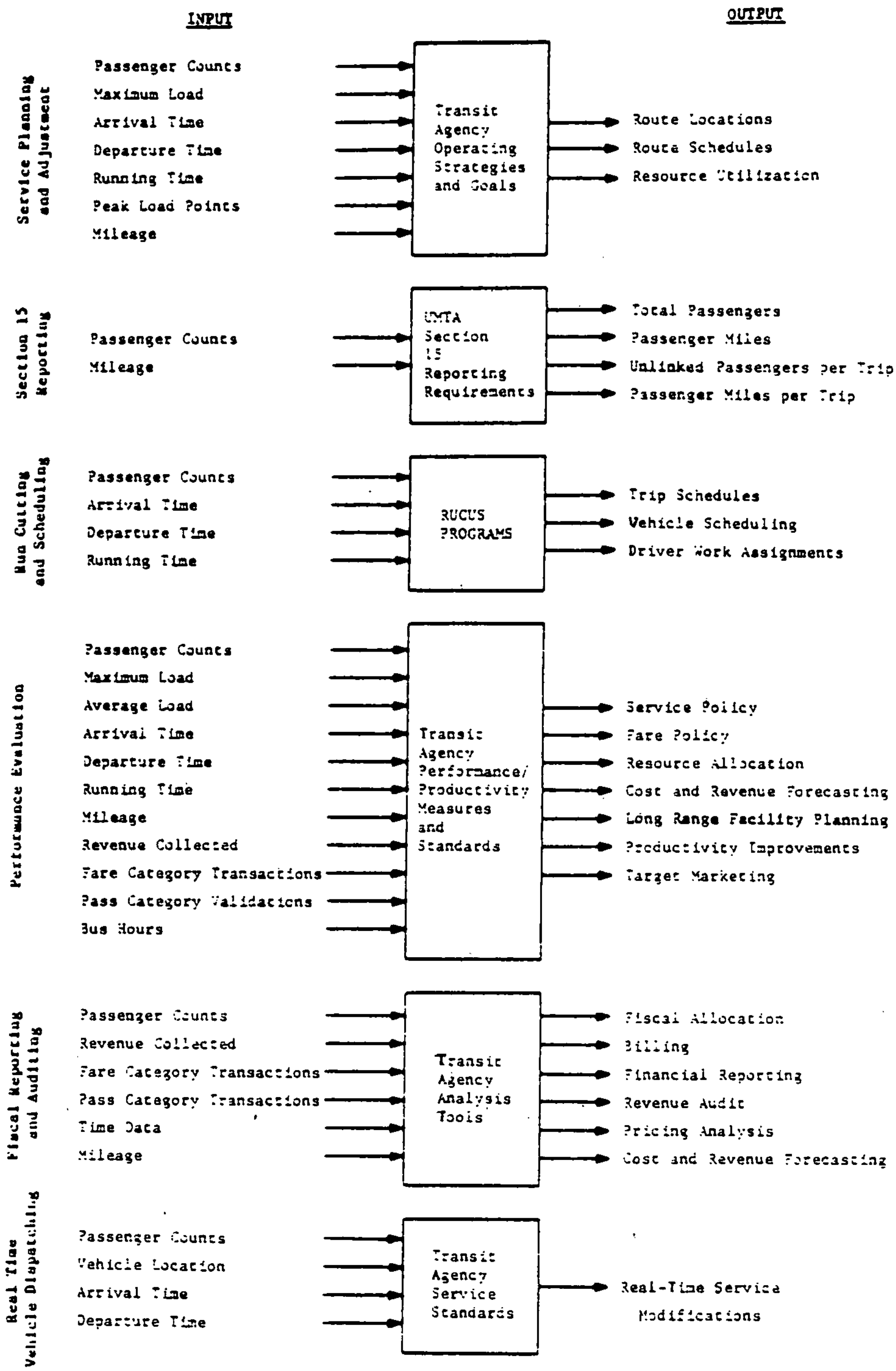


Figure I-2. Input-output map of transit information needs.

Generally the person collecting the data records the information by hand on preprinted checksheets and is required to include information that identifies the data for analytical purposes. This might include, for example, date, time, route, trip, or bus stop information.

The data generated by the checkers must be compiled into meaningful information. Using the raw checksheet data for building or adjusting headways is common scheduling practice (*3*, p. 35). However, other management functions require that the checksheets be processed to produce the summary statistics needed for analysis. Statistical analysis is needed to arrive at conclusions based on these data. For example, the data must be aggregated to analyze trends in passenger loading and schedule conformance, and interrelationships between these factors must also be determined. Reduction and analysis of data using hand calculators is time consuming and sometimes inaccurate. Where data analysis has been computerized, the checksheets must be coded and keypunched before they can be processed. Data transcription can be a major source of data errors.

Obtaining good management information through manual data collection procedures can be difficult and expensive. The most common problems are discussed below. In assessing the current data collection system, site-specific problems should be added to the list.

The most important shortcomings of a manual data collection system are the following:

- Some traditional data collection procedures have become unreliable. The accuracy of peak load estimates from street corner point checks has been degraded by the introduction of buses with tinted windows that diminish the checker's ability to observe the number of passengers on the bus. Use of revenue counts to estimate ridership becomes less practical as pass and other fare prepayment methods are introduced, as the number of passeneger fare categories is increased, or as more fare zones are added.

- The time delay between data collection and data analysis can be a problem. Some transit properties that use manual data collection programs have experienced delays up to one year between data collection and data analysis and reporting. Typically, the longest delay is caused by the data preparation functions—data validation, editing, and keypunching (*5*, pp. 38–39).

- The reliability of the data cannot always be guaranteed. The accuracy of data collected by checkers and drivers can vary from day-to-day. Research conducted by the Transportaiton Systems Center suggests accuracy is influenced by a number of factors; standing loads, volume of activity at a bus stop, the duration of the shift, distractions from passengers, educational background, and motivation (*6*, p. 12).

- Depending on local labor practices, the cost of manual data collection systems can be high. Manpower—checker salaries and fringe benefits—is usually the largest budget item for a manual data collection system. Cost considerations may limit the frequency and amount of data that can be obtained.

- Because of the time-consuming and tedious nature of data analysis and interpretation, substantial amounts of the data collected may not be analyzed. A survey conducted by Flusberg, for example, found that only about 50 percent of point check data is processed and analyzed (*3*, p. 35).

2.2 EXAMINE AUTOMATED DATA COLLECTION SYSTEM CAPABILITIES

An on-board automatic data collection system is an alternative technique for collecting the transit management information data identified in Figure I-2. These systems include the hardware to collect and record data and the transfer mechanisms and computer software required to process the data into useful information. The systems use microprocessor technology to acquire data on passenger activity and vehicle performance, as well as location and time information.

Figure I-3 shows the four essential elements of an automated data collection system: data acquisition, data recording, data transfer, and data processing. The components that can be used to construct a system are also shown. Passenger counting sensors located at each doorway of the bus detect passenger activity, and the passenger-counting electronics translate this activity into boarding and alighting counts. If desired, one or more fare category counters—electronic farebox, pass reader and or ticket validator—can be added to collect revenue data by user category.

The remaining data acquisition and data recording components provide the necessary information to reference the data by location and time. A door sensor is used to monitor the opening and closing of the doors in order to define the beginning and end of passenger activity at each bus stop. An internal clock is used to denote the time and date of each data recording. An odometer is used to denote vehicle mileage and provides one means of matching data records to stop locations along the route. Typically, distance referencing is supplemented by locating wayside transmitters (signposts) at designated intervals along the route to periodically provide a known location reference.

In a sense the system controller serves as the checksheet for an automated data collection system. All of the equipment described above is electronically connected to the system controller. Data from the equipment are stored on-board the vehicle until data transfer takes place. In most cases, the data transfer takes place in the garage.

Each vehicle is equipped with a data transmitting device that is connected to an external data receiver when data transfer takes place. Basically, the external data receiver provides intermediate storage for data, and the link between the vehicles and the computer facility which processes the data.

Once the data are fed into the computer, software is used to validate the data and to construct the data base. External data files such as route schedule times, time point locations, and signpost locations are used to assign route and run numbers as well as bus stop numbers to the data collected from each vehicle. The detailed records from each vehicle are then converted to the desired data base or master file. Generally, the master file stores data by bus stop or bus trip. Finally, the desired management reports are produced.

Significant management benefits can be derived from automated data collection systems—lower data collection costs, improved turnaround time, and better quality data.

- *Lower data collection costs*—Given a comparable data collection effort, the annual cost of an automated system will generally be less than that for a manual data collection system. As indicated in Figure I-4, the annual cost of an automated system

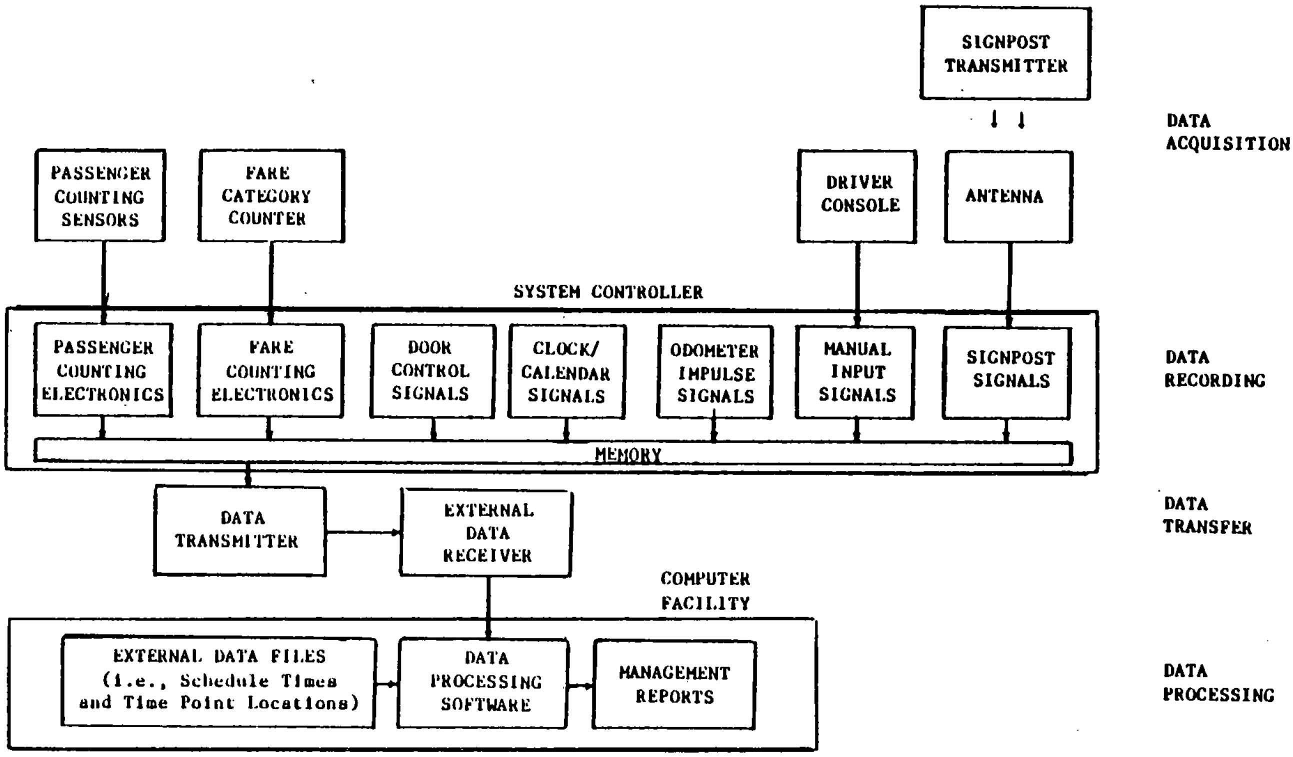


Figure I-3. Elements of on-board automatic data collection system.

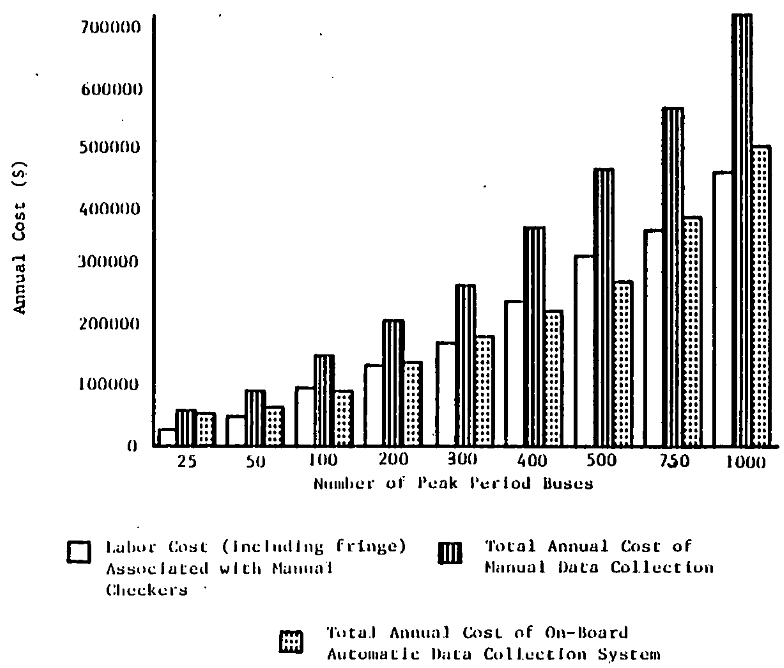


Figure I-4. Comparison of manual and automated data collection costs.

Table I-1. Evaluation criteria guidelines.

General Management Goals For System Operation
System provides essential data needed to meet management information needs.
System provides data at sufficient level of detail (system-wide, block, route, trip, service period, day of the week, type of service, etc.) to meet management information and reporting requirements.
Time and location information needed to identify the data (i.e., stop event records, vehicle location, time point location) are sufficiently accurate to meet management reporting requirements.
Collection of unessential data is minimized.
Data formats are compatible with existing management information systems.
Requirements and procedures for handling and processing the data lead to reductions in data turnaround time.
The number of equipped buses is sufficient to meet minimum sampling requirements.
Data collection frequency and coverage is improved.
Technical risk associated with technology options is compatible with historical management perspectives regarding innovation.
The system offers the capacity to meet planned expansion without major modifications.
Potential suppliers of the equipment can provide adequate production support--replacement parts, service, training, and warranties.
System Implementation Goals
The level of operator involvement in data collection activities is compatible with historical roles and responsibilities.
The level of human involvement in data transmission and retrieval is compatible with existing job functions and organizational responsibilities.
The cost and disruption resulting from physical modifications to existing facilities (e.g., garages) is acceptable to management.
Potential modifications to existing operational practices (vehicle check-out or check-in, bus cleaning, vehicle assignment procedures) are acceptable to management.
The implementation schedule reflects management goals for the system and the required changes to transit agency procedures.
The potential for vandalism and theft of equipment is minimized.
Available Agency Resources
The automated system offers the potential for long-term incremental benefits from reducing external reporting costs, improving scheduling procedures, etc.
The annual costs of the automated system are lower than other alternatives for collecting comparable data.
Sufficient capital funding is available to procure the system.
Sufficient funding is available to operate and maintain the system.
Current maintenance support is sufficiently staffed and skilled to handle preventative as well as unscheduled maintenance of sophisticated electronic equipment.
Adequate in-house computer expertise is available for developing software and managing the data base.
Adequate computer facilities are available.
Changes to operator, scheduler, dispatcher, fare collection, or maintenance roles and responsibilities are acceptable to labor/union perspectives.
Facilities for data storage are available.

(consisting of passenger counters plus two signposts per route) is approximately equal to the cost of the salaries of just the manual checkers at many transit agencies.

- *Improved data turnaround time*—Transit decision-making can be more timely because data from an automated system will generally be available sooner than data from a manual data collection system. Seattle Metro and Metro Transit in Kalamazoo report approximately a one-week data turnaround time from their automated system.
- *Better quality data*—Tests have shown that the accuracy of on-board ridership data obtained from a well-designed automated system is equal to or better than the accuracy of data taken manually (*6*). When compared to data collected by operators or street-side checkers, the accuracy of data collected by automated systems is frequently much better.

Nonetheless, implementation of an on-board automatic data collection system requires careful attention to detail. Acquisition of the equipment and development of the necessary software require a substantial capital outlay. Implementing and operating an automatic data collection system is not a simple task. Effective application of the technology requires extensive cooperation and coordination by all participating personnel and may necessitate changes in agency operating procedures. In contrast to a manual data collection system, the assistance of maintenance, dispatching, and hostling personnel is needed to ensure that equipped buses are available, that data collection assignments are carried out, and that the data collection system does not interfere with transit operations. These and other issues are discussed in greater detail in the remainder of the manual.

2.3 DEVELOP CRITERIA FOR EVALUATING THE SYSTEM

The initial step in the evaluation process is to develop criteria for evaluating the potential cost-effectiveness of the automatic data collection system. These criteria should reflect management goals and objectives for the system and the institutional environment in which the system is to be implemented. If the system configuration is not compatible with management perspectives or available resources, integrating the system into existing transit operations will be difficult; maintaining and operating the system could be a problem; and the utility of the data obtained from the system may be questionable.

Because transit systems differ markedly in size, operating characteristics, and resources, it is difficult to develop a single set of evaluation criteria that could be used by every transit agency. In general, however, the criteria should take into account management goals for the system operation, management goals for system implementation, and available agency resources (funding, staff, computer).

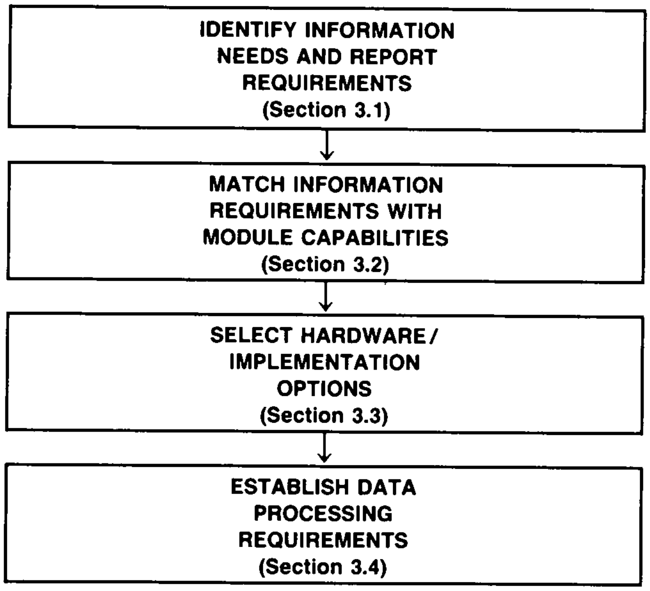
Table I-1 presents a list of potential goals that can be used as the basis for developing evaluation criteria. Transit agencies should review the table to establish the criteria relevant to their application and are encouraged to expand the list with additional site-specific goals and criteria appropriate to their individual circumstances. These evaluation criteria are to be used as a decision-making guide throughout the design, selection, and implementation process.

Personnel in the various transit agency departments that will be affected by system implementation should be contacted to obtain their perspectives on goals and objectives for the data collection system, issues to be included in the evaluation criteria, and their particular data requirements. Early involvement of transit agency staff will assist in minimizing system operation and maintenance problems and ensuring that the data obtained from the system are useful. These personnel include:

- Policy makers.
- Operations planners.
- Schedulers.
- Dispatchers.
- Maintenance supervisors.
- Hostlers.
- Traffic checkers.
- Management information specialists.
- Drivers.
- Facilities engineers.
- Union representatives.

CHAPTER I.3

CONFIGURING THE HARDWARE AND SOFTWARE



■Once a transit agency's goals and objectives for the automatic data collection system have been outlined, the process of designing the system may begin. This chapter provides information and worksheets for selecting the appropriate hardware and software configurations. Because trade-offs can be made between hardware, implementation options, and software, this is an iterative process. Basic knowledge of the elements used to design an automated data collection system is assumed. Further information is contained in Appendixes I.B, I.C, I.D, and I.E.

3.1 IDENTIFY INFORMATION NEEDS AND REQUIREMENTS

Part of the purpose of involving the personnel in various departments in the planning and evaluation is to determine the level and type of management information being sought. This step is an important prerequisite to estimating the extent of the proposed system, because the detail required in the management information will influence the selection of the hardware and software and impact the day-to-day activities of the data collection effort.

The management information reports in Table I-2 are typical of those that might be selected as products of the data collection system. (See App. I.B for sample reports produced by some current data collection systems.) The table is presented in the form of a worksheet that can be used to rank the importance of particular information at three levels: essential, desirable, not required. This ranking is intended to assist transit agencies in ensuring that the data collection system meets its essential needs. It allows for identification of data that could be omitted without sacrificing the utility of the system. Information products not present in the table but considered necessary should be added to the table.

Table I-3 expands the information checklist to include examples of the form in which the data are expected and the frequency with which they must be generated. Reports can range from simple summaries of data, such as that required by Section 15, to more detailed reports in which information is broken down by route, direction, days of the week, time of day, time point, etc. Data requirements not present in the table but considered necessary should be added to the table. Careful consideration of the actual form and frequency of the information is essential because these directly impact how the data are processed, how much storage and processing capacity is required, and how manageable the overall system will be. This worksheet should be completed on the basis of a realistic assessment of the need for the information. For example, it is important not to specify a running time report as a weekly report if it will only be required as an input to quarterly schedule changes.

Table I-2. Management information data requirements checklist.

		System Priority (Check One Column)		
Report Type	Typical Data/Statistic Entries	Essential	Desired	Not Required
Section 15	Passengers Boarded, Passenger Miles, Capacity Miles, Seat Miles, Bus Trips (Sample Size & Total)			
Ridership Report	Passengers Boarded, Passenger Loads, Passengers Per Trip/Mile/Vehicle Hour			
Running Time	Observed Running Time, Scheduled Running Time, Deviation			
Schedule Deviation	Schedule Time, Observed Time, Measure of Late or Early			
Overloading	Maximum Passenger Load, Load Factors, Time/Distance with Standees			
Revenue Report	Passengers Carried, Revenue, Revenue Per Passenger/Trip/Mile, Recovery Ratio			
Fare Category	Boarding Passengers by Category, Revenue Percent by Ridership Category			
Revenue Audit	Revenue Received, Vaulted Amounts, Revenue Discrepancies			

Table I-3. Management information reporting checklist.

REPORTING REQUIREMENT (For each report type, select requirement in each heading that best meets information needs)	REPORT TYPE							
	Section 15	Ridership	Running Time	Schedule Deviation	Overloading	Revenue and Ridership	Fare Category	Revenue Accounting
Frequency Needed								
Annually								
Quarterly								
Monthly								
Weekly								
Daily								
Day of Week								
Individual Day								
Weekday/Sat/Sun								
Weekday/Weekend								
Time of Interval								
Full Day								
AM/PM/Midday/Night								
Hourly Interval								
Half-Hour Interval								
Less or Equal 15 Min								
Data Segmentation								
Route-Level Summary								
Trip Summary								
Time Points								
Stop by Stop								
Graphics Requirements								
No Graphics								
Report and Graphics								
Graphic Only								
High Quality Line Graph								
Archive Requirements								
None								
Less Than One Year								
Permanent-Hard Copy								
Permanent-Computer								
Special Requirements								
Weather Condition								
School Day								
Holiday Period								
Type of Vehicle								
Type of Service								
Garage/Division								

3.2 MATCH INFORMATION REQUIREMENTS WITH MODULE CAPABILITIES

This research identified 13 hardware modules or components that can be used to construct an automatic data collection system. These modules are described in Table I-4. More detailed information is provided in Appendix I.C.

Certain modules are required for all data collection systems. These are the modules that are necessary to provide the information storage, control, and retrieval functions within the system. These modules are:

1. *System control*—Required to accept, monitor, and control all data collection and transmission activities.
2. *Memory*—Required to store the data on-board the vehicle. This module might be eliminated in a real-time data collection system, but in most instances some memory would be required.
3. *Data transmission*—Required to transfer data from the vehicle to the external retrieval unit.
4. *External data receiver*—Required to receive data and provide interface to computer.
5. *Power supply*—Required to convert, condition, and filter primary bus voltage.
6. *Data gathering module*—At least one of the primary data collection modules (e.g. passenger counter, fare category counter) is needed to provide the data.

Other modules are selected to provide data to meet particular management information needs. Table I-5 provides a checklist to identify the modules to be included in a transit agency's automated data collection system. The results of Tables I-2 and I-3 should be used to complete this table. Those modules that are considered to be essential for meeting a transit agency's management information needs should be noted on the left side of Table I-5. Modules that are not essential, but are desired by a transit agency, should also be noted. This ranking allows transit agencies to identify those modules that could be omitted without sacrificing the usefulness of the system.

The cost analysis undertaken in this research revealed that the decisions regarding signpost and fare collection modules warrant special consideration. The annual costs of a system with an average of two signposts per route and a system without

Table I-4. Description of automatic data collection system modules.

MODULE DESIGNATION	FUNCTIONAL DESCRIPTION
1. System Controller	Microprocessor located on the vehicle that accepts, monitors, and controls the data collection and data transfer functions of all other modules. In addition, it includes a clock and calendar with back-up battery. Also accepts data from odometer and driver door control switches.
2. Passenger Counter	Sensors that detect the number of passengers boarding and alighting at each bus stop.
3. Fare Category Counter	Fare collection equipment that detects the number of passengers per fare category. Maintains cumulative value of revenue received.
4. Memory	Stores data on the vehicle. At least 64K of non-volatile memory is provided.
5. Memory Expansion	Provides additional memory where needed.
6. Signpost	Signpost transmitter installed along routes transmits an encoded identification number to an antenna mounted on the bus roof.
7. Manual Input	Console for driver to enter data reference information such as bus number, farebox number, farezone identification, etc.
8. Door Status Sensors	Additional door switches that can be used to detect and count the number of passengers boarding and alighting at each door.
9. Status Display	Portable data transfer equipment that allows transit personnel to monitor counter accuracy and perform other system diagnostic checks.
10. Data Transmission	On-board data communications device for transferring data from memory to the external data receiver.
11. Expansion Module	Provides the capability to add other data collection functions. For example, the destination sign could be used to automate route/trip information.
12. Power Supply	Converts, conditions, and filters primary bus voltage to provide power to the data collection system.
13. External Data Receiver	Data retrieval unit used to receive data from the vehicle and send it to the computer for processing.

signposts are comparable. The choice between the two alternatives depends largely on the extent dispatching procedures and driver involvement can be relied on to identify data according to specific blocks of work and particular trips within the assignment. Most data collection experts recommend signposts because the reliability of the information provided by drivers cannot be guaranteed.

Adding new fare collection equipment, such as electronic registering fareboxes, or self-service fare collection equipment, solely for the purpose of collection fare and revenue data is not cost effective. Electronic registering fareboxes alone will approximately double the unit cost of on-board equipment. Purchase of new fare collection equipment should be evaluated and justified independently from data collection issues. Where new fare collection equipment can be justified on the basis of revenue security, bill handling capability, fare evasion reduction, etc., the upgrade of the equipment for data collection purposes should be considered as part of the automated data collection system.

3.3 SELECT HARDWARE/IMPLEMENTATION OPTIONS

Some modules allow for technology or implementation options. Although the technology or implementation option selected does not affect the functional capabilities of the automatic data collection system, it can have an impact on system costs or operational characteristics. For example, reliable transmission of the data from the on-board microprocessor can be accomplished with any of the hardware options currently available. Although the cost of the alternatives can be significantly different, transit agency managers may feel a more expensive alternative (e.g., infrared data retrieval and transmission) is appropriate to minimize human involvement in the data retrieval process. A brief description of various options is provided in Table I-6, and detailed information is contained in Appendix I.C.

Hardware and/or implementation options preferred by a transit agency can be noted on the right side of Table I-5. In selecting the appropriate option, the following issues should be considered.

1. Cost, reliability, and accuracy trade-offs.
2. Management perspectives regarding approaches to data collection system implementation and operation.
3. Institutional constraints that may affect hardware selection.
4. Modifications to existing transit operation functions that may be required by a particular option.
5. Technical risk associated with the hardware option.
6. Ability of potential suppliers to provide adequate product support.

3.4 ESTABLISH DATA PROCESSING REQUIREMENTS

The volume of data that is generated by automated data collection systems precludes manual processing. Software is needed to sort, aggregate, and maintain data and to extract management information. Table I-7 presents the type of processing required between the collection of the raw data on-board the vehicle and generation of a final management report or statistical summary.

Appendix I.D contains a more detailed discussion of the overall structure of the data processing activities and includes a proposed framework for an integrated data software package that could have broad application. Although the focus of this appendix is oriented to the future, it also provides a detailed view of the typical data interactions today.

Transforming the raw data provided by the on-board unit into the typical information supplied in the management reports is not an elementary data processing operation. Vehicle-specific data obtained from the on-board units must be restructured to fit other information key or keys such as route, time-of-day intervals, etc. This is a complex operation that requires iden-

Table I-5. Module selection checklist.

MODULE SELECTION			OPTION SELECTION	
Essential Module	Desired Module	Module	Hardware/ Implementation Option	Preferred Option
*		System Controller		
		Passenger Counter	Photoelectric Mat	
		Fare Category Counter		
*		Memory	Solid State Cassette	
		Memory Expansion		
		Signpost		
		Manual Input	Minimum Expanded	
		Door Status		
		Status Display		
*		Data Transmission	Female Plug Infrared Unit RF Transmitter Other	
		Expansion Module		
*		Power Supply		
*		External Data Receiver	Umbilical Infrared Unit RF Transmitter Modem Other	

*These modules are required in any automated data collection system.

tifying the route segments to which the vehicle was assigned and completing an accurate data segmentation under circumstances that often complicate this matching—for example, the bus runs late, is turned around at an earlier relief point, or perhaps misses an assignment altogether. Commonly, a number of external files must be referenced either to obtain data not provided by the on-board equipment or to verify that the data provided by the on-board unit agree with this external information. Appendix I.E describes these external data files.

Sheer data volume also complicates data processing. The number of data manipulations coupled with frequent file referencing and data screening to eliminate errors makes the data processing function a sizable operation even for a small number of buses. Data management activities, therefore, constitute a significant

Table I-6. Technology or implementation options.

MODULE OPTIONS	POTENTIAL ADVANTAGE
Passenger Counter	
Switch Mat Sensors	High counting accuracy
Inductive Loop Mat Sensors	Improved reliability
Photoelectric Beam	Lower cost
Fare Category Counter	
Standard: Electronic Farebox	On-board fare payment and fare categories provided
Expanded: Multiple fare media devices	On-board and off-vehicle fare payment and fare categories provided
Manual Input	
Minimum configuration	Minimum operator involvement
Expanded configeration	Detailed identification data generated
Memory	
Solid State	Reduced data loss from human error, mishandling, damage
Cassette	Data storage capacity reduces frequency of data transfer functions
Data Transmission and Retrieval	
Umbilical/direct contact data extraction to intermediate storage unit	Low cost
Umbilical/direct contact extraction to computer	Eliminates problems with intermediate data handling
Non-contact data extraction: RF transmitters, infrared, etc.	Eliminates labor from data transfer
Real-time data transfer	Real-time schedule changes can be made

Table I-7. Data processing requirements.

On-Board Processing

- On-Board error detection
- Record formatting
- Additional data input: run number, route number (or block number), date, time-of-day

Data Validation

- Data screening for consistency and error-checking
- Reconstruction of data where possible to salvage useable information
- Pre-processing to segment data by route or other designation to facilitate data referencing

Data Referencing and File Construction

- Conversion from vehicle-specific files to master data file
- Location matching to identify stop location

Management Information

- Statistical and summary reporting
- Schedule adherence comparisons with run sheets
- Schedule construction

Data Management

- Data archiving and housekeeping including updating and destruction/retention of historical data

Diagnostic Reports

- Sensor accuracy tests
- Memory capacity

portion of the data processing effort. This includes the creation of aggregate files, updating these files, and archiving historical information.

Data processing involves a number of economic trade-offs. Some involve only the software itself and others require additional hardware to achieve less software, less processing, and fewer errors. Regarding software, there are decisions such as whether data should be stored in an aggregated form that directly corresponds to specific reports or whether an extensive data base management system providing reporting flexibility should be maintained. Use of signposts is an example of the hardware/software trade-offs. With signposts at time points, data referencing to time points becomes more or less a simple look-up procedure. Without signposts, identification of trip ends and intervening time points depends on time and/or distance matching. Time matching tends to be unreliable; while distance matching, to be effective, requires considerable programming and additional processing costs. Both vehicle-hours and vehicle-mileage (time and distance) vary by operator, traffic conditions, and the number of stops made.

Tables I-8 and I-9 provide checklists for identifying the software programs and external data files needed to support an on-board data collection system.

Table I-8. Software development checklist.

Program Name	Program Description*	Program Need (Check One) Essential	Desired
Unpack Data	Program to convert data from the packed decimal format (four-bit BCD reppresentation recorded on-board to the eight-bit ASCII format for data processing	x	
Back-Tag Data	Program converts (reconstructs) recorded time/date based on reference time provided by retrieval unit. (Required in systems using microprocessor cycles as clock-based systems--data discarded if mismatch detected.)		
Vehicle Identification	Identifies vehicle number from on-board unit number by referencing external file.	x	
Date Segmentation	Segments data into date-specific data blocks and classifies date by day of week, weather, school day, etc. (Desirable in all systems but may be foregone if data collection procedure provides this segmentation & labelling.)		
Block Identification	Identifies vehicle block number associated with each data segment. (Required in all systems to determine run/route/driver assignments corresponding to the recorded data.)	x	
Signpost Referencing	Identifies the physical location of the bus based on signpost numbers recorded. (Applicable only in systems deploying signposts.)		
Time Referencing	Identifies trip start/end points based on detecting layovers, i.e., intervals where no vehicle movement occurs for a specified time, from the data. (High data loss potential if this is only means of detecting trips.)		
Distance Referencing	Identifies trip start/end points and locations along the route based on matching recorded mileage with known route distances. (More complex than timebased referencing but potentially more accurate.)		
Manual Adjudication	Special software routines that permit data inspection and editing by computer operator to salvage data where possible.		
Vehicle Profiles	Graphical representations of passenger loading characteristics.		

*See Appendix I.D for additional descriptions.

Table I-9. External data file checklist.

File Name	File Description*	File Need (Check One) Essential	Desired
Data Conditions	External file used to maintain weather, school, holiday conditions, etc. to label dated data.		
Deadhead Distance	Defines distance between all route terminals including turnaround points.		
Performance Standards	Contains all service standards used for comparison in the various management reports.		
Route Distance	Measured distance from the route terminal to each time point along the route.		
Route Geography	Identifies locations corresponding to each signpost number.		
Running Time	Scheduled running time between time points (used to calculate running time deviations).		
Schedule File	Contains vehicle schedule including all schedule times and run/route assignments within each vehicle block.		
System Assignment	Identifies vehicle number of each installed data collection unit.		
Vehicle Dispatch	Identifies vehicle assignments made on each date.		

*See Appendix I.E for detailed description of each file.

CHAPTER I.4

DETERMINE SYSTEM SIZE

ESTIMATE THE NUMBER OF EQUIPPED BUSES (Section 4.1)

↓

ESTIMATE SIGNPOST REQUIREMENTS (Section 4.2)

↓

ESTIMATE OTHER EQUIPMENT NEEDS (Section 4.3)

↓

ESTIMATE VOLUME OF DATA PROCESSING (Section 4.4)

■Once the hardware and software configuration has been established, the next activity is to determine the amount of equipment necessary to implement an on-board, automatic data collection system. This section presents step-by-step procedures and worksheets for estimating how much equipment is required to meet the management information needs identified in Chapter I.3 or in other data collection program design, with the exception of specialized AVM applications of on-board automatic data collection systems.

The premise of these procedures is that reliable data on ridership, schedule adherence, and fare collection can be obtained from a representative sample of bus trips. The determination of appropriate amounts of equipment involves trade-offs between acceptable data accuracy and overall system costs. The sizing methodologies presented here are structured to permit transit agencies to analyze the implications of these trade-offs.

4.1 ESTIMATE EQUIPPED BUS REQUIREMENTS

The number of equipped buses required to implement an automated data collection system at a transit agency is dependent on several site-specific factors. Generally, the most significant factors are:

- Sampling strategy for collecting the data.
- Number of operating divisions or garages.
- Expected reliability of the data.
- The number and distribution of coach types.
- Special study requirements.

Background information on these and other issues that may affect equipped bus requirements is provided in Appendix I.F.

Two procedures that take into account these factors are presented below. The differences between these procedures reflect the two most common approaches to data sampling at bus transit agencies: systematic sampling and statistical sampling. Systematic sampling is accomplished by methodically assigning the equipped buses to different routes for the same number of days during each driver signup or seasonal schedule period. Statistical sampling is accomplished by varying the number of days equipped buses are assigned to individual routes to reflect the variability of ridership patterns on different routes. The sampling strategies and the advantages and disadvantages are described in Sections 4.1.1 and 4.1.2. Transit agencies should review the introductory material of both procedures and select the most appropriate method.

Both procedures for estimating equipped bus requirements are based on the following assumptions:

1. Data collection requirements for the largest peak period will dictate the number of equipped buses required. If sufficient equipment is purchased to obtain the data for this time period, it will be adequate to cover all other time periods.
2. Route interlining and trippers will not have a major impact on equipped bus requirements at most transit agencies. Some transit agencies may need to increase the equipped bus estimates to account for these operating characteristics.
3. Equipment requirements will be directly influenced by the reliability of the automated data collection system: accuracy of counting sensors, the approach used for location referencing, and reliability of the vehicles. Conservative estimates of equipment reliability factors are provided for typical system configurations.
4. Estimates based on typical routes can be used to determine equipped bus requirements. Individual route data collection requirements can be met by assigning more equipment to routes with higher sampling needs and less equipment to other routes.

It is not necessary to saturate a route with equipped vehicles in order to obtain adequate data. In fact, this practice tends to generate data that are biased by external factors such as weather or traffic conditions. The statistical accuracy of the data will be better if data are collected at different times selected randomly.

4.1.1 Estimating Equipped Buses Needed for Systematic Sampling

Systematic sampling is accomplished by methodically assigning the equipped buses to different routes or route blocks for the same number of days during each data collection period (i.e., driver signup or seasonal schedule change). Generally the goal is to obtain 3 to 5 valid data points on each vehicle trip or driver assignment during each data collection period. Such goals are usually established as the result of expert opinions expressed by schedule-makers, planners, and other professionals in the scheduling department. In fact, schedulers frequently perceive that a minimum of 5-days data each data collection period is imperative to obtain useful information.

From a practical viewpoint, this approach is relatively simple to implement because it is compatible with typical servicing and dispatching procedures. Systematic sampling is conceptually simple and does not require extensive prior data collection to implement. This approach is suitable to meet a range of transit agency data needs from annual systemwide data to route segment data by time period.

However, this process does not guarantee that the data collection for indvidual routes will yield estimates at the same prescribed level of confidence. Routes with stable ridership may not need the prescribed amount of sampling, while routes with fluctuating ridership may require much more sampling. However, where the overriding concern is not statistical accuracy but the acceptance and use of the data by participating departments, this policy-oriented approach may be deemed the only acceptable procedure despite a certain lack of statistical "purity."

The systematic sampling approach does not preclude the possibility of obtaining statistically reliable data. The initial data collected can be used to develop individual route sampling plans as time and experience with the system progresses. Differences between routes can be accommodated by selectively changing the sampling scheme to include more data collection where necessary. As the system matures, equipped bus requirements can be modified, if necessary, to accommodate unique system characteristics. Appendix I.F provides information and procedures that can be used to evaluate the statistical reliability of route level data.

Table I-10 contains the worksheet for estimating the number of equipped buses needed for systematic sampling. As noted on the worksheet, the first step is to select the appropriate systematic sampling scheme. Typical policies adopted in current applications of automated data collection systems (*5, 6*) are:

1. One 3-day check per data collection period.
2. One 5-day check per data collection period.
3. Two 5-day checks per data collection period.
4. Two 3-day checks per data collection period.

Three-day schemes are used where day-of-week differences are not a major concern to transit management. Where day-of-week information is important, a 5-day check is appropriate.

Table I-10. Systematic sampling equipped-bus requirements worksheet.

1. PRELIMINARY:

   a. Select systematic sampling scheme (Section 4.1.1).
   b. Identify the weekday peak period (AM or PM) requiring the largest number of vehicles.
   c. Identify appropriate geographic division (systemwide or operating division). Separate worksheets should be completed for each operating division.

2. PEAK PERIOD SAMPLE SIZE:

   S = (B x D)

   S = peak period vehicle blocks to be sampled for the system or operating division in each data collection period
   B = the total number of scheduled vehicles or vehicle blocks in largest weekday peak period
   D = the number of days of data desired (i.e., 3, 5, 10) ________

3. NUMBER OF AVAILABLE SAMPLING DAYS:

   Count the number of weekdays in the data collection period and subtract holidays, the first week of service change period, etc. ________

4. RELIABILITY FACTOR: Select reliability factor from Table I-11. ________

5. MINIMUM NUMBER OF EQUIPPED BUSES: Divide the peak period sample size by the number of available sampling days and reliability factor. (line 2 ÷ line 3 ÷ line 4) ________

6. ADDITIONAL NUMBER OF EQUIPPED BUSES:

   a. If transit agency has multiple coach types, and/or coaches dedicated to specific routes, increase the number of equipped buses by 10%. (line 5 x 0.1) ________

   and

   b. The number of buses reserved for special studies. ________ ________

7. EQUIPPED FLEET SIZE: Add lines 5 and 6. ________

Table I-11. Equipment reliability factors.*

Data Collection System with passenger counters, but no signposts	0.60
Passenger Data Collection System with passenger counters and signposts	0.70 - 0.75
Data Collection System with passenger counters, electronic fareboxes, and signposts	0.65 - 0.70
Data Collection System with passenger counters, multiple fare collection equipment, and signposts	0.60 - 0.65

*Reliability Factors include corrections for bus breakdowns, data collection equipment breakdowns, missed data collection assignments, bad data, and unidentifiable data. Some transit agencies have reported lower reliability factors. However these factors are considered to be realistic given improvements in equipment reliability and software design.

However, scheduling a 5-day sample can be complicated if data are missed or are invalid.

Repeated sampling (i.e., two checks per data collection period) can improve data reliability. The advantage of repeated sampling is that ridership patterns could be analyzed independent of schedule changes. For example, data taken early in a service change period could be compared with data taken later in the period.

4.1.2 Estimating Equipped Buses Needed for Statistical Sampling

In statistical sampling, route-level sampling requirements for individual routes are developed to ensure that the data meet prescribed confidence and tolerance levels (*1*). The number of trips to be sampled for each route depends on the variability of ridership. For example, a stable route may require only 1 or 2 days of limited data collection, while a new route might require a 10-day sample of all trips to obtain accurate ridership forecasts. Once individual route sampling requirements are determined, an estimate of the number of equipped buses can be made.

This approach generates statistically reliable data for all routes, meets UMTA's Section 15 requirements, and typically reduces the number of equipped buses as compared to the systematic sampling approach. However, there are some drawbacks in implementing it with automated data collection systems. The major difficulty with the approach is that the statistical validity is based on the assumption that all trips can be sampled randomly. This is more readily accomplished with manual checkers who can move from bus to bus. With an automated system where the equipment is assigned to vehicle blocks, usually with multiple trips per route, random trip sampling can only be achieved by selecting from the trips surveyed. In general, larger samples and thus more equipment may be required than suggested by research in this area to date (*7*).

UMTA-sponsored research has developed a method for designing a comprehensive statistically based data collection program that may be used to generate route-level sampling plans (*1*). However, because this method requires extensive prior data and complex procedures, it may not be wholly appropriate for estimating equipped-bus quantities.

An adaptation of the comprehensive statistical sampling approach is presented in Table I-12. The worksheet estimates the sample and equipment requirements for the average or typical route. Systemwide requirements are derived by simply scaling up these route-specific requirements to cover all routes. The premise in this approach is that the resulting equipment requirements will be adequate to ensure a statistically valid sample for all routes because equipment excesses on some routes will be shifted to make up equipment deficiencies on other routes. Provided the characteristics of the system's routes do not greatly deviate from a normal distribution, equipment schedule adjustments will accommodate route variations.

In order to complete the worksheet in Table I-12, statistical measures of ridership fluctuations are required. The coefficient of variation is used here and in related UMTA-sponsored research (*1, 8, 9*). Default values provided in Steps 3 and 4 are average values derived from these sources. Information that can be used for evaluating the default values is provided in Appendix I.F. Transit agencies which prefer to develop exact sampling plans for individual routes should use the procedures outlined in the "Bus Transit Monitoring Manual" (*1*) and enter the results on line 11.

4.2 ESTIMATE SIGNPOST REQUIREMENTS

The number of signposts required depends on the transit agency's management information needs and the level of accuracy required for stop record identification. The worksheet in Table I-14 includes two basic implementation options for

Table I-12. Statistical sampling equipped-bus requirements worksheet.

1. PRELIMINARY:

   a. Identify the weekday peak period (AM or PM) with the largest number of vehicle assignments.
   b. Determine if transit agency-specific values for the coefficients of variation are desirable and if data are available to estimate these values. If agency specific values are used, obtain a copy of the Bus Transit Monitoring (BTM) Manual (7).
   c. Identify appropriate geographic division (system-wide or operating division). Separate worksheets should be completed for each operating division.

2. AVERAGE DAILY NUMBER OF PEAK PERIOD TRIPS PER ROUTE:

   $T = S \div R$

   T = the average number of scheduled peak direction, trips per route in largest weekday peak period.
   S = the total number of scheduled peak direction, trips in largest weekday peak period. The estimate should only include trips which have at least fifty percent of the schedule in the peak period.
   R = the number of routes served in the largest weekday peak period. ________

3. WITHIN-DAY COEFFICIENT OF VARIATION: Estimate the variance of ridership on different trips within the peak period using information provided in Appendix I.F. Default: 0.45 ________

4. BETWEEN-DAY COEFFICIENT OF VARIATION: Estimate the variance of ridership on peak period trips on different days using information provided in Appendix I.F. Default: 0.15 ________

5. AVERAGE DAILY NUMBER OF SAMPLED TRIPS PER BUS: Estimate the average number of round trips per bus in the largest weekday peak period. Default: 2 ________

6. AVERAGE NUMBER OF DAYS SAMPLING REQUIRED ON AVERAGE ROUTE: If default values for lines 3 and 4 are used, select appropriate values from Table I-13. For other coefficients of variation consult Volume 2 of the BTM Manual and assume a 10 percent tolerance level. ________

7. TOTAL NUMBER OF SAMPLING DAYS REQUIRED: Multiply the average number of sampling days by the total number of routes (R) from Step 1. (Line 6 x R) ________

8. NUMBER OF AVAILABLE SAMPLING DAYS: Count the number of weekdays in the data collection period and subtract holidays, the first week of service change period, etc. ________

9. RELIABILITY FACTOR: Select reliability factor from Table I-11. ________

10. MINIMUM NUMBER OF EQUIPPED BUSES: Divide the total number of sampling days required by the number of available sampling days and reliability factor (line 7 $\div$ line 8 $\div$ line 9) ________

11. ADDITIONAL NUMBER OF EQUIPPED BUSES:

    a. Increase the number of equipped buses by 10 percent if a transit agency has multiple coach types and/or coaches dedicated to specific routes (line 10 x 0.1) ________
    and
    b. The number of buses reserved for special studies. ________

    ____

12. EQUIPPED FLEET SIZE: Add lines 10 and 11. ________

Table I-13. Required sampling days.[a, b]

NUMBER OF PEAK PERIOD TRIPS PER ROUTE (LINE 2, TABLE I-12)	NUMBER OF TRIPS SAMPLED PER DAY BY ONE TRANSIT BUS (LINE 5 OF TABLE I-12)			
	2	3	4	5
4	27	13	6	-
5	29	16	9	-
6	31	18	12	9
7	32	20	14	10
8	33	21	15	11
9	33	21	15	12
10	34	22	16	13
11	34	22	16	13
12	34	22	16	13
13	34	23	17	14
14	34	23	17	14
15	35	24	18	15
16	35	24	18	15
17	35	24	18	15
18	35	24	18	15
19	35	24	18	15
20	35	25	19	16
25	36	25	20	16
30	36	25	20	16
40	36	25	20	16

a. This table assumes a 10 percent tolerance level, 10 percent confidence level, and the default values on lines 3 and 4 from Table I-12.

b. Adapted from Bus Transit Monitoring Manual, Volume 2, Sample Size Tables.

signposts: (1) *minimum coverage*—two signposts per route, and (2) *comprehensive coverage*—one signpost per time point.

These two options represent the range of signpost requirements. Portable signposts may be a viable alternative to permanent installations at some transit agencies. For example, the minimum coverage option could be backed up by portable signpost transmitters. This would allow for more detailed route studies as necessary without installation of permanent signposts.

In implementing the minimum option, a transit agency would be provided with two odometer corrections per route. Assuming two signposts per route provides a quick estimate, but it may lead to higher equipment requirements than necessary at many transit agencies. An alternative is to map the route structure to identify locations shared by multiple routes. This philosophy was used in Seattle to minimize signpost requirements and yet obtain two corrections per route. A ring of signposts around the central business district is used to obtain one of the signpost records. One other signpost record per route is obtained using common signposts to the extent possible. Locating the signposts in this manner requires some effort, but significant cost savings can result. Seattle has 250 signposts for 174 routes.

Placement of signposts at time points provides improved running time data accuracy and stop-record identification. It would be particularly appropriate for transit agencies that require detailed route segment data for schedule adherence and construction applications. Theoretically, comprehensive signpost coverage would reduce the amount of data that had to be discarded because a location match could not be verified, and reduce the processing needed to associate individual data points with particular bus-stop locations.

The cost-effectiveness of installing large numbers of signposts has not been tested in actual operation. Sensitivity analysis undertaken in this research indicates that equipment and maintenance costs associated with deploying signposts at all time points would be approximately 20 percent more than the costs

Table I-14. Signpost requirements worksheet.

IMPLEMENTATION OPTION:	ESTIMATING PROCEDURE:	
Minimum Coverage: two odometer corrections per route.	Enter results of mapping the route structure to determine common locations.	______
	Default: 2 signposts per route.	
Comprehensive Coverage: one odometer correction per time point.	Enter total number of unique time points.	______
	Default: 5 signposts per route.	

associated with the recommended configuration of two signposts per route. It is doubtful that offsetting benefits can be realized.

4.3 ESTIMATE OTHER EQUIPMENT REQUIREMENTS

The final step in determining hardware requirements is to specify the amount of supporting equipment required. Table I-15 provides a worksheet for estimating the number of data retrieval units, status display units, and data transfer units. Other site-specific items should be added to the worksheet. This could include, for example, additional passenger counter sensors, odometers, wiring, and so on, for applications where the system controller will be transferred between vehicles. Diagnostic equipment should also be included here.

4.3.1 Data Retrieval Units

The number of data retrieval units required will be a function of the following:

1. The number of garages of operating divisions.
2. Procedures to be implemented in accomplishing data transfer.
3. Technology option selected for external receiver unit.
4. The number of data records to be generated.

In estimating the number of external retrieval units to be required, transit managers must decide how the data retrieval functions will be integrated into existing transit operations and then calculate the number of units and spares required.

Where portable data retrieval units are employed and data retrieval is not part of bus check-in or check-out procedures, as a minimum a transit agency should provide one data retrieval unit per garage, and one spare unit per five operating units to cover equipment failures. Providing a spare unit at each garage may be desired by some agencies. For those operating divisions where a large number of data records is to be generated routinely because of the number of equipped buses, a large number of retrieval units may be necessary depending on how frequently the data are dumped into the processing computer.

If a transit agency implements noncontact external units and/ or links data transfer functions with other bus check-in and check-out procedures such as fueling, fare collection dumps, or routing maintenance, the number of data retrieval units at each garage should be equal to the number of vehicle queues. Normally one spare for each five operating units would be adequate.

4.3.2 Status Display Units

One status display module for every 100 equipped buses is generally sufficient for effective monitoring of equipment performance. A spare unit may be desired by some transit agencies.

4.3.3 Data Transfer Units

The data transfer unit is the device that is used to transfer the data from the data retrieval unit to the host computer. If remote data entry from individual garages is used, one modem per garage plus one system spare would be appropriate. If the intermediate storage media (e.g., cassette tape or floppy disk) are physically transported to a central facility for processing, a total of two devices will be adequate (one operating unit plus one spare unit). Transit agencies interested in estimating connect time should refer to Section 4.4.1.

4.4 ESTIMATE VOLUME OF DATA PROCESSING

The volume of the data processing required for an automated data collection system will reflect the transit agency management information requirements specified in Tables I-2 and I-3, the efficiency of software programs, and the number of records to be processed. Although it is extremely difficult to quantify data processing functions, it is important to attempt an estimate because of the impact on annual data analysis costs and the computer capacity required to support the data collection sys-

Table I-15. Other equipment requirements worksheet.

1.	DATA RETRIEVAL UNITS	
	a. Enter the number of garages or operating divisions	____
	or	
	Enter the number of vehicle queue points at each operating division.	____
	b. Enter desired number of spare units (one per five operating units).	____
	c. Compute data retrieval units required (add lines 1 and 2).	____
2.	STATUS DISPLAY UNITS	
	a. Enter one unit per 100 equipped buses	____
	b. Enter desired number of spare units	____
	c. Compute status display units required (add lines 1 and 2)	____
3.	DATA TRANSFER UNITS	
	a. Remote data transfer: enter the number of garages	____
	or	
	Central data transfer: one unit	
	b. Enter desired number of spare units (one spare)	____
	c. Compute data transfer units required (add lines 1 and 2)	____

tem. Even more importantly, such an analysis provides managers with a gauge of the amount of data and paper that will result. If the results seem unreasonable, reevaluation of the system requirements may be appropriate.

The worksheets provided in this section are aimed at providing an assessment of the size and scope of four key aspects of data processing functions:

1. Volume of raw data to be handled.
2. Magnitude of management and diagnostic reports.
3. Data archive requirements.
4. Computer facility requirements.

4.4.1 Volume of Raw Data

Data processing involves extracting required route and system level information out of the data collected by each vehicle. The magnitude of this processing operation is extremely difficult to quantify. It is not possible to determine the number of data calculations and data manipulations that will take place and, even if known, such values could not be translated into costs unless known software is used to provide a benchmark on a particular computer. Nonetheless, it is desirable to attempt some estimate of the magnitude of this operation.

Table I-16 provides one possible means for approximating the amount of data that will be processed. The estimated data input volume shown on line 5 or connect time on line 9 can be used by the transit agency processing center or computer services vendor to estimate processing costs where a mainframe computer is used for processing.

4.4.2 Management Information and Diagnostic Reports

Developing and generating specific management and diagnostic reports is identified as a separate step from the general processing data in the previous step for several reasons. First, some additional software development effort can be associated with each report or output required from the system. Typically, the effort associated with this development is a function that

Table I-16. Data input volume worksheet.

1.	Enter number of equipped buses actually assigned to daily data collection activities. Default: 90 percent of total equipped buses unless experience differs.	_____
2.	Enter number of records generated per bus per day. Default: 1,000 records per bus unless experience differs.	_____
3.	Enter average number of days per month sampled. Default: 22 days.	_____
4.	Enter average number of bytes of data per record. Default: 13 without fare component; 28 with fare component.	_____
5.	Calculate annual record volume. (12 x line 1 x line 2 x line 3)	_____
6.	Calculate average daily record volume. (line 5 ÷ 250)	_____
7.	Calculate average daily bytes of data transferred to host computer. (line 6 x line 4)	_____
8.	Enter data transfer rate from intermediate storage to host computer (assume 9,600 baud unless known different)	_____
9.	Calculate average daily time consumed (in minutes) inputting data to computer. $\frac{(\text{line 7} \div \text{line 8})}{60}$	_____

monotonically decreases with the number of reports generated, particularly, if a data base management system is used. That is, within limits, each additional report or output will cost less to program than the previous one.

Second, the level of detail and the frequency of the management reports and other outputs as identified in Table I-3 drive several cost items. The greater the detail and the more frequently these outputs occur, the greater the cost will be for computer time, analyst time, printer and plotter costs, and data storage charges.

Table I-17 provides a general procedure for estimating the impact data detail and frequency will likely have on the printed output costs estimated in Chapter I.5. These estimates also provide a general measure of the overall magnitude of this activity and how much printed output will be generated. A single numeric value is assigned to each row/column intersection using the estimator provided in each column heading. The values are multiplied in the last column and summed to produce a rough estimate of the volume of output that will be generated. At this point transit agency managers should take a critical look at the amount of data to be generated to determine whether the information can be used effectively. If the volume of data seems unreasonable, it may be desirable to scale down the amount of reporting initially specified.

4.4.3 Data Archiving Requirements

An often overlooked step (and cost) is the activity associated with maintaining an up-to-date data base and whatever historical record is required. Off-line data storage must be planned for all data that will be retained and charges will be incurred for maintaining the data. More significantly, considerable time and effort must be devoted to establishing the procedures by which data will be periodically reviewed, updated, and archived, as well as to maintaining a custodial role over this archive, including data retrieval and reporting from historical files. The worksheet in Table I-18 provides a procedure for estimating data storage requirements.

4.4.4 Computer Facility Requirements

Once general estimates of the size and scope of the data processing effort are obtained, one can begin to consider how the system will be implemented. For most large agencies, this step means summarizing the requirements posed by the data collection system and determining whether or not the existing computer facilities can accommodate the increased workload. This includes not only machine capacity but also programming/analyst support.

Table I-17. Management information report output worksheet.

Report Name	Number Of Routes	Report Frequency 4-Quarterly 12-Monthly 52-Weekly	Time of Day Interval 5-Limited Periods 24-Hourly Interval 96-15 Min. Interval	Data Segmentation 1-Trip/Rte Summ. 3-Time Point 5-Stop-By-Stop	Printed Output Estimate (Multiply all columns together to estimate approximate lines of printed output annually)
Section 15					
Ridership					
Running Time					
Schedule Deviation					
Overloading					
Revenue Statistics					
Fare Category					
Revenue Accounting					
TOTAL: (Sum last column.)					

Table I-18. Report file size worksheet.

Report Type (Enter Each Major Report)	Number Of Routes	Data Segmentation (Enter Number of Data Intervals Maintained; Enter 1 If Not Segmented)						Approximate File Size (Bytes) (Multiply all Colm Entries & Double)
		Number Of Directions[a]	Day of Week Intervals[b]	Time of Day Intervals[b]	Number Of Segments/Stops[b]	No. of Records Maintained[c]	No. of Statistics Reported[d]	
Section 15								
Ridership								
Running Time								
Schedule Deviation								
Overloading								
Revenue Report								
Fare Category								
Revenue Accounting								

(a)Where inbound and outbound data are needed, enter 2.
(b)See Table I-3 for typical data segmentation categories.
(c)Entry for Number of Records maintained should reflect how much data is retained in the active database. For example, if each new data point is used to calculate a new average and only the new average is retained, enter the value 1. Otherwise enter number of data points that will be distinctly retained.
(d)See Table I-2 for typical statistics contained within each report type.

More frequently, costs will not be so straightforward and will have to be determined on the basis of estimated demands on an in-house or outside computing facility on the basis of input/output, lines printed, plots generated, etc. For the present, the major concern is to attempt to characterize the type of data processing equipment that will likely be needed to support a particular proposed operation. As will be discussed in Chapter I.5, the type of processing equipment can have a significant impact on system cost. Table I-19 summarizes the general characteristics of typical hardware that could be considered for the various tasks of computing, storing, printing, and plotting the information. By comparing these capabilities, an overall view of the potential system requirements may be developed. A fairly good estimate of the restrictions certain equipment present and conversely of the types of equipment required to support specified operational levels can be obtained by comparing the estimates derived for the automatic data collection system with Tables I-17 and I-18 with the capabilities presented in the Table I-19. In examining system requirements, assistance from the agency processing department or system vendor should be obtained.

Table I-19. Representative equipment characteristics.

COMPUTER SYSTEMS

System Type	Word Length	Typical Internal Memory Capacity (Bytes)	Representative Cost (Excluding Peripherals)
Mainframe	32-64 bits	1M to 10 M+	$200K-Million+
SuperMini	32 bits	512K to 8 M	$ 50K - $ 200K
Mini	16 bits	256K to 4 M	$ 20K - $ 50K
Advanced Micro	16 bits	128 K to 1 M	$5,000-$10,000
Micro	8/16 bits	64K to 640K	$2,000- $5,000

AUXILIARY MEMORY

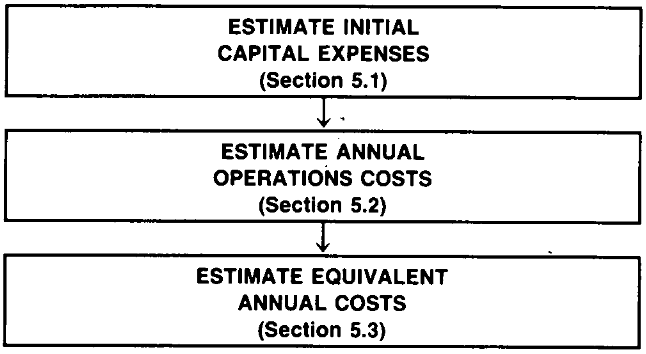
Device Type	Typical Application	Representative Storage (Bytes)
Multiple Head, Multi Platter Disk	Mainframe	300 M
Nine-Track Tape	Mainframe	40 M
Single Head Hard Disk	Mainframe/Mini/Micro	10 - 40 M
Eight-Inch Floppy	Mini/Micro	1 M
Five-Inch Floppy	Micro	160 -320 K

PRINTERS

Device Type	Typical Application	Representative Speed (Lines per Minute)
High-Speed Line Printer	Mainframe	2,000 +
Medium-Speed Line Printer	Mainframe/Mini	1,200
Low-Speed Line Printer	Mainframe/Mini	200 - 400
Dot Matrix	Micro	100
Daisy Wheel	Micro	25

CHAPTER I.5

COST ANALYSIS



■The potential costs of the on-board automatic data collection system are estimated after the amount of equipment has been determined. Step-by-step procedures and unit cost data for developing these cost estimates are presented in this chapter.

5.1 ESTIMATE INITIAL CAPITAL EXPENSES

The initial capital investment in automated data collection consists of:

1. Data gathering hardware costs to include the equipment located on-board the vehicle, wayside equipment, and the hardware required to extract data from the vehicle.
2. Data analysis investment costs to include computer hardware costs, if any, and the cost of developing the required software and external files.
3. Miscellaneous initial costs to include operator, mechanic, or other training.

5.1.1 Data Gathering Hardware Costs

A worksheet for determining capital costs of the data gathering hardware for an automated system is provided in Table I-20. The capital costs of the automated data collection are estimated by multiplying the results of the system sizing procedure in Chapter I.4 with appropriate unit costs. To this estimate, additional costs for contingencies, shipping and acceptance, general and administrative requirements, installation, and spare parts are added.

The worksheet contains unit prices for each module component. These prices are based on data provided by equipment manufacturers. Where data were not available from equipment manufacturers, an estimate of the likely high cost of the component is provided. This estimate is based on data available from electronic trade publications and expert judgment and should be interpreted as the upper limit; in other words, the cost should not exceed this amount.

Where fare data are to be collected with the automated passenger counting system and new fare collection equipment is purchased—fareboxes, pass readers, etc.—only the incremental costs associated with data collecting functions should be attributed to the data collection system. This research has found that the costs of modifications to a transit agency's fare collection system cannot be supported by the data collection system.

Other costs related to the initial investment—contingencies, shipping and acceptance, general and administrative, installation, and spare parts—can be estimated as a percentage of the hardware costs. The values suggested in Table I-20 generally reflect current industry practices. Spare parts requirements are lower than might be expected because the sizing procedures incorporate reliability factors for equipped vehicles. Spare parts would be limited to those items susceptible to damage (e.g., passenger counter sensors, data transmission units). If the data collection system is to be rotated among the buses, the extra cabling and brackets should be included in the worksheets.

Where specific unit costs for individual suppliers are desired, transit agencies should contact suppliers listed in Appendix I.C. Specific manufacturer estimates would take into account equipment order sizes, any site modifications, acceptance testing, and warranty requirements.

5.1.2 Data Analysis Investment Cost

Table I-21 provides a worksheet for estimating the three capital cost components associated with data analysis:

1. Computer facilities including peripheral devices to enter, process, output, and store the data.
2. Software programs to process the data and extract management information.
3. External files to reference and validate data.

5.1.2.1 Computer Hardware

As indicated in Table I-21, computer hardware costs are incurred only if a microcomputer or a minicomputer is purchased for the exclusive use of the data collection system. If a mainframe computer is used, processing costs are assumed to include capital recovery. The costs quoted for computer equipment are general estimates based on trade publications.

Careful consideration should be given to the type of computer facilities to be used. Some transit agencies may find dedicated computer facilities desirable because they can exercise more control over system development and day-to-day operations.

Table I-20. Data collection hardware cost estimate worksheet.

Hardware Item	Unit Price(a)	Estimated Quantity (Chapter I.4)	Per Unit Cost	Total Cost
1. Passenger Counter Sensors				
a. Photoelectric	$300(b)			
b. Switch Mats	$300 - $350(b)			
2. Passenger Counter Electronics	$200(c)			
3. Fare Category Counter				
a. Electronic Farebox	$4000(d)			
b. Pass Reader	$500			
c. Ticket Validator	$1200 -$1500			
4. Odometer	$120			
5. Signpost				
a. Wayside Transmitter	$300			
b. On-Board Receiver & Antenna	$800 - $1000(e)			
6. Manual Input Console				
a. Minimum Version	$100			
b. Expanded Version	$400			
7. System Controller	$1000 - $1200(f)			
8. System Memory				
a. Cassette	$300			
b. Base Solid-State (to 32K)	$400			
c. Expanded Solid State(to 64K)	$500			
9. External Control	$100			
10. Status Display Device	$1000			
11. Data Transmission: On-Vehicle				
a. Off-Line (Physical Con.)	$50			
b. Off-Line (Infrared Transc.)	$125			
c. Real-Time (Radio)	$2000			
12. External Receiver: Operating Station				
a. Direct Cassette Transfer	$2000			
b. Interm. Storage (Cassette/ Disk)	$6000			
c. Base Radio Station	20,000-40,000			
13. SUBTOTAL (Sum Entries in 1 thru 12)				
14. Contingency(g)	10%			
15. Shipping and Acceptance(g)	10%			
16. General and Administrative(g)	20%			
17. Installation(g)	10%			
18. Spare Parts(g)	5%			
19. TOTAL HARDWARE COST (Sum Entries in 13 thru 17)				

(a)Prices include cabling and mounting brackets or hardware where required.
(b)Unit prices for passenger counter sensors are quoted per passenger stream. Costs assume two sensors per passenger stream. Quantity value must be expressed in terms of the total number of doors on which sensors must be installed. For standard size bus, the number of sensors would be 2 x the number of buses. Double wide doors with two passenger streams should be counted as two doors.
(c)Price quoted for passenger counter electronics is for the separate logic board required in the modular system.
(d)Price quoted is for a new electronic registering farebox. Non-registering electronic fareboxes can be upgraded at a cost of $500-1,000 per unit.
(e)Price quoted includes antenna on vehicle as well as the on-board receiver required for the modular system.
(f)Price quoted for system controller does not include interface electronics for other modules or memory. These items are priced separately in the modular system.
(g)Use line 13 to determine total cost.

Dedicated computer facilities can also produce substantial savings in processing costs compared to third-party time-share arrangements. The research suggests that, at large transit agencies, an in-house mainframe can produce substantial benefits through lower processing costs and sale of excess computer time. At medium-size transit agencies, the cost of an advanced microcomputer or midrange minicomputer would be rapidly offset by savings in processing costs with a payback of 2 to 5 years depending on the size of the system.

In addition, after the automated data collection system is implemented, changing the type of computer facilities could be expensive. It is not a simple task to modify software written for one type of computer for use with another. In many cases, new software may be required.

5.1.2.2 Software Development

Table I-21 provides estimates of software development costs for automated passenger counting systems both without and with signposts. The estimates are based on judgments of the relative complexity of the programs constituting the overall management information system. Because software development is particularly difficult to estimate, a general sensitivity analysis should be undertaken to examine the effects of varying software development costs on total system costs.

It is not uncommon for software development to exceed expenditures for hardware because software development costs are relatively independent of transit agency size (*5, 6*). The basic software to assemble, edit, analyze, and report the data is independent of the size of the data collection system. Smaller transit agencies can expect to bear the same costs as larger agencies.

5.1.2.3 External File Development

The costs associated with the set-up of the external files (see

Table I-9) are almost exclusively labor costs. Staff time is required to collect the data that will be maintained in each file and to develop the computerized version of the file. The estimates provided in Table I-21 were developed from historical values to approximate the cost of developing these external files. More detailed estimates may be obtained by costing each file individually based on the resources that would have to be devoted to its construction.

5.1.3 Other Miscellaneous Initial Costs

Implementation of an on-board data collection system will involve some additional miscellaneous costs for training. Training programs for bus operators and mechanics have to be designed. Vehicle operators should be familiar with the operation of the equipment, how to resolve anticipated problems, and how to handle the public's reaction to new equipment. The revised training program should also be incorporated into the new operator training program. Where driver input is required, procedural manuals will have to be altered. The type and amount of mechanic training will be a function of existing skill levels and the modules selected for specific system configurations. If these costs are expected to be significant, transit agencies may desire to include them in capital cost estimates. Since specific information on these costs is not available, the costs of providing similar functions in a transit agency should be used as a base for estimating purposes.

5.2 ESTIMATE ANNUAL OPERATIONS COSTS

Annual costs for the automated data collection system include equipment monitoring and maintenance, data processing and storage costs, and staff costs. In addition, rotating equipment among buses is labor-intensive. Annual budgets should include the labor required for equipment transfer. A worksheet for determining annual costs is contained in Table I-22.

5.2.1 Hardware Maintenance

Automated equipment requires monitoring and adjustment and scheduled as well as unscheduled maintenance. Because of

Table I-21. Initial data analysis investment cost estimate worksheet (1983 dollars).

1. COMPUTER FACILITIES

   Estimated investment in computer hardware including auxillary storage and peripheral devices: ________

   Default:
   Mainframe application: Cost = 0
   System-level application utilizing an advanced microcomputer: Cost = \$10,000
   Special purpose/limited application utilizing a low-range minicomputer: Cost = \$30,000
   Management information system application utilizing mid-range minicomputer: Cost = \$50,000

2. SOFTWARE DEVELOPMENT

   Estimated investment in software development: ________

   Default:*
   System without signposts: \$123,000
   System with signposts: \$78,000

3. EXTERNAL FILE DEVELOPMENT

   Estimated investment in creating external files: ________

   Default:
   If system schedules are currently automated and computerized schedule files are available: Cost = \$50 per peak vehicle.
   If current schedule is not automated and computerized schedule files must be developed: Cost = \$150 per peak vehicle.

4. TOTAL DATA PROCESSING INVESTMENT

   (Sum lines 1, 2, and 3) ________

*Default values are based on software cost analyses undertaken by the Economic and Cost Group of The MITRE Corporation using the Constructive Cost Model (COCOMO) developed by Boehm in Software Engineering Economics, Prentice-Hall, Inc. (1981). The default values are based on estimates of the number of lines of code required and assume the report generator would be an off-the-shelf software package.

the relatively high maintenance requirements that have been associated with electronic fareboxes, annual maintenance requirements for the passenger and fare collection hardware should be determined separately.

5.2.1.1 Passenger Data Collection Hardware

In the past, 18 percent of the capital budget has been used as an estimate of annual maintenance expenditures. This value compares favorably with budget estimates from Cincinnati and Kalamazoo (*5*, p. 44 and p. 50). Seattle Metro reports that its maintenance costs are about 12 percent of the capital budget.

To determine annual maintenance costs, the capital costs of any fare collection equipment (electronic fareboxes, ticket validators, pass readers) should be subtracted from the total system costs derived in Table I-20 and the appropriate factor applied. The higher 18 percent factor should be used at transit agencies which may be required to increase mechanic salaries as a result of increased skill requirements. These cost factors are assumed to apply to maintenance performed in-house or by a contractor.

5.2.1.2 Fare Data Collection Hardware

Electronic fare data collection equipment, particularly reg-

Table I-22. Annual maintenance and operations cost estimate worksheet.

1.	HARDWARE MAINTENANCE	
	A. Passenger Data Collection Hardware: 12 to 18 percent of hardware cost excluding fare collection hardware (Table I-20, line 13 - line 3). Default: 15 percent	________
	B. Fare Data Collection Hardware: Estimate incremental maintenance cost for fare data collection equipment. Default: 1 mechanic per 100 data gathering fareboxes multiplied by local annual wage and fringe benefits rate.	________
	C. Computer Hardware: 12 percent of computer facilities cost (Table I-21, line 1).	________
2.	DATA PROCESSING COSTS	
	A. Computer Processing: Estimate annual charges for cost center or time share mainframe application. No cost for micro/mini computer application. Default: System without signpost reference: $0.004 per input record (Table I-16, line 5). System with signpost reference: $0.0036 per input record (Table I-16, line 5).	________
	B. Printed Output Cost: $0.001 per line output (Table I-17). Default: $2.00 per equipped bus.	________
	C. Plotted Output Cost: $4.00 per graph. Estimate the number of graphs desired. Default: 12 graphs per route.	________
3.	STAFF Estimate the total staff costs to operate the system excluding hardware maintenance. Default: A. System Administration/Coordination/Support: 0.50 person years (transit analyst or equivalent wage category) plus one full-time equivalent per 300 peak-period buses. B. Management and Supervision: 25 percent of labor costs associated with administration, coordination, and support.	________
4.	TOTAL ANNUAL O&M COSTS Sum lines 1, 2, and 3.	________

istering fareboxes, appears to be sensitive to environmental factors and some components have a short life. Extensive preventative maintenance is particularly critical for those units which have been upgraded for data collection so that bus downtime is minimized. The incremental cost of maintaining this equipment should be attributed to the data collection system.

Estimates of farebox maintenance requirements range from 60 to 125 boxes per mechanic (*10*). Recent Southern California Rapid Transit District (SCRTD) analysis suggests one mechanic per 100 fareboxes may be representative (*11*, p.2).

5.2.1.3 Computer Hardware

Maintenance of computer hardware is only required where dedicated computer facilities are used. The 12 percent factor is based on a survey of maintenance contracts provided by computer manufacturers.

5.2.2 Data Processing Costs

The annual costs of data processing include computer processing costs and output costs as given in Table I-22.

5.2.2.1 Computer Processing

For a mainframe application, computer costs are typically those charges by the supporting computer center or time-share service. It is virtually impossible to estimate these charges reliably because the cost will depend on the type of computer used, program efficiency, data loss rates, location matching effectiveness, and so on.

The default values included in Table I-22 are reasonable values to expect from an internal computer cost center based on the general amount of data handling and verification in typical automated systems. Time-share service costs are likely to be higher because they generally include a profit margin as well as capital recovery of facilities, connect time, and staff.

If the annual costs of processing the data appear excessive, transit agencies should reconsider the possibility of purchasing a dedicated computer (see Section 5.1.2.1). If a microcomputer or minicomputer is used, annual data processing costs are assumed to be zero.

5.2.2.2 Output Costs

The cost of generating hard copy output and graphics is similar for all computer hardware. The default values in Table I-22 are based on reasonable charges from a computer cost center. A microcomputer or minicomputer application will incur similar costs for paper, ribbons, and the like.

5.2.3 Staff

Staff costs include all labor costs associated with administering and managing the date collection system, with the exception of hardware maintenance. These costs include, but are not limited to, the effort required to coordinate and supervise the assignment of buses, review and verify data, update external files, analyze and interpret information, and develop reports. The estimates provided in the worksheet assume a comprehensive management information system in which a substantial effort is devoted to information interpretation and historical comparisons. A transit agency is encouraged to define its own requirements in this particular area. Staff costs quoted by most transit systems currently involved in automated data collection are lower than the default values. This is because a complete management information system has not yet been implemented or, alternatively, the cost accounting does not include all of the staff resources that are actually involved in data collection activities. The latter may be especially true where data interpretation is considered a planning, an operations, or a scheduling activity rather than a data collection one.

5.3 ESTIMATE EQUIVALENT ANNUAL COSTS

Analysis of the economic feasibility of various options for data collection requires comparisons of sums of money disbursed at various points in time. Evaluation techniques that take into account the time value of money or interest and recognize differences in cash flow over time are required.

Several procedural methods for analyzing the economics of investment alternatives are available. The method recommended here is the equivalent annual cost approach. In this approach a time discount factor reduces all cash expenditures occurring at different time periods to an equivalent uniform amount for each year of the analysis period.

Table I-23 provides a worksheet that can be used for calculating the equivalent annual costs for automated data collection system configurations. The equivalent annual cost is determined by applying the appropriate compound interest formula factors to major cost components for each alternative, and summing the annualized component costs (*12*).

The recovery factors in Table I-23 are based on a 10 percent discount rate, the discount rate specified by the Office of Management and Budget for evaluations of Federal Government procurements (*13*). This discount rate represents the Federal Government's estimate of the average rate of return on private investment, before taxes and after inflation.

The economic life of the data collection system is the number of years of service a transit agency expects to retain the specific data collection system that is being procured. It does not equal the physical life of individual modules.

Some modules such as the passenger counter sensors may have to be replaced because of their relatively short physical life. Other modules such as the system controller will be useful for many years. The major issue for determining the life of the system is likely to be technology obsolescence. Transit managers may very well decide to replace a data collection system which is still functioning with one that uses improved technology. Ten years has been selected as the basis for overall system life on the basis of Seattle METRO's experiences. A 5-year life is assumed for shorter life components.

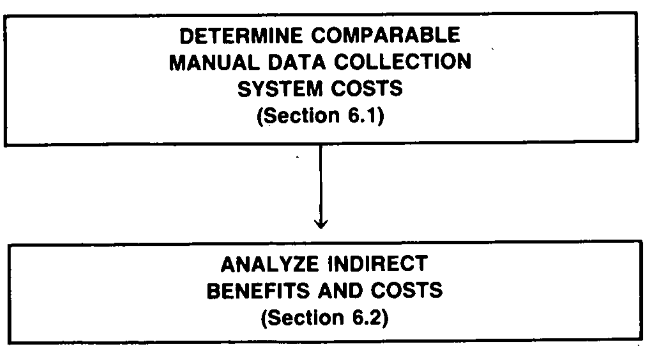
Table I-23. Equivalent annual cost estimation worksheet.

Cost Component	Total Cost (A)	Recovery Factor (B)	Annualized Cost (A x B)
1. Hardware Costs[a] (from Line 19, Table I-20)		0.16275[b]	
2. Incremental Cost Associated with Replacement of Items with Less than 10 Year Life. (Sum of Total Cost in Lines 1, 11 & 12, Table I-20)		0.10105[c]	
3. Data Processing Investment (From Table I-21)		0.16275[d]	
4. Annual Maintenance and Operations Costs (From Table I-22)		1.000[e]	
5. Total Annualized Cost (Sum lines 1 through 4)			

(a)Where Federal and State funds will be used for equipment procurement, the total hardware cost can be reduced accordingly, to determine the real cost to the transit agency.
(b)10 percent discount rate and 10 year life.
(c)Value indicated is for replacement in year 5.
(d)Assumes software costs recovered in 10 years.
(e)No discount factor is applied to annual costs.

CHAPTER I.6

CONDUCTING BENEFIT ASSESSMENT



The cost analysis outlined in Chapter I.5 provides only one part of the economic evaluation. It does not include an assessment of the potential benefits that can result from implementation of an automated data collection system. Automated systems have the potential for lowering data collection costs compared to a similar manual data collection system. Improvements in the quality of transit agency management information in terms of reliability, coverage, and availability can generate indirect benefits such as better management decision-making and operating cost savings.

Although this assessment is optional, the results can play an important function in the agency decision to implement an on-board, automatic data collection system. In particular it can provide the justification for the investment in the system. Because the type and magnitude of any benefits are directly related to conditions at a particular transit agency, the analysis is presented in a directed, but open-ended format to encourage exploration of a range of site-specific benefits.

6.1 DETERMINE COMPARABLE MANUAL DATA COLLECTION SYSTEM COSTS

As illustrated in Figure I-3, the annual cost of an automated system can be less than that of a manual data collection system for a comparable data collection effort. At small transit agencies (less than 100 peak buses), the annual cost of an automated system would be comparable to the annual cost for a manual system. At larger transit agencies, the total annual cost of the automated system approximates the cost of the checker salaries alone and can be significantly lower than the total costs of manual data collection.

Comparative analysis of the economics of an automated data collection system with a manual system should be based on comparable data collection activities. This is not generally equivalent to the typical transit agency's expenditures for manual data collection programs. Generally, manual data collection systems collect fewer data items, less frequently. In many cases, vehicle operators provide some or all of the data.

Table I-24 provides a worksheet for estimating the costs of a comparable manual data collection system. This procedure assumes a data collection effort comparable to an automated system in terms of both the amount and accuracy of data collected. It also assumes that automatic data processing is used for manual systems. Transit agencies that intend to replace their current manual data collection program with a comparable automated system should use historical records to complete Table I-24. For other transit agencies, default values are provided for completing the worksheet.

6.1.1 Cost of Data Collection

The cost of collecting the data includes the salaries of manual checkers and administrative/supervisory personnel needed to train checkers and monitor data collection.

6.1.1.1 Manual Checker Costs

Estimates of checker staff size requirements for bus systems of different sizes were developed in conjunction with the statistically based sampling plan developed by Attanucci (*1*, p. 8). The results are included in Table I-25 and may be used to estimate the number of checkers needed based on the number of peak period buses and the level of data required. The lower end of the range is appropriate for transit agencies desiring systemwide data, while the upper limit reflects checker staff sizes necessary for route level analysis.

These manpower estimates assume point or peak load checks to supplement on-board ride checks. The estimates also assume that every route of the system is monitored four times a year (i.e., four data collection periods each year). If more or less frequent monitoring is desired, these requirements should be changed correspondingly. These guidelines provide for sufficient personnel to cover all data collection activities, not just for peak hours.

Ideally checker salary and fringe benefits should be based on local wage scales. The default value included in Table I-24 is reported in other research and approximates the salary and fringe benefits at several transit agencies (*5*, p. 50).

6.1.1.2 Administrative and Supervisory Personnel

Administrative and supervisory staff are required for scheduling traffic checkers, data analysis, and other management responsibilities. Staff requirements will depend on checker staff size and scheduling complexity. However, a conservative average of 1 per 20 checkers can be used as an estimate. Local wage rates should be used to estimate annual costs.

6.1.2 Data Processing Investment

The initial cost of a manual data collection system includes the cost of acquiring computer facilities and development of software to analyze the data. As noted in Table I-24, the initial cost of these items should be amortized in estimating the annualized cost of the manual data collection system.

6.1.2.1 Computer Facilities

Capital costs are involved only if a microcomputer or a minicomputer is purchased for the exclusive use of the manual data collection system. Storage and processing requirements for a manual data collection program are expected to be lower than the requirements for an automated system and less sophisticated equipment can be used.

6.1.2.2 Software Development

There is a relatively high initial start-up cost for software development and external file creation even for small agencies. The sum of $135,000 has been suggested as an informed estimate for software development (*5*, p. 51). However, if compatible software can be acquired, the cost could be less. Some transit agencies (e.g., SCRTD in Los Angeles, Metropolitan Transit Commission (MTC) in Minneapolis-St. Paul, Massachusetts Bay Transit Authority (MBTA) in Boston) have developed software to analyze point and ride check counts, as well as some other types of transit performance data (such as revenue). These programs are usually made available to other agencies at no cost upon request (*1*, p. 80). The default value used in the worksheep assumes that significant savings in software development can be achieved by taking advantage of such industry sharing arrangements.

6.1.3 Annual Maintenance and Processing Costs

The manual data collection system will also require expenditures for computer maintenance if dedicated computer facilities are purchased, as well as data entry, data processing, and staff costs. Compared to an automated system, the data processing activities in a manual data collection program will have higher data entry costs and lower processing costs.

Table I-24. Manual data collection cost estimation worksheet.

1. COST OF DATA COLLECTION

A. Manual Checkers: Determine number of manual checkers required and multiply by prevailing annual wage and benefit rate. Default: Select value from Table I-25 and assume $23,000 annual rate. ________

B. Administrative/Supervisory Personnel: Determine staff requirements and multiply by prevailing annual wage and benefit rate. Default: 1 person per 20 checkers with $35,000 annual rate. ________

2. DATA PROCESSING INVESTMENT

A. Computer Facilities: Estimate investment in computer hardware and multiply by 0.16275 capital recovery factor. Default: Assume 50 percent of automated system cost from Table I-21 and multiply by 0.16275 capital recovery factor.

B. Software Development: Estimate investment in software and multiply by 0.16275 capital recovery factor. Default: $50,000 initial cost or $8,100 annual cost. ________

3. MAINTENANCE AND OPERATIONS COST

A. Computer Maintenance: 12 percent of total capital investment in computer facilities. ________

B. Data Entry: Use historical records. Default: $1,000 per checker per year. ________

C. Data Processing: Use historical records. Default: 80 percent of automated system costs from Table I-22, lines 2A, 2B, and 2C. ________

D. Data Processing Staff: Use historical records. Default: 80 percent of automated system costs from Table I-22, line 3.

4. TOTAL ANNUAL COST OF MANUAL DATA COLLECTION ________

Sum lines 1, 2, and 3.

6.1.3.1 Computer Maintenance

A survey of computer manufacturers' service contracts indicates that the annual cost of computer maintenance will be approximately 12 percent of the total initial cost.

6.1.3.2 Data Entry

Generally it is necessary to transcribe the handwritten data on the completed forms to another medium that is capable of being read and interpreted by a computer. (Automated data entry devices and portable computers are being developed that could eliminate this step. An assessment of the cost implications is not possible at this time.) Data transcription is time consuming, error prone, and requires trained personnel. Studies have shown that of all errors detected in the data, only about 15 percent of the errors occur in the source data content, with the remaining 85 percent introduced through data transcription (*14*, p. 481). Salaries of data entry personnel can represent as much as 80 percent of the total cost of data preparation (*14*, p. 481).

The default value for data entry in Table I-24 assumes data entry will require approximately one-half hour per checker day (i.e., $5.00 per checker day with each checker working 200 days on the average). Actual costs are expected to be higher than these estimates. For example, one transit system reports its checker staff of 30 (including three field supervisors and one field coordinator) requires 18 people for data entry. A conservative value was chosen deliberately in order to favor the manual system in the comparison of manual and automated programs.

6.1.3.3 Data Processing

Because of the potential errors, the computer itself may have to carry out extensive checking of the validity of the data and may have to access other files for confirmation through a process that closely resembles the procedures used in an automated system. However, the total cost of the processing is expected to be less than in an automated system because fewer records are involved and because the data obtained through manual checkers is already annotated to identify run, route, location, etc. Data processing costs are assumed to be approximately 80 percent of the processing costs associated with an automated system.

6.1.3.4 Staff

Staff costs associated with manual data collection will not be significantly less than staff costs associated with an automated system. Assuming a comprehensive management information system, many of the activities associated with administration, coordination, support, and management are required. In the absence of historical values for comparison, 80 percent of the staff costs of the automated system should be assumed.

6.1.4 Analysis of Results

The equivalent annual costs of the automatic data collection system and the manual data collection system are estimated in Tables I-23 and I-24, respectively. In strict economic terms, the alternative with the lowest equivalent annual cost is the most feasible. It is the alternative that minimizes the data collection cost to the transit agency where the indirect benefits and costs are equal. As discussed in Section 6.2, there are significant, potentially quantifiable as well as intangible factors associated with implementation of an automated data collection system which suggests the options are not equal in benefits.

6.2 ANALYZE INDIRECT BENEFITS AND COSTS

To the extent an automated data collection system improves the quality of data and data turnaround time at a transit agency, the system can have beneficial effects on the management decision-making process and agency productivity and efficiency. At the same time, however, introduction of sophisticated electronic equipment and the changes in operating procedures that are required as a result can increase some operating and maintenance costs and in some instances may represent a major barrier to implementation of automatic data collection systems. A list of potential benefits and costs is provided in Table I-26.

The potential dollar value of the benefits and costs contained in the checklist is directly related to conditions at a particular transit agency, particularly the quality of each transit agency's current data collection program and schedule efficiency. It is difficult to speculate in advance what benefits may occur and the magnitude of any potential benefits. Some significant benefits of automated data collection systems (i.e., improved management decision-making) cannot be expressed in monetary terms.

These difficulties should not imply that these potential benefits are insignificant and should not be considered. On the contrary, decision-makers frequently use unquantifiable benefits to justify proceeding with investments which appear to be marginal or nonproductive in financial terms, (*15*, pp. 3–16).

Since dollar estimates of the benefits and costs are tenuous, a qualitative approach is recommended. Using Table I-26 as a guide, the potential for achieving any of the benefits or incurring any of the costs should be determined. A discussion of the conditions associated with the various benefits and costs is provided in the following to assist in this analysis. Other site-specific issues should be added to Table I-26.

6.2.1 Indirect Benefits

An on-board automatic data collection system can improve the reliability, quantity, and timeliness of transit management information. Data improvements provide several opportunities

Table I-25. Manual checker staff size requirements.

Peak Period Buses	Number of Checkers Required: Systemwide Data	Number of Checkers Required: Route Level Data
25	.25	1
50	1	2
100	1.5	4
300	3	7
500	6	13
750	8	15
1000	10	19
2000	20	38

Source: Attanucci, J., I. Burns and N. Wilson, "Bus Transit Monitoring Manual, Volume I: Data Collection Program Design," Multisystems, Inc., August 1981.

Table I-26. Benefit assessment checklist.

BENEFITS	
Improved Management Decision-making	______
Schedule Improvements	
Vehicle Fleet Reductions	______
Vehicle O&M Cost Reductions	______
Personnel Cost Reductions	______
Service Improvements	______
Reduced Administrative Costs	
Schedule Development	______
External Reporting Requirements	______
Manual Checker Staff Size	______
Fare Collection Efficiencies	
Bill Processing Cost Reductions	______
Reduced Fare Underpayment	______
Revenue Security Improvements	______
COSTS	
Vehicle Dispatching and Scheduling	______
Vehicle Pull-in Procedures	______
Driver Responsibilities	______
Vehicle Downtime	______
Bus Cleaning	______

to make productivity and efficiency improvements and free system resources that in turn can be translated into cost reductions or improved service.

6.2.1.1 Improved Management Decision-Making

The most significant incremental benefit of an automated data collection compared to a manual program is related to time savings. Data from the automated system will generally be available sooner and in greater quantity than a comparable manual data collection program. For example, in Seattle, data are typically available within one week of data collection. The availability of route summary statistics is a function of the sampling strategy selected rather than the time required for processing. An exception is discussed in Section 6.2.1.3. This quicker turnaround time facilitates improved transit decision-making in several ways:

1. Decisions can be made at an earlier date.
2. Potential problem areas can be identified at an earlier date.
3. Managers can gain time in making decisions.
4. More choices and impact analyses can be made.

The extent of these benefits depends on the current quality of the data and data turnaround time, and the opportunities for faster decision-making provided by the management and policy-making structure. The importance of any of these time benefits is subjective and will vary from one transit agency to another, even among managers in a given agency.

6.2.1.2 Schedule Improvements

Reliable passenger and running time data can be the basis for developing and optimizing schedules and for readjusting routes and vehicle assignments to respond most effectively to overall demand. Good data enable schedulers to free buses on some routes by lengthening headways without degrading a passenger's perception of service (i.e., average wait time or average load). Where schedule improvements can be translated into fleet productivity improvements, capital, operating and payroll savings can result (*15*, p. 5-1 to 5-7). The potential dollar value of schedule improvements depends on the quality of the current data collection program and schedule efficiency (*15*, p. 4-2 and 4-3).

Vehicle Fleet Reductions. Vehicle capital savings could result from reductions in the number of buses required to produce the same level of service. Such savings are typically not realized by selling excess vehicles, but by avoiding normal replacement purchases. Therefore, savings would be realized at the fleet replacement rate.

Vehicle O&M Cost Reductions. Reductions in fleet size generally lead to lower overall vehicle operating costs. Although a substantial portion of operating costs is tied directly to vehicle mileage, other cost elements do not vary with mileage. The first category includes fuel, tires, and most periodic maintenance; the second category, insurance and some time-dependent maintenance.

Personnel Cost Reductions. In some cases, the number of positions that can be saved is tied directly to the number of vehicles saved; in other cases, it is determined by the reduction in operating hours. Legal, labor, and community practices limit management's freedom of action in realizing staff reductions. Staff savings may not be achieved immediately, and must usually be realized through attrition over a period of years.

Service Improvements. Schedule improvements should enhance the quality of service provided to passengers (actual and perceived) and can increase passenger satisfaction with transit service. Good running time data permit accurate timetable updates and improved schedule adherence. Data on passenger activity on specific routes can be used to determine if the amount of service is adequate.

6.2.1.3 Reduced Administrative Costs

Implementation of an automated data collection system can reduce administrative costs in three major areas: (1) schedule development, (2) external reporting, and (3) manual checker staff.

Schedule Development. Computerized schedule files are essential for an automatic data collection system. Transit agencies that automate schedule files in conjunction with system implementation can expect reductions in staff time required to develop new schedules.

External Reporting Requirements. Because separate data or analysis is involved, some transit agencies differentiate between the costs of data collection and analysis for scheduling purposes and those for external reporting requirements. Implementation of an automated data collection system can reduce the overall cost because the two sets of data can be collected simultaneously. Seattle reports an annual savings of $50,000 for developing Section 15 data as a result of its automated data collection system (*6*, p. 6).

Manual Checker Staff. Introduction of an on-board data collection system can lead to reductions in staff requirements at those transit agencies where manual checkers are used. However, it may not be either possible or desirable to eliminate the entire checker staff. Local labor agreements and checker employment policies will dictate the extent of staff reductions. In addition, manual checkers can collect chronological point check data more quickly and efficiently than equipped vehicles. Transit agencies which frequently need quick turnaround (less than one month) for chronological point check data for special studies may desire to retain a few checkers for this purpose.

6.2.1.4 Fare Collection Efficiencies

In general, installation of new fare collection equipment solely for data collection is *not* recommended because of the high cost of equipping the entire fleet. However, transit agencies that elect to do so can reduce some of the major problems in fare collection currently experienced by transit agencies—bill processing costs, patron underpayment, and employee skimming funds. Realization of these benefits is dependent on the fare structure of transit property, type of farebox used, and internal security procedures.

Bill Processing Costs. Installation of electronic fareboxes that can accept unfolded currency should significantly reduce the costs associated with processing dollar bills. SCRTD eliminates that 65 percent of total bill processing time is devoted to unfolding dollar bills and another 15 percent for flattening (*16*, p. 5). SCRTD projected that the manpower requirements and costs associated with fare processing in an electonic farebox system would be half that required for its current drop-type farebox system (*11*, p. 7).

Patron Underpayment. The amount of lost revenue due to underpayment is unknown. Duncan Industries estimated that about 5 percent of revenue is lost because of patron underpayment at transit agencies using drop-type fareboxes (*17*, p. 3). A 1981 SCRTD survey of 10 transit agencies that had recently installed electonic fareboxes found that increases in revenue collection ranged from 0 to 7 percent, with most transit properties reporting no increase in revenue. However, many of these transit properties had relatively low fares (*16*, p. M-1).

Revenue Security. Although it is difficult to estimate the magnitude of the problem, the potential for employee skimming of fare revenue appears to increase dramatically with the introduction of dollar bills into a nonregistering farebox system (*18*). An electronic farebox allows for the money to be stored in the cashbox until it is transferred intact to counting facilities. To the extent registering fareboxes are installed in a bus system, revenue accountability will be improved.

6.2.2 Indirect Costs

Changes to existing system operations may be required for effective implementation of an automated data collection system. In many cases, it can be assumed that these changes would increase transit agency operation costs. The actual impacts of the automated data collection system will depend on current agency practices and the modules included in the automated data collection system. Those aspects of transit agency operations which could be affected are given in Table I-26. Additional information on these and other issues is provided in Chapter I.7.

The most significant impact on system operations will occur where vehicle dispatching procedures must be changed in order to schedule equipped buses for data collection. Particularly where vehicles are dispatched on a first driver/first bus basis, changes to existing procedures could reduce dispatching efficiency. Depending on the procedure and technology for data transmission from the bus, vehicle check-in time could be increased.

The possibility that wage rate increases may be necessary where driver responsibilities are increased should be considered. Local union agreements and negotiations practices will determine whether this is required.

Generally, malfunctions in the automated data collection system will not affect transit system operations. The exception occurs when electronic registering fareboxes are incorporated into the system. Since the bus is usally taken out of service until repairs can be made, the economic impacts of vehicle downtime should be considered. One daily road call lasting 1 hour for every 50 electronic farebox boxes in service was used in a recent analysis of farebox alternatives (*11*, p. D-1) Local estimates of vehicle downtime to include the cost of dispatching another bus, lost revenue, and unproductive driver time should be used to estimate these costs. Finally, because of the sensitivity of the electronic fareboxes, dust covers may be required. Time allotments for cleaning buses may have to be adjusted to allow for placing and removing these hoods (*11*, p. 6).

CHAPTER I.7

IMPLEMENTING AN AUTOMATIC DATA COLLECTION SYSTEM

IDENTIFY POTENTIAL BARRIERS TO IMPLEMENTATION (Section 7.1)

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DEVELOP SYSTEM IMPLEMENTATION PLAN (Section 7.2)

The feasibility analysis contained in this manual is but the start of a lengthy process for transit agencies contemplating implementation of an automatic data collection system.

First, assuming the results of the general feasibility analysis are positive, two actions will determine whether or not the implementation will proceed. The first is to justify the system to upper management and/or the board of directors. The second is to obtain the money to pursue the implementation. The two actions are obviously related but they are separate because justification of the cost-effectiveness of a system does not automatically imply that funds will be available for its implementation.

Whatever the size and scope of the system that will be pursued, considerable effort must be expended in planning, procurement, and installation. This chapter summarizes the key issues that will have a major impact on the success of the automated data collection system implementations.

7.1 IDENTIFY POTENTIAL BARRIERS TO SUCCESSFUL IMPLEMENTATION

One of the necessary activities on the part of those responsible for analyzing the feasibility of, and/or responsible for implementing, an automated data collection system is to gauge the level of commitment and cooperation to be expected from various transit agency departments. Table I-27 presents the issues that could lead to problems and therefore need to be addressed prior to and during implementation.

Some of the more significant issues involve labor. Are the personnel capable of doing the expected task? Will they cooperate? How much is it going to cost in time, effort, increased wages, supervision, lost data, etc. to achieve their involvement?

Those transit agencies that have already implemented automated systems apparently have not experienced significant problems, possibly because they anticipated the problems and acted to prevent them from arising. Portland, for example, specified its system to minimize driver involvement. Columbus avoids significant in-house support of its system by contracting with an outside consultant to process and analyze the data. The apparent lack of problems thus far may also be due to the somewhat limited nature of the implementations. Fare category counters have not been implemented and a full-scale management information system has not been established for any system.

One of the first challenges is to convince transit personnel that the automated system is not intended to be a monitoring device that will be used to penalize poor performance. Previous experience has shown that failing to alleviate this apprehension will lead to attempts to defeat the system. Trucking firms that installed tachographs, for example, have found them disconnected and/or tampered with. Even some police organizations that tried AVM systems note deliberate attempts by some officers to confuse the system so that movements could not be monitored.

Driver involvement in the data process is a continuing concern. It is usually desirable to limit driver involvement to the greatest extent possible. However, this is not entirely practical because in some instances, such as in the use of electronic fareboxes, this involvement is necessary. The driver is also in the best position to monitor equipment malfunctions and should be brought into that role through a careful orientation and training program.

One labor element that cannot be ignored even in the most automated of systems is the dispatching operation. Dispatching equipped buses to serve specified vehicle blocks is a critical human element that cannot be avoided. Special efforts are nec-

Table I-27. Potential implementation barriers.

Labor

Drivers may perceive the data collection devices as management surveillance of performance and attempt to defeat its operation.

Drivers and other personnel may cite additional responsibilities and duties as justification for increased wage demands.

Unions may resist automation in principle because they may perceive the intent of improved performance is to eliminate jobs.

Wages of manual checkers may still have to be paid since frequently these positions are filled by drivers who are currently unable to drive. If this occurs cost savings of an automated system would be reduced significantly.

Schedulers/planners may impose unrealistic data demands such as 100 percent route coverage to underscore the importance of manual skills in schedule construction, and to avoid automation.

Dispatchers may claim it is not possible to assign buses because of the way buses must be serviced and handled by hostlers.

Management

Data collection may be perceived as a low priority item.

There may be apprehension about technical risk and potential for failure.

Organizational

Where the data collection system is required to use a central, autonomous, in-house data processing facility, skills and equipment may not be the most desirable. The data collection system may have a low priority compared to other operations such as payroll, budget, etc.

A similar circumstance may also arise with respect to maintenance if all maintenance is a centralized function. Buses, fareboxes, radios, etc. will take precedence and data system maintenance postponed as not critical.

A change in organizational procedures may be difficult to implement because of "the way things are done." For example, vehicles may be washed then serviced. A change in this routine would be desirable but could be difficult to impose.

A pre-existing management information system may dictate the nature and form of the information provided by the data collection system.

essary not only at the dispatcher level to orient, train, and retrain the individuals directly responsible for vehicle assignments, but also to enlist the cooperation of drivers and bus hostlers in the process.

In fact, the vehicle dispatching procedure is the single most important element in achieving an effective data collection program. Modification of current practices is also potentially the most disruptive to traditional operating procedures. Agencies operating in cold weather and accustomed to dispatching buses from a line-up in the garage will likely experience the most problems in coordinating the vehicle dispatch since hostler activities the previous night determine the order of the next day's departures. A workable but simple procedure must be established to reduce the complications of dispatching, even if it means more buses will need to be equipped.

7.2 DEVELOP SYSTEM IMPLEMENTATION PLAN

By far, the most important step in attempting to overcome these potential problems is to develop a comprehensive step-by-step plan for implementing the data collection system. The plan

Table I-28. Recommended planning activities.

Comprehensive Planning

Begin with a workable plan:

- outline goals and procedures
- define management/staff responsibilities
- determine labor resources/skills required
- detail implementation schedule
- consider phased implementation

Solicit input from all parties and seek comments on all aspects of the plan:

- impact on current operations
- ability/resources to handle proposed system
- suggestions for revisions

Modify plan in light of comments:

- accept and incorporate suggestions or respond with reasons why suggestions cannot be adopted
- build constituency through involvement in revisions

Information Dissemination

Inform all personnel of plans and goals:

- invite comments
- demonstrate agency sensitivity to concerns

Training and Retraining

Establish orientation program:

- current and new employees
- develop manuals/procedure guidelines

Establish retraining program:

- current and new employees
- routine refresher program

Organizational Structure

Establish clear organization responsibilities:

- high level management oversight/commitment
- guarantees of resources/personnel
- distinct reporting hierarchy
- identified point of contact for each functional area

Establish procedures for dealing with problems:

- information contracts and suggestion procedures
- grievance resolution
- correction of deficiencies

should include an overview of the purpose and functions of the system, define the expected responsibilities of all individuals, and detail the schedule.

The plan should be circulated for comment to the departments and the personnel who would assume the functions and responsibilities. The experiences of transit agencies that have implemented automated data collection systems suggest that including personnel from scheduling, maintenance, and dispatching in the planning process is most critical to achieve a consensus regarding system design and cooperation in system operation. Their feedback, including their apprehensions, their estimates of the resources required, and their comments on what they perceive is needed to implement the system, would be used to refine the plan and begin a broader program of information dissemination and training. Training programs should cover a broad spectrum—from simple information dissemination for drivers to detailed electromechanical orientation for maintenance personnel. Well-informed and properly trained employees are essential since their activities have a direct impact on system operation. Table I-28 enumerates activities that should be considered.

Development of a master schedule for implementation of the automated data collection system should occur early in the planning process. Because there are a large number of elements and many people involved in implementing such a project, there is the risk that tasks maybe overlooked without such a schedule. The schedule should be realistic and allow for adequate time to undertake preliminary testing of the hardware on the vehicle prior to a full-scale procurement, to develop and debug the software, and to test the complete data collection system in simulated revenue service.

Because of the complex coordination required for an automated data collection system, transit agencies should seriously consider phased implementation. Some inefficiencies will obviously be present if, for example, only a few routes are targeted. However, these could be less than the learning and start-up inefficiencies that would result from attempting to implement a complete system.

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APPENDIX I.A

GLOSSARY

Backtagging data—Procedure for assigning actual time and date values to data during data transfer operations because only relative time is recorded on-board the vehicle. This procedure can be used to correct data in the event the bus clock does not correspond to the time of the data transfer.

Coefficient of variation—A statistical measure of data variability that normalizes the variance to facilitate comparisons among sample populations. It is calculated by dividing the standard deviation of the data by the overall mean of the data.

Computer bus—A set of addresses, data, control and power lines arranged in a standardized manner and operating under a strict set of data communication rules.

Confidence level—The degree of assurance that the true value associated with the total data population is within a specified interval of the calculated statistical value. It is used in conjunction with tolerance level to define the accuracy of a statistical calculation.

Data collection period—The time period over which a prescribed data sample is taken. In transit, the data collection cycle usually corresponds to the interval between seasonal service changes, driver sign-up periods, or accounting periods (i.e., quarter).

Equipped bus—Transit vehicle instrumented with on-board modules of an automatic data collection system.

Interlining—A term used to refer to the circumstance where a vehicle block consists of trips on different routes.

Maximum load point—The point on a transit route at which the maximum passenger loads occur during a specified time interval.

Owl run—A run that operates during late night and early morning hours.

Peak load check—A point check conducted at or near the location of the maximum load point.

Point check—A data collection technique in which a checker is located at a prescribed location along a route or routes and records selected data for all vehicles passing by that location. Typical data collected include bus number, route number, passenger load, and time of arrival.

Random sampling—A method of selecting *N* units out of a population of *M* units such that every unit in the population has an equal chance of being selected. The typical unit in transit data collection is an individual, one-way trip.

Ride check—A data collection technique in which a checker rides on-board the vehicle to record data. Typical data collected include the number of passengers boarding and alighting at each stop, stop location, arrival time, and fare categories.

Route-level data—Data collected to evaluate ridership, revenue, and vehicle performance on individual routes.

Run—The composite of the trips (and partial trips) assigned to a driver during a day's duty.

Statistical sampling—Random sampling procedures that are designed to produce estimates that meet prescribed confidence and tolerance levels. Statistical sampling requires data to be collected in a manner that takes into account route characteristics and time-of-day variations.

Systematic sampling—The process by which data are collected according to a predetermined and methodical selection/collection plan. Collecting data on every trip five times during a schedule period is an example of systematic sampling.

Systemwide data—Data collected to evaluate overall transit agency performance (e.g., Section 15 data).

Terminal point—Either end of a route, usually refers to the end point of a primary route where a driver layover is scheduled.

Time point—A designated point on a route where specific vehicle arrival and/or departure times are scheduled. Referred to as a node in some transit systems.

Tolerance level—The interval surrounding the observed (calculated) value in which the true value will occur given a specified confidence level.

Train—The composite of all trips assigned to a particular vehicle from pull-out to pull-in. More commonly referred to as a vehicle block in most transit systems.

Trip—A one-way trip in revenue service beginning at one terminal point (or turnaround point) of a route and ending at another terminal point (or turnaround location) along the same route.

Tripper—A scheduled trip or combination of trips whose total time is less than that specified for a regular run.

Vehicle block—The composite of all trips assigned to a particular vehicle from pull-out to pull-in. Also referred to as a train at some transit systems.

APPENDIX I.B

EXAMPLES OF AUTOMATIC DATA COLLECTION SYSTEM REPORTS AND GRAPHICS

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ROUTE ANALYSIS REPORT
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GM TRANSPORTATION SYSTEMS
TRANSIT INFORMATION SYSTEM

KALAMAZOO METRO TRANSIT
ROUTE 1
WESTNEDGE
SOUTH

WEEKDAY AVERAGES FOR
NOV 1982

TIME PERIOD SUMMARY

TIME PERIOD	SEGMENT 1 MICHIGAN/ROSE FOREST/WESTNEDGE			SEGMENT 2 FOREST/WESTNEDGE DENWAY/WESTNEDGE			SEGMENT 3 DENWAY/WESTNEDGE SOUTHLAND MALL			SEGMENT 4 MICHIGAN/ROSE SOUTHLAND MALL			SEGMENT					
	ON	OFF	RUN TIME	ON	OFF	RUN TIME	ON	OFF	RUN TIME	ON	OFF	RUN TIME	ON	OFF	RUN TIME	ON	OFF	RUN TIME
6: 0A- 8:59A	64	111	10.8	8	11	5.6	35	39	8.3	21	2	0.0						
9: 0A- 2:59P	217	202	11.5	24	52	6.6	86	139	9.1	0	0	0.0						
3: 0P- 5:59P	141	111	11.0	10	35	6.9	41	73	9.5	2	5	0.0						
6: 0P-10: 0P	33	36	8.2	3	6	5.7	7	13	8.7	0	0	0.0						
5: 0A-10: 0P	456	460	11.1	45	104	6.3	171	265	8.9	22	7	0.0						

TIME PERIOD TOTALS

TIME PERIOD		TOTAL ON	TOTAL OFF	AVE. RUN TIME	NO. OF VEH. TRIPS	VEH.-MILES	VEH.-HOURS	PASS. PER VEH. TRIP ON	PASS. PER VEH. TRIP OFF	PASS. PER VEH.-MILE ON	PASS. PER VEH.-MILE OFF	PASS. PER VEH.-HOUR ON	PASS. PER VEH.-HOUR OFF
AM PEAK	6: 0A- 8:59A	127	163	24.7	8	46.1	2.9	15.9	20.4	2.7	3.5	43.6	56.1
MID DAY	9: 0A- 2:59P	328	393	27.2	12	73.4	5.4	27.3	32.8	4.5	5.4	60.1	72.2
PM PEAK	3: 0P- 5:59P	194	224	27.4	9	50.8	3.5	21.5	24.9	3.8	4.4	56.0	64.8
NIGHT	6: 0P-10: 0P	43	55	22.6	7	24.2	1.5	6.1	7.9	1.8	2.3	29.3	37.6
ALL DAY	5: 0A-10: 0P	693	837	26.3	37	200.6	13.7	18.7	22.6	3.5	4.2	50.8	61.3

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ROUTE ANALYSIS REPORT
****

GM TRANSPORTATION SYSTEMS
TRANSIT INFORMATION SYSTEM

KALAMAZOO METRO TRANSIT
ROUTE 1
WESTNEDGE
SOUTH

NO. WEEKDAY SAMPLES FOR
NOV 1982

SCHED DEPT TIME	BLK NO.	SEGMENT 1 MICHIGAN/ROSE FOREST/WESTNEDGE ON	OFF	RUN TIME	MAX LOD	SEGMENT 2 FOREST/WESTNEDGE DENWAY/WESTNEDGE ON	OFF	RUN TIME	MAX LOD	SEGMENT 3 DENWAY/WESTNEDGE SOUTHLAND MALL ON	OFF	RUN TIME	MAX LOD	SEGMENT 4 MICHIGAN/ROSE SOUTHLAND MALL ON	OFF	RUN TIME	MAX LOD	SEGMENT ON	OFF	RUN TIME	MAX LOD	ON	OFF	RUN TIME	MAX LOD
5:58A	1	8	8	6	8	14	14	9	10	11	11	9	11	0	0	0	0								
6:20A	2	6	6	5	6	7	7	6	7	6	6	5	6	0	0	0	0								
6:45A	1	8	8	6	8	14	14	9	13	11	11	11	11	0	0	0	0								
A 7: 6A	11	0	0	0	0	0	0	0	0	0	0	0	0	5	5	4	5								
7:15A	2	6	6	6	6	7	7	7	7	5	5	5	5	0	0	0	0								
A 7:35A	11	0	0	0	0	0	0	0	0	0	0	0	0	4	4	3	4								
7:45A	1	9	9	7	9	14	14	9	14	10	10	8	9	0	0	0	0								
8:15A	2	6	6	6	5	7	7	7	5	6	6	6	5	0	0	0	0								
8:45A	1	8	8	7	5	13	13	9	12	10	10	9	6	0	0	0	0								
9:15A	2	7	7	7	7	7	7	7	7	6	6	6	6	0	0	0	0								
9:45A	1	8	8	8	8	12	12	8	12	10	10	10	10	0	0	0	0								
10:15A	2	7	7	7	7	7	7	7	7	7	7	7	6	0	0	0	0								
10:45A	1	8	8	8	8	13	13	10	11	10	10	10	9	0	0	0	0								
11:15A	2	5	5	5	5	7	7	7	7	5	5	5	3	0	0	0	0								
11:45A	1	8	8	8	7	13	13	9	11	11	11	10	10	0	0	0	0								
12:15P	2	6	6	6	6	7	7	7	7	6	6	6	5	0	0	0	0								
12:45P	1	8	8	8	8	14	14	12	12	10	10	10	6	0	0	0	0								
1:15P	2	7	7	7	7	7	7	7	6	6	6	4	4	0	0	0	0								
1:45P	1	9	9	9	9	13	13	10	13	10	10	9	9	0	0	0	0								
2:15P	2	6	6	6	6	7	7	6	7	6	6	5	5	0	0	0	0								
2:45P	1	8	8	7	8	13	13	11	12	9	9	9	6	0	0	0	0								
3:15P	2	6	6	6	6	7	7	7	7	6	6	5	4	0	0	0	0								
3:45P	1	8	8	8	7	12	12	9	11	9	9	9	4	0	0	0	0								
A 4:15P	12	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	1								
4:15P	2	7	7	7	6	7	7	7	4	6	6	5	5	0	0	0	0								
A 4:45P	12	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1								
4:45P	1	9	9	9	9	14	14	13	12	10	10	10	5	0	0	0	0								
5:15P	2	7	7	7	7	7	7	7	7	6	6	5	5	0	0	0	0								
A 5:20P	12	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2								
5:45P	1	8	8	7	7	13	13	9	12	10	10	10	7	0	0	0	0								
6:15P	2	7	7	7	6	7	7	7	6	7	7	6	6	0	0	0	0								
B 6:45P	1	4	4	4	4	4	4	4	3	4	4	4	3	0	0	0	0								
B 7:15P	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
B 7:45P	1	4	4	4	3	4	4	4	4	4	4	3	3	0	0	0	0								
B 8:15P	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								

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ROUTE PRODUCTIVITY REPORT
****

GM TRANSPORTATION SYSTEMS
TRANSIT INFORMATION SYSTEM

KALAMAZOO METRO TRANSIT
ROUTE 1
WESTNEDGE
NORTH

WEEKDAY AVERAGES FOR
NOV 1982

TIME PERIOD TOTALS

TIME PERIOD	TOTAL ON	TOTAL OFF	NO. OF VEH. TRIPS	SEAT-MILES	SEAT-HOURS	PASS.-MILES	PASS.-HOURS	LOAD* FACTOR	OCCUP** FACTOR
AM PEAK 6: 0A- 8:59A	98	46	8	1502.0	90.9	449.4	30.9	29.9	34.0
MID DAY 9: 0A- 2:59P	173	136	12	2320.3	157.5	782.8	62.3	33.7	39.5
PM PEAK 3: 0P- 5:59P	83	108	9	1518.4	94.0	458.8	34.7	30.2	36.9
NIGHT 6: 0P-10: 0P	26	25	8	956.7	51.3	182.4	14.4	19.1	28.0
ALL DAY 5: 0A-10: 0P	380	315	37	6297.4	393.8	1873.4	142.2	29.7	36.1

*LOAD FACTOR = PASS.-MILES/SEAT-MILES X 100%
**OCCUP FACTOR = PASS.-HOURS/SEAT-HOURS X 100%

****
KALAMAZOO ROUTES

HISTORICAL RIDERSHIP SUMMARY
AUGUST 1982 -- JANUARY 1983
****

****
WEEKDAY
****

ROUTE	RUN	DATE	VEH	ON	OFF	PASS-MILES	PASS-HOURS	DAILY MILES	DAILY HOURS	TRIP LNTH	TRIP DURN	PASS PER MILE	PASS PER HOUR	VEL (MPH)	LOAD FACTR	MAX LOAD	MIN LOAD	AVG LOAD	SEAT MILES
		07/30/82	1020	369	413	751	58	181.6	13.6	1.8	.14	2.3	30.4	13.4	.115	26	0	5	6538
		10/18/82	1025	376	437	691	51	185.5	13.6	1.6	.12	2.4	32.1	13.6	.103	18	0	4	6678
		10/19/82	1025	373	439	618	47	166.5	12.3	1.4	.11	2.6	35.7	13.5	.103	16	0	4	5994
		10/21/82	1025	335	412	636	47	186.6	13.8	1.5	.11	2.2	29.9	13.5	.075	17	0	4	6718
		11/09/82	1011	307	441	740	58	181.1	13.8	1.7	.13	2.4	32.0	13.1	.115	20	0	5	6520
		11/11/82	1020	345	393	841	64	181.4	13.8	2.1	.16	2.2	28.5	13.1	.129	19	0	5	6530
		11/29/82	1020	364	445	659	48	183.1	13.7	1.5	.11	2.4	32.5	13.4	.100	20	0	4	6572
		11/30/82	1027	378	428	840	65	184.7	13.8	2.0	.15	2.3	31.0	13.4	.126	19	0	5	6649
		12/02/82	1015	360	420	817	63	177.3	14.2	1.9	.15	2.4	29.6	12.5	.128	24	0	5	6383
		12/23/82	1017	210	266	612	42	183.3	13.7	2.3	.16	1.5	17.4	13.4	.093	23	0	3	6599
		01/04/83	1019	377	455	601	45	181.8	13.7	1.3	.10	2.5	33.2	13.3	.072	21	0	4	6545
		01/10/83	1020	356	425	652	52	181.7	13.7	1.5	.12	2.3	31.0	13.3	.100	24	0	4	6541
		01/13/83	1017	307	457	547	43	182.0	13.7	1.2	.09	2.5	33.4	13.3	.083	18	0	4	6552
		02/03/83	1029	416	402	662	54	182.4	13.7	1.4	.11	2.6	35.2	13.3	.101	22	0	5	6566
		02/04/83	1015	403	457	818	65	180.2	13.7	1.8	.14	2.5	33.4	13.2	.126	23	0	5	6487
	MEAN			357	409	938	71	178.8	13.7	2.4	.18	2.3	30.1	13.1	.144	22.4	M	5.7	6437
	STDEV			45	54	1015	76	14	0		.	0	4	1	.149	10	M	5	
MEAN				374	423	1346	103	170.4	13.4	3.1	.24	2.5	31.7	12.6	.219	28	M	8	6055
STDEV				59	78	1909	143	32.0	.6	4.5	.3	3.3	6.7	2.3	.283	20.3	M	11.0	1338
MAX				651	844	8244	617	194.9	14.2	20 8	1.5	30.1	76.0	14.2	1.274	77.0	M	40.0	7016
MIN				210	262	107	38	28.0	10.7	.1	.0	1.5	17.4	2.5	0.0	13.0	M	3.0	0.0
VALIDN				78	78	77	78	77.0	78.0	77.0	78.0	77.0	78.0	77.0	78.00	78 0	0.0	78.0	78.0
SUM				29181	33005	*****	8024	13120	1042	247	19.0	228	2530	980.3	16.39	2214	M	638	*****

****
SCHEDULE ADHERENCE REPORT
****

GM TRANSPORTATION SYSTEMS
TRANSIT INFORMATION SYSTEM

KALAMAZOO METRO TRANSIT
ROUTE 1
WESTNEDGE
SOUTH

% OF OBSERVATIONS
EARLY, ON TIME, AND LATE, FOR
WEEKDAY
NOV 1982

T I M E P O I N T S

SCHED DEPT TIME	BLK NO.	MICHIGAN/ROSE % EAR	% O-T	% LAT	NO. DAYS	DENWAY % EAR	% O-T	% LAT	NO. DAYS	SOUTHLAND % EAR	% O-T	% LAT	NO. DAYS	% EAR	% O-T	% LAT	NO. DAYS	% EAR	% O-T	% LAT	NO. DAYS	% EAR	% O-T	% LAT	NO. DAYS
5:58A	1	14	71	14	7	0	78	22	9	44	44	11	9												
6:20A	2	0	60	40	5	0	50	50	4	25	75	0	4												
6:45A	1	0	67	33	6	0	73	27	11	45	45	9	11												
7: 0A	11	***	***	***	0	***	***	***	0	33	33	33	3												
7:15A	2	0	83	17	6	0	100	0	4	25	75	0	4												
7:35A	11	0	0	100	2	***	***	***	0	33	33	33	3												
7:45A	1	0	75	25	8	0	0	100	8	38	50	13	8												
8:15A	2	0	83	17	6	0	0	100	5	40	60	0	5												
8:45A	1	0	75	25	8	0	11	89	9	44	22	33	9												
9:15A	2	0	86	14	7	0	20	80	5	40	40	20	5												
9:45A	1	0	75	25	8	0	40	60	10	40	50	10	10												
10:15A	2	0	71	29	7	0	17	83	6	50	17	33	6												
10:45A	1	0	75	25	8	0	20	80	10	50	40	10	10												
11:15A	2	0	60	40	5	0	0	100	4	25	50	25	4												
11:45A	1	0	50	50	8	0	0	100	10	40	50	10	10												
12:15P	2	0	83	17	6	0	0	100	5	40	40	20	5												
12:45P	1	0	88	13	8	0	30	70	10	40	50	10	10												
1:15P	2	0	86	14	7	0	0	100	3	67	33	0	3												
1:45P	1	0	78	22	9	0	0	100	9	100	0	0	9												
2:15P	2	0	86	14	7	0	0	100	4	50	25	25	4												
2:45P	1	0	63	38	8	0	0	100	9	22	67	11	9												
3:15P	2	0	67	33	6	0	0	100	4	50	25	25	4												
3:45P	1	0	75	25	8	0	11	89	9	44	44	11	9												
4:15P	2	0	71	29	7	0	0	100	4	50	50	0	4												
4:15P	12	0	100	0	1	***	***	***	0	0	100	0	2												
4:45P	1	0	78	22	9	0	10	90	10	40	50	10	10												
4:45P	12	0	100	0	1	***	***	***	0	0	100	0	1												
5:15P	2	0	71	29	7	0	0	100	4	50	50	0	4												
5:20P	12	0	100	0	1	***	***	***	0	0	100	0	2												
5:45P	1	0	78	22	9	0	40	60	10	30	50	20	10												
6:15P	2	0	86	14	7	0	40	60	5	60	40	0	5												
6:45P	1	0	75	25	4	0	25	75	4	50	25	25	4												
7:15P	2	100	0	0	1	***	***	***	0	***	***	***	0												
7:45P	1	0	75	25	4	0	67	33	3	67	0	33	3												
8:15P	2	***	***	***	0	***	***	***	0	***	***	***	0												

SCHEDULE ADHERENCE REPORT

QUEEN CITY METRO
ROUTE 43
READING ROAD
INBOUND
PM PEAK

% OF SCHEDULE DEVIATION OBSERVATIONS
WITHIN 1-MIN INTERVALS
FOR
DECEMBER 1978

	SCHEDULE DEVIATION	WILLIAMS & WYOMING	READING & SUMMIT	READING & CALIFORNIA	READING & CLINTON SPRINGS	READING & LINCOLN	GOVERNMENT SQUARE DOWNTOWN
	OVER 10	0	0	0	1	1	1
M	10 TO 9	0	0	0	0	0	0
I	9 TO 8	0	0	0	0	0	0
N	8 TO 7	0	0	0	0	0	0
	7 TO 6	0	0	0	0	0	0
E	6 TO 5	3	0	0	0	0	0
A	5 TO 4	5	0	0	0	0	1
R	4 TO 3	4	0	0	2	2	1
L	3 TO 2	4	6	2	6	3	1
Y	* 2 TO 1	13	3	4	10	9	4
	* 1 TO 0	14	12	7	11	16	12
	* 0 TO 1	15	6	12	10	10	9
M	* 1 TO 2	10	6	16	14	9	11
I	* 2 TO 3	11	18	12	9	8	16
N	* 3 TO 4	11	15	10	4	7	11
	* 4 TO 5	2	12	7	8	6	7
L	5 TO 6	3	6	11	6	8	6
A	6 TO 7	2	6	5	7	5	8
T	7 TO 8	1	3	5	4	4	3
E	8 TO 9	1	0	2	3	6	4
	9 TO 10	1	0	3	1	3	2
	OVER 10	2	6	4	4	5	3

*DENOTES ON TIME DEFINITION

SOURCE: CM

SCHEDULE DEVIATION REPORT FOR SCHEDULING DEPARTMENT
FOR 01-09-79

JAN 10,1979

PAGE 0001

LINE 041 EARLY THRESHOLD 01:00 (MN:SS) LATE THRESHOLD 10:00 (MN:SS)

RUN 01 DIVISION 02 BUS NUMBER 7200

DIRECTION NORTHBOUND

TIMEPOINT (DEVIATED)	TRIP NUMB		THIS RUN SCHEDULE DEPART HR:MN:SS	THIS RUN DEPARTURE DEVIATION MN:SS	REMARKS		PREVIOUS RUN SCHEDULE DEPART HR:MN:SS	PREVIOUS RUN DEPARTURE DEVIATION MN:SS		FOLLOWING RUN SCHEDULE DEPART HR:MN:SS	FOLLOWING RUN DEPARTUR DEVIATIO MN:SS
ALVARADO/PICO	1070		06:00:30	+01:33			05:39:30	0:00		06:28:30	0:00
MONTANA/LIBERTY			06:20:00	+01:45			06:00:00	0:00		06:40:00	0:00
ALVARADO/6TH	1080		07:23:30	+01:45			07:12:30	0:00		07:31:00	0:00
ALVARADO/PICO	1090		08:33:30	-11:30			08:20:30	+02:00		08:47:00	0:00
ALVARADO/6TH			08:40:30	-13:30			08:27:30	+02:30		08:53:30	0:00
DRIVER NUMBER 6407											
ALVARADO/6TH	1150	13:50:00	13:50:30	+01:45		13:35:00	13:35:30	0:00	14:04:00	14:04:30	0:00

DIRECTION SOUTHBOUND

TIMEPOINT (DEVIATED)	TRIP NUMB		THIS RUN SCHEDULE DEPART HR:MN:SS	THIS RUN DEPARTURE DEVIATION MN:SS	REMARKS		PREVIOUS RUN SCHEDULE DEPART HR:MN:SS	PREVIOUS RUN DEPARTURE DEVIATION MN:SS		FOLLOWING RUN SCHEDULE DEPART HR:MN:SS	FOLLOWING RUN DEPARTUR DEVIATIO MN:SS
ALVARADO/BEVERLY	1070	06:26:00	06:26:30	+01:30		06:05:00	06:05:30	0:00	06:46:00	06:47:00	0:00
ALVARADO/6TH		06:29:00	06:29:30	+02:00		06:08:00	06:08:30	0:00	06:49:00	06:49:30	0:00
ALVARADO/PICO	1080	07:53:00	07:53:30	-11:30		07:42:00	07:42:30	-06:15	08:03:00	08:03:30	0:00
SANBARB/FIGUEROA		08:09:00	08:17:00	-05:30		07:58:00	08:04:00	-01:30	08:19:00	08:30:00	0:00
SANBARB/FIGUEROA	1150	14:40:00	14:54:00	+01:30		14:25:00	14:42:00	0:00	14:55:00	15:09:00	0:00

>

SOURCE: GOULD, Inc.

GM TRANSPORTATION SYSTEMS
TRANSIT INFORMATION SYSTEM

****
SCHEDULE ADHERENCE REPORT
****

KALAMAZOO METRO TRANSIT
ROUTE 1
WESTNEDGE
NORTH
ALL DAY
5: 0A-11: 0P

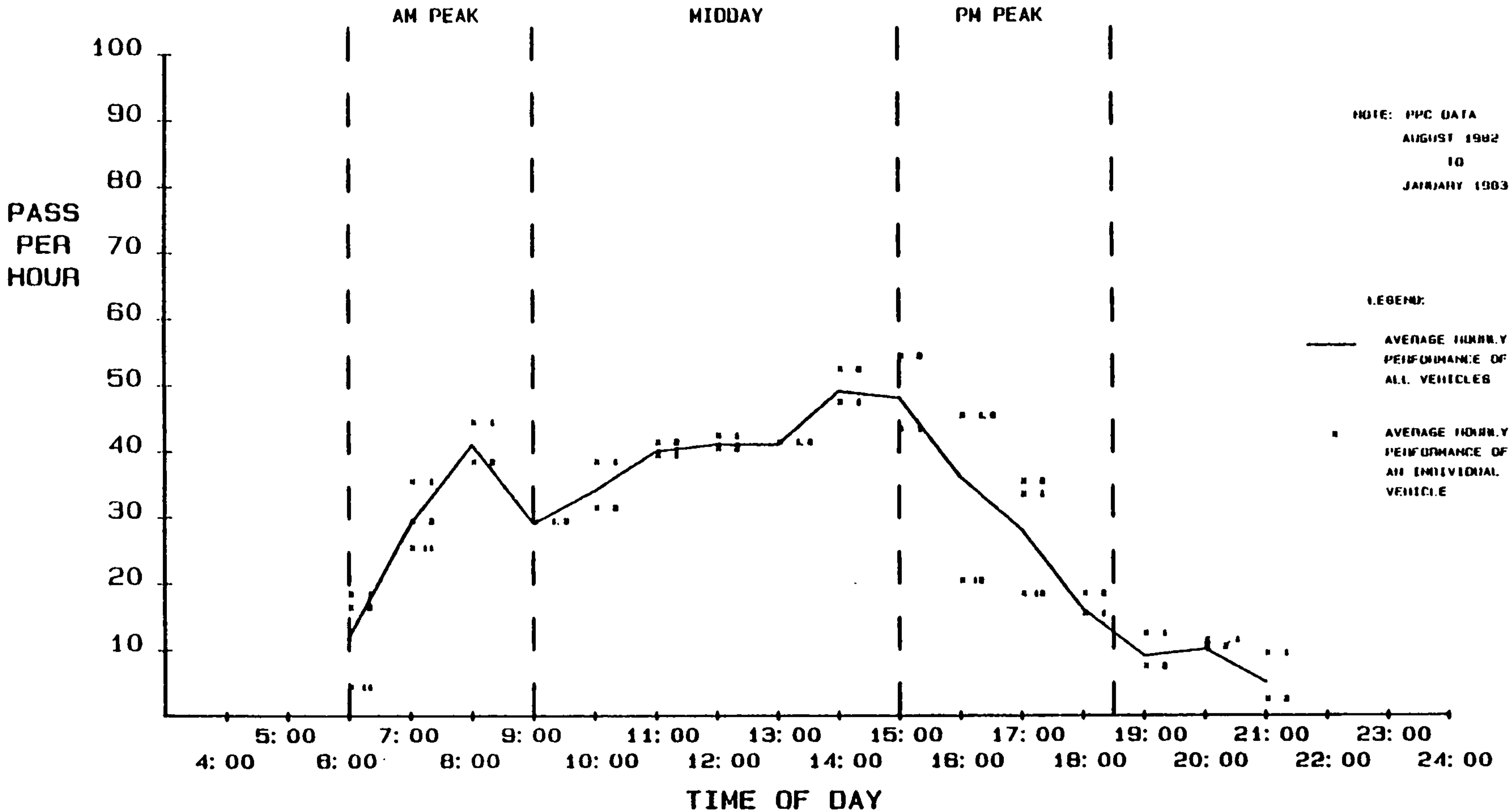
% OF SCHEDULE DEVIATION OBSERVATIONS
WITHIN 1-MIN INTERVALS FOR
WEEKDAY
NOV 1982

	SCHEDULE DEVIATION	TIMEPOINTS: SOUTHLAND	FORESTPARK	MICHIGAN/ROSE			
	OVER 10	8	0	7			
M	10 TO 9	6	0	1			
I	9 TO 8	4	0	8			
N	8 TO 7	4	0	8			
	7 TO 6	2	0	12			
E	6 TO 5	6	0	12			
A	5 TO 4	3	1	13			
R	4 TO 3	2	4	11			
L	3 TO 2	2	9	4			
Y	2 TO 1	0	14	5			
	1 TO 0	2	18	3			
	0 TO 1	13	13	3			
M	1 TO 2	17	14	1			
I	2 TO 3	6	7	2			
N	3 TO 4	3	4	3			
	4 TO 5	7	3	2			
L	5 TO 6	3	5	2			
A	6 TO 7	0	2	2			
T	7 TO 8	1	1	1			
E	8 TO 9	1	1	0			
	9 TO 10	0	2	0			
	OVER 10	9	4	0			

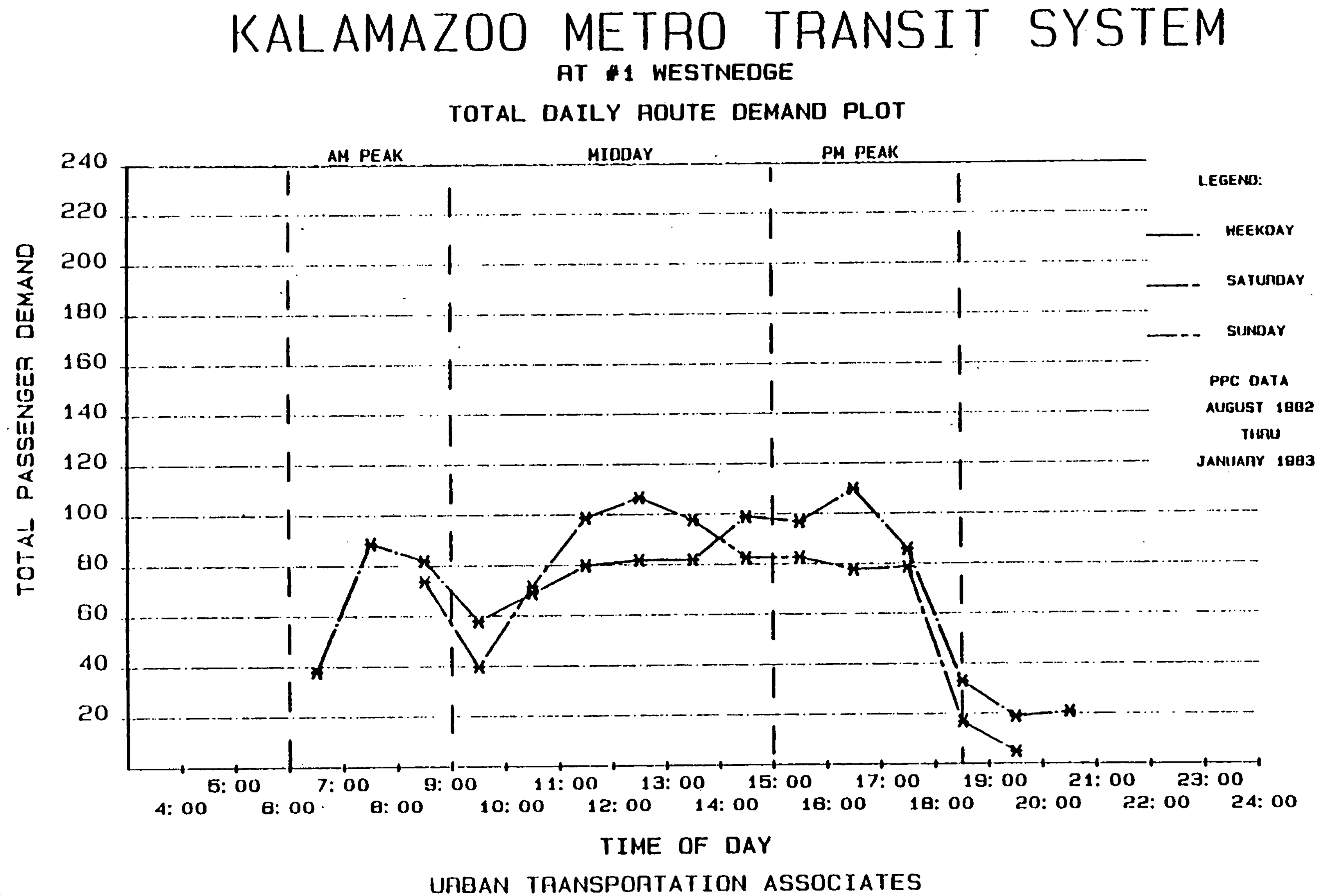
=DENOTES ON TIME DEFINITION

% EAR	% O-T	% LAT	NO. SAMP	% EAR	% O-T	% LAT	NO. SAMP	% EAR	% O-T	% LAT	NO. SAMP	% EAR	% O-T	% LAT	NO. SAMP	% EAR	% O-T	% LAT	NO. SAMP	% EAR	% O-T	% LAT	NO. SAMP
37	39	24	178	14	65	22	185	77	14	9	236												

RT #1 WESTNEDGE
RUN PERFORMANCE ANALYSIS
WEEKDAY



URBAN TRANSPORTATION ASSOCIATES
FEBRUARY 1983



KALAMAZOO METRO TRANSIT SYSTEM
AT #1 WESTNEDGE
TOTAL DAILY ROUTE DEMAND PLOT
AM PEAK
MIDDAY
PM PEAK
LEGEND:
WEEKDAY
SATURDAY
SUNDAY
PPC DATA
AUGUST 1982
THRU
JANUARY 1983
TOTAL PASSENGER DEMAND
240
220
200
180
160
140
120
100
80
60
40
20
4: 00
5: 00
6: 00
7: 00
8: 00
9: 00
10: 00
11: 00
12: 00
13: 00
14: 00
15: 00
16: 00
17: 00
18: 00
19: 00
20: 00
21: 00
22: 00
23: 00
24: 00
TIME OF DAY
URBAN TRANSPORTATION ASSOCIATES

AUTOMATIC PASSENGER COUNTER
DETAIL TIME MATCH REPORT

JOB APC12184 882-3126 METRO PAGE 1
PROCESS DATE (07/02/82) 14:16

VEHICLE ASSIGNMENT 190/ 5 WEEK DAY
MONDAY JUNE 14, 1982
COACH NUMBER 1255 (34)

LOCATION	SCHED ARR TIME		ACCUM MILES	DOOR OPEN	DOOR SHUT	TIME AT STOP	PSGR LOAD	RIDERS OFF	RIDERS ON	LEG DIST	LEG SPEED	ACCUM ONS	ACCUM PSGR MILES	ACCUM PSGR HOURS
			0.0	6:12A	6:13A	1:00	0	0	1	0.0	0.	0	0	0.0
SO. BASE	6:13A	PULL OUT *******												
			9.96	6:25A	6:31A	5:51	1	1	30	9.96	49.	1	0	0.0
STAR LAKE P & R	6:30A	START TRIP- 19001040												
			10.22	6:33A	6:33A	:08	30	0	1	0.26	12.	31	8	0.7
			26.30	6:54A	6:54A	:12	31	1	1	16.08	45.	32	490	11.4
4 AV S S SPOKANE	6:57A													
			27.45	6:57A	6:58A	:42	31	1	0	1.15	23.	33	524	13.0
			28.21	7:00A	7:00A	:12	30	1	0	0.76	21.	33	546	14.4
			28.57	7:02A	7:02A	:15	29	6	0	0.36	13.	33	557	15.3
			28.73	7:04A	7:04A	:17	23	5	1	0.16	8.	33	560	15.8
			28.91	7:04A	7:05A	:27	19	8	1	0.18	17.	34	563	16.1
			29.13	7:06A	7:06A	:17	12	3	1	0.22	12.	35	566	16.4
			29.34	7:08A	7:09A	:25	10	5	0	0.21	7.	36	568	16.7
4 AV UNION ST	7:10A	E N D TRIP												
4 AV UNION ST	7:10A	**START DEADHEAD												
			29.50	7:10A	7:10A	:14	5	4	0	0.16	8.	36	568	16.8
			48.66	7:34A	7:54A	19:33	1	1	13	19.16	48.	36	568	16.8
STAR LAKE P & R	7:42A	****END DEADHEAD												
STAR LAKE P & R	7:53A	START TRIP- 19001110												
			50.32	7:59A	7:59A	:07	13	0	1	1.66	19.	49	588	17.8
			50.57	7:59A	8:00A	:10	14	0	1	0.25	24.	50	591	18.0
			51.15	8:01A	8:01A	:09	15	0	1	0.58	26.	51	600	18.3
CENT/DES P & R	8:03A													
			51.45	8:03A	8:06A	2:36	16	1	15	0.30	9.	52	604	18.9
			51.62	8:07A	8:07A	:09	30	0	2	0.17	10.	67	609	20.0
4 AV S S SPOKANE	8:27A													
			66.09	8:27A	8:27A	:05	32	0	1	14.47	43.	69	1058	30.5
			66.51	8:29A	8:29A	:17	33	0	2	0.42	17.	70	1071	31.4
			67.06	8:32A	8:32A	:10	35	0	1	0.55	13.	72	1090	33.0
			67.42	8:33A	8:33A	:09	36	1	0	0.36	14.	73	1102	34.0
			67.60	8:34A	8:35A	:26	35	5	0	0.18	15.	73	1108	34.5
			67.76	8:35A	8:36A	:13	30	6	0	0.16	12.	73	1113	35.1
			67.94	8:38A	8:38A	:16	24	6	0	0.18	4.	73	1117	36.1
4 AV UNION ST	8:40A	E N D TRIP												
			68.12	8:40A	8:41A	:17	18	9	0	0.18	6.	73	1120	36.7
			68.34	8:42A	8:42A	:17	9	7	0	0.22	9.	73	1122	37.0
			68.55	8:44A	8:44A	:09	2	1	0	0.21	7.	73	1122	37.0
			78.44	9:00A	9:01A	1:00	1	1	0	9.89	37.	73	1122	37.0
SO. BASE	9:05A	PULL IN *******												

*** WARNING *** TIME MATCHING ASSUMES BUS IS ON TIME.
PASSENGER LOAD IS THE LOAD ARRIVING AT A STOP.
DISTANCE AND SPEED REFER TO THE LEG SINCE THE PREVIOUS STOP.

PROGRAM APCTCB (ORIG: APCTMOD)

PREPARED FOR TRANSIT DEPARTMENT STAFF (ALL DIVISIONS)

A-P-C REPORT SUMMARY FOR NOVEMBER 8, 1982

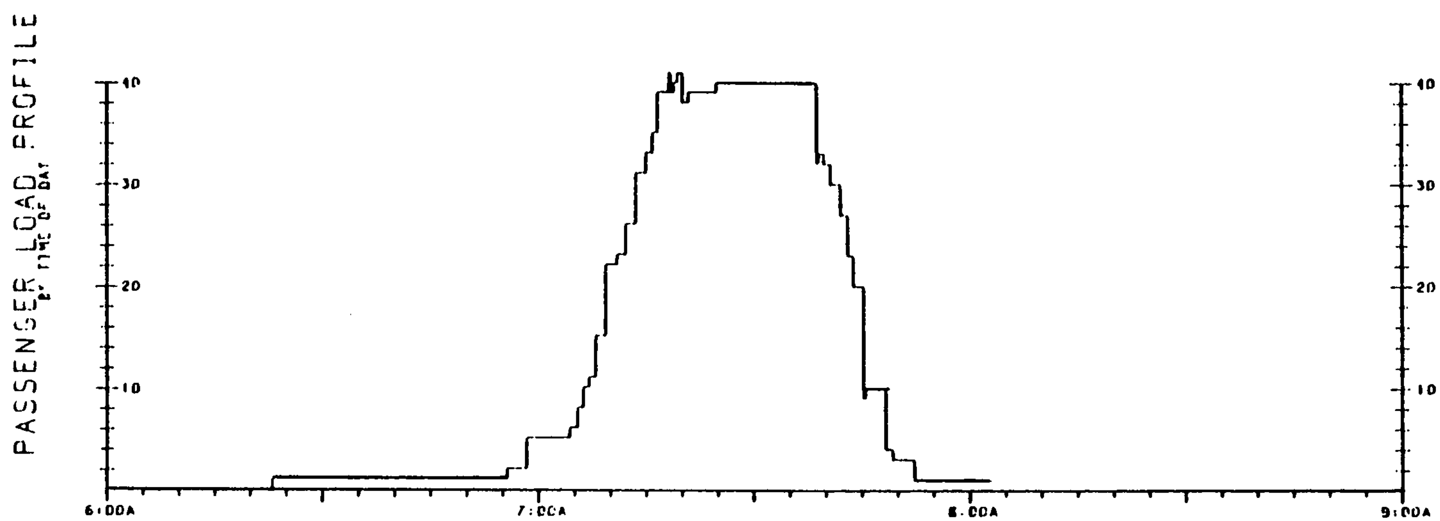
RTE GRP	RUN	DAY	SINCE LAST REPORT	SURVEY DATE	MILES	COACH	PCU #	NORMAL SCHED SEATS	TUNED RUN TOTAL	NUM OVER LOADS	TUNED HIGH LOAD	TIME OF MAX LOAD	MAX STAND TIME	NUM TIMES STAND PSGRS	RELIA-BILITY FACTOR
5	1	WD		82/09/29	77	1699	8	47	142	0	45	6:38A	0	0	99.31
		WD	NEW	82/10/15	61	1699	8	47	116	0	40	6:37A	0	0	93.91
	6	WD	NEW	82/10/26	17	1699	8	47	34	0	25	7:04A	0	0	96.97
	11	WD	NEW	82/10/25	160	1699	8	47	606	2	62	5:14P	25	2	98.52
	16	WD		82/10/07	105	1699	8	47	462	1	69	7:20A	20	1	96.40
		WD		82/10/12	105	1699	8	47	473	1	65	7:18A	20	1	99.79
	19	WD		82/10/14	18	1699	8	48	61	1	55	7:36A	10	1	96.72
	34	WD		82/09/29	50	1699	8	47	79	0	31	4:51P	0	0	96.39
	44	WD		82/10/14	35	1699	8	47	113	0	44	6:14P	0	0	99.12
	2	SA		82/10/02	154	1699	8	47	550	1	67	3:24P	25	1	97.81
	5	SA	NEW	82/10/16	149	1699	8	47	516	1	49	4:15P	5	1	96.44
	9	SA	NEW	82/10/23	146	1699	8	47	420	0	39	3:54P	0	0	99.53
6	7	WD	NEW	82/10/20	56	1669	35	47	131	0	42	8:02A	0	0	94.74
	12	WD		82/09/29	36	1279	29	45	168	1	48	7:24A	3	1	98.22
		WD		82/10/05	36	1273	45	45	160	3	49	7:27A	4	3	98.77
		WD		82/10/11	36	1307	51	45	145	1	50	7:23A	4	1	100.00
	14	WD		82/10/08	50	1294	16	45	170	4	57	7:30A	9	4	98.82
		WD	NEW	82/10/25	50	1249	24	45	161	1	49	6:34A	3	1	99.38
		WD	NEW	82/10/26	49	1294	16	45	139	0	41	6:34A	0	0	97.81
	17	WD		82/10/14	158	1600	50	47	627	3	62	4:38P	28	3	98.27
	24	WD		82/09/27	30	1273	45	45	47	0	37	7:38A	0	0	93.62
		WD		82/10/01	30	1273	45	45	39	0	31	7:43A	0	0	92.31
		WD		82/10/13	29	1307	51	45	16	0	11	7:38A	0	0	93.75
	27	WD	NEW	82/10/21	19	1600	50	47	51	0	35	7:45A	0	0	98.04

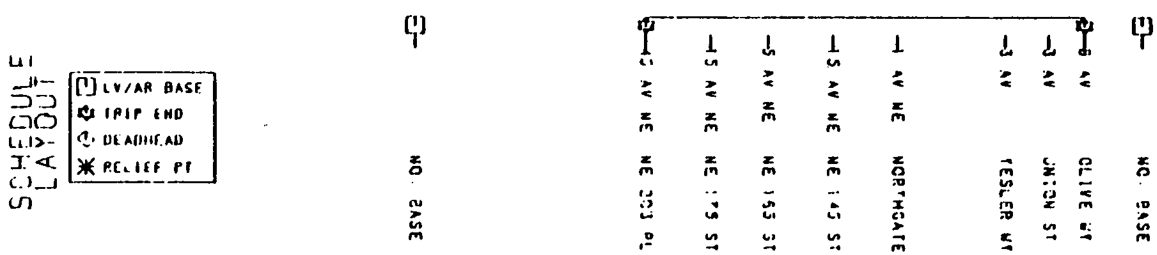
THIS REPORT, PREPARED WEEKLY, LISTS USEABLE APC-SURVEYED RTE/RUNS
ALL DATA, UNLESS OTHERWISE INDICATED, IS RAW AND UNTUNED.

VEHICLE ASSIGNMENT 477/ 6 WEEK DAY

FRIDAY JUNE 11, 1982

COACH NUMBER 1305 PROCESS DATE 107/02/82) 14:16 PCU DEVICE 13





APPENDIX I.C

AUTOMATED DATA COLLECTION SYSTEM HARDWARE

This appendix contains additional background information on the hardware components of automated data collection systems to supplement the overview presented in Chapter I.2 and to assist transit agencies in selecting appropriate modules and hardware options for their systems (Chapter I.3). This information includes: (1) hardware options for modular units, (2) status of current transit applications of automated data collection systems, and (3) equipment provided by major system suppliers.

Specifications for the modular system described are contained in Appendix II.

I.C.1 DESCRIPTION OF AUTOMATIC DATA COLLECTION SYSTEM HARDWARE

The modular approach allows for several choices of hardware or implementation options in configuring an automated data collection system. The options selected by a transit agency depend on a variety of factors including consideration of cost, accuracy, reliability, and information needs.

Hardware options for the modular automatic data collection system are summarized in Table I.C-1. The options identified reflect the system design philosophy for the proposed modular system and the available technology. A description of each hardware and/or implementation option follows.

Passenger Counter

The passenger counter module detects and counts the number of passengers boarding and the number of passengers alighting at each door of the vehicle. It is capable of counting parallel streams at each door. The passenger counter accumulates values for both boarding and alighting passengers at each vehicle stop.

Three types of passenger counter sensors are currently available and have been implemented at several transit properties:

1. *Photoelectric beam sensors*—Light beams are projected horizontally across bus doorways to a light sensitive receiver. A count is registered when the light beam is interrupted. The sequence in which the beams are broken determines the direction of movement. Photoelectric beam sensors have been installed in Columbus, Ohio; Kalamazoo, Michigan, Minneapolis/St. Paul; and Portland, Oregon.
2. *Switch mat sensors*—Pressure sensitive mats are installed on two steps at each door. The mats contain pressure sensitive switch elements that are actuated under a specific load. The sequence in which the steps are activated determines the direction of movement. Switch mats have been installed in Los Angeles, California, and Seattle, Washington, and will be used in Rochester, New York.
3. *Inductive loop mat*—Similar to switch mats, these mats are installed on two steps at each door. Instead of contacting switches, the inductive loop mat contains a noncontacting inductive proximity switch that permits the mats themselves to be designed without using sealing materials. These mats are used in Amsterdam, Utrecht, and Düsseldorf.

Ultrasonic interruption sensors have been developed for detection and distance measuring problems. These sensors have been applied in security systems, vehicular safety sensing systems, and robotic manufacturing operations. They have not yet been used in a transit application, although they were tested in an earlier program by MITRE (*1*). Kalamazoo plans to evaluate a new ultrasonic system under an Urban Mass Transportation Administration (UMTA) grant. The characteristics and limitations of passenger counter sensors are summarized in Table I.C-2.

Fare Category Counter

The fare category counter accumulates and stores counts of the number of passengers within each specified fare category at each bus stop. Two types of fare category counter modules have been identified for the on-board, automatic data collection system:

1. *"Standard" fare category counter module*—Includes a single detection device, an electronic farebox, which would be capable of counting a limited number of user categories.
2. *"Expanded" fare category counter module*—Includes multiple fare media detection devices—an electronic farebox, a pass-reader, and a ticket validator and would be capable of recording greater numbers of user categories.

Electronic registering fareboxes accept and count all denominations of coins, as well as tokens and dollar bills. Individual fare payments are displayed on a digital read-out for operator fare verification. Data on individual and cumulative fare payments by fare category are retained. Driver-actuated push buttons on the farebox or driver console allow operators to record types of fares received. A disadvantage of this option is that the accuracy of driver input cannot be guaranteed. Many cities have implemented electronic fareboxes including Dallas, Texas; Norfolk, Virginia; St. Louis, Missouri; Atlanta, Georgia; Cleveland, Ohio; and Washington, D.C.

The expanded fare category counter provides the transit operator with the opportunity to obtain passenger and revenue data about passengers that use the off-vehicle fare payment options offered by many transit properties. Fare category counts result from passenger interaction with the system via passes or prepurchased tickets. This option is more accurate and expensive than driver input options. The expanded fare category counter module involves types of hardware not commonly used in U.S. bus transit systems:

1. *Period pass reader*—Reads the pass, verifies its validity, and retains data on the number of pass uses by fare category. Period pass readers are being used experimentally on rail transit systems in Boston and Chicago.

2. *Multi-ticket validator*—Used by passengers in time-clock fashion to validate multi-ride tickets and electronically verify that the document is a valid ticket. The validation would retain data on the number of multi-ticket users by fare category. Validators are currently used in Portland, San Diego, and Kalamazoo; these validators do not collect data by fare but several such devices are available in the marketplace.

3. *Stored-value and stored-ride pass reader*—Reads the pass, deducts the fare from the card's stored value, and verifies the validity of the pass. The pass reader retains data on the number of pass users by fare category. This type of equipment is used in San Diego and on the rail systems in San Francisco and Washington, D.C.

To date, no U.S. transit agencies have linked automatic passenger counter systems with fare category counters to obtain complete information on passenger movement and fares. Kalamazoo and Atlanta are experimenting with this type of application.

Distance Measurement

Distance measurement is incorporated into the system controller module. The module provides for the accumulation and

Table I.C-1. On-board, automatic data collection system technology.

Functional Unit	Technology/Implementation Options	Data Supported/Maintained
Passenger Counter	Photoelectric Beam Sensors Switch Mat Sensors Inductive Loop Mat Ultrasonic Sensors	Passengers Boarding/Alighting
Fare Category Counter	Standard: Electronic Farebox Expanded: Electronic Farebox Pass Reader Multi-Ride Ticket Validators	Revenue & Fare Category Counts
Distance Measurement	Odometer	Cumulative Distance
Signpost	RF Transmitter Antenna	Signpost Identification Number
Manual Input	Minimum Expanded	Time and Date Time, Date, and Identification Data
System Controller	Microprocessor	None System Program
Memory	Solid State Memory Magnetic Tape	Stores All Input Data
Status Display	Hand Held Display Unit	None Maintained Internally
Data Transmission	Female Data Plug of Umbilical Non-Contacting Transmitter	None Maintained Internally
External Receiver	Male Data Plug/Interim Storage Unit Non-Contacting Receiver/Interim Storage Unit Direct Communication Link	None

data retention of the cumulative distance at each bus stop and initiates a data recording whenever the vehicle travels a specified distance without intervening data recordings. The bus odometer is the most commonly used technology. Distance measurement is considered a mandatory feature of all on-board data collection systems.

Signpost

The signpost module consists of the signpost radio transmitter unit located along bus routes, a vehicle-mounted antenna, and interface electronics. The signpost transmitter is a self-contained unit consisting of an RF transmitter, a data encoder, and an internal battery. The signpost transmitter continuously transmits a low-level radio signal modulated with a selectable digital location code. A location record is generated each time a vehicle enters and leaves the transmission range. The recording of a signpost signal positions the location of the vehicle in time and space and allows easy referencing of all bus stop and trip records. Signposts are used to reference vehicle location in many of the current automated systems, including Seattle, Columbus, and Kalamazoo.

Manual Input

The manual input console provides time and date information, and other data identification elements such as run number, route number, bus number, etc. The primary driver contact with the data collection system is through the manual input console. Two configurations for the manual input console are defined.

1. *Minimum configuration* for the manual input module con-

Table I.C-2. Characteristics and limitations of passenger-counter sensor options.

TECHNOLOGY OPTIONS	GENERAL CHARACTERISTICS & LIMITATIONS
Switch-Mat Sensors	Higher counting accuracy than photoelectric systems but also higher cost for both sensors and counting logic. In general, has a lower reliability than photoelectric sensors.
Photoelectric Beam Sensors	Low cost sensors and logic. However, most systems require a different installation configuration for each type of bus since accuracy depends on sensor location. Sensor alignment needs to be verified routinely because they can be easily moved. Infrared beam sensors generally require replacement of safety glass on vehicle doors.
Inductive Loop Mat Sensors	Results of field tests suggest accuracy generally similar to switch mat sensors. Especially accurate with low passenger activity levels. Design appears to offer the potential for improved reliability since hermetic sealing is not critical to operation. No U.S. applications to date.
Ultrasonic Sensors	Ultrasonic sensors mounted on step risers were tested in a UMTA program in 1975 but the results did not reveal the potential for improved accuracy. Overhead ultrasonic sensors have not been applied to passenger counter systems to date.

tains a clock providing military time; a calendar that is either derived through clock circuitry or manually input by driver; and a driver-actuated switch to generate a data record.

2. *Expanded configuration* of the manual input console provides for run number; route and driver identification; zone or type of service data; and bus or farebox identification as defined by the user. Time and date information is also provided. The console provides for drivers to execute data recording commands and includes any displays that may be necessary to verify system operation.

System Controller

The system controller consists of a microprocessor, power supply, data input and output connectors, and a programmable read-only memory. The program provides control of all data transfer operations between modules and acts as data monitor and manager for the data collection system. All data gathering modules interface directly with the system controller via a standard microcomputer bus. The system controller specified for the modular system contains standard, identical connectors—one for each on-board module plus additional connectors for a second memory module and the power supply.

Memory

The system accommodates two plug-in memory modules. One module provides the basic solid-state memory for the system; the second provides for expansion of memory. CMOS circuitry has been selected for the proposed modular system and is typical of most current systems because of its extremely low power consumption and high immunity to electrical interference generated by motors, solenoids, fluorescent lights, generators, etc. Its low power consumption also permits efficient battery backup.

Memory and clock back-up power by internal batteries is optional and if used would back-up both data and clock memory for not less than 72 hours. Data and clock memory back-up is assumed to be sufficiently important to be a system requirement; however, it is considered an option to the extent that the system will function without requiring internal, back-up batteries to be in place.

Solid-state memory storage has been implemented by Seattle, Portland, and CALTRANS; magnetic tape memory is used in Columbus and Kalamazoo. Solid-state is preferred because of the reduced possibility of human error, mishandling, or damage.

Status Display Module

The display unit is a hand-held device containing a display which permits an observer to monitor preselected functions of the system. These functions include passenger counts, cumulative distance, cumulative revenue, signpost number, and fare category counts.

Data Transmission

The data transmission module is the on-board mechanism for transferring data from the solid-state memory on the vehicle to the external receiver module. The module consists of a transmission unit connected directly to the system controller, and an output device. Data are transmitted in serial form at a rate of 9600 baud in conformance to standard data communications protocols.

Several hardware options are available depending on the data retrieval philosophy desired by a transit property, as discussed below. The output device typically used is a female connector located on the vehicle. Alternative noncontact output devices such as radio frequency transmitters, or ultrasonic or infrared sending units can be implemented. Portland has installed an infrared communications link that automatically transfers data from bus storage to sensors located at the garage entrance.

External Receiver

Data retrieval can be provided in several configurations:

1. Off-line data transfer to an interim storage unit prior to data processing.
2. On-line serial data transfer via modem to data processing facilities.
3. On-line real-time data transfer via radio-link.

The characteristics and limitations of these data retrieval options are outlined in Table I.C-3.

Off-line data transfer can be accomplished with an umbilical cable or with noncontact data transfer devices. Interim storage is achieved with a portable retrieval unit, such as a portable cassette recorder, portable disk unit or solid-state memory. Most applications of automated data collection systems employ portable retrieval units for interim storage. At CALTRANS, however, data were transmitted directly from the bus to the computing facility over telephone lines. Real-time data transfer is a characteristic of automatic vehicle monitoring systems (AVM) and as such is a special application of the automatic data collection system. A U.S. demonstration of AVM technology was undertaken at Southern California Rapid Transit District in 1981.

I.C.2 STATUS OF CURRENT TRANSIT APPLICATIONS

In recent years, several North American transit agencies have implemented automated data collection systems to gather passenger and schedule statistics. A summary description of the eight operational automated data collection systems is provided in Table I.C-4. Further information can be obtained by reviewing "An Assessment of Automatic Passenger Counters" (*2*) or contacting the transit agency personnel listed in Table I.C-4.

Passenger counter technology has also been implemented in conjunction with comprehensive automated vehicle monitoring (AVM) systems at several transit agencies. From 1977–1981 General Motors Transportation Systems Division experimented with an AVM system in Cincinnati, Ohio. The full Cincinnati system has been moved to Windsor, Ontario. In 1976 the Toronto Transit Commission designed and installed 100 dual beam counter units and 16 signposts as part of its AVM system. An UMTA-sponsored demonstration of AVM at Southern Califor-

Table I.C-3. Data retrieval options.

Implementation Option	General Characteristics and Limitations
Umbilical Transfer to Intermediate Storage Media	Data are extracted from on-board units and stored on intermediate media such as cassette tape, floppy disk, or solid-state memory. The option provides a distinct separation between data extraction and data processing and automatically results in an archive of raw data. However, it requires manual involvement including careful handling of both the umbilical and storage unit and appropriate safeguards to ensure positive connection and to prevent loss of data due to premature disconnection.
Umbilical Transfer Directly to Computer	Data are transferred via modem directly from on-board units to the data processing facility. This option avoids the problems associated with the handling of intermediate storage media. Potential problems associated with the umbilical remain. Delays in data transmission can be expected if multiple input channels are used and buffer storage is not provided. The option also requires a computer capable of multi-task processing.
Non-Contact Data Transfer	Data are transferred at the service island (or other location) automatically, e.g., by infrared link. The option requires high data transfer rates and typically a storage buffer or intermediate storage media. It is desirable because it eliminates the labor element but is experimental and expensive to implement.
Real-Time Data Transfer	Data are transferred while the vehicle is in service, e.g., by radio as in automated vehicle monitoring systems. The option requires additional equipment (in addition to on-board or wayside transmitters/receivers) to poll vehicles and control data transmissions. The costs associated with this option are high compared to other options and are justified only if data will be acted on in real-time, e.g., to respond to schedule adherence problems.

nia Rapid Transit District in 1980 through 1981 included installation of passenger counting equipment on 200 buses and 500 signposts. General Railway Signal plans to test its Bus Fleet Management System which includes passenger counters on 20 buses at the Regional Transit Service in Rochester, New York. In Hull, Quebec, 15 buses will be equipped with passenger counters as part of a fleet-wide communication system.

Several transit agencies are considering the implementation of automated data collection systems. These include Jacksonville Transit Authority in Jacksonville, Florida; the Regional Transit District in Denver, Colorado; SUNTRAN in Tucson, Arizona; and the Chicago Transit Authority. Finally, the CALTRANS demonstration program which began in 1979 is no longer active. In this program, passenger counting equipment was to be rotated among six transit agencies (Bakersfield, Golden Gate Transit, Montebello, Monterey, Sacramento, and Santa Cruz).

Several major European cities have installed passenger counting equipment in conjunction with automated vehicle monitoring systems, including Barcelona, Dublin, Hamburg, and Stockholm. Passenger counting systems have also been installed in Amsterdam, Utrecht, Düsseldorf, Tours, and Paris. The French approach to implementation of automated data collection systems differs somewhat from North American practices because of the high use of passes for fare payment (*3, 4*). In Paris and Tours, all transit buses are equipped with switch mat passenger counter sensors on *one* set of doors only. The total number of daily on/off counts at that door are used in conjunction with data about on-vehicle fare payments to determine pass usage on each route.

I.C.3 CURRENT EQUIPMENT SUPPLIERS

Numerous domestic and foreign firms supply equipment that can be used for automated data collection in transit applications. Generally, the products fall into one of four groups:

1. Complete passenger counter systems.
2. Automatic vehicle monitoring systems.
3. Electronic fareboxes.
4. "Self-service" fare equipment.

Table I.C-4. North American automated data collection systems.

Transit Agency and Implementation Date	Number of Units	Sensors	Storage and Transmission	Identification Data	Agency Contact
Calgary Transit Alberta, Canada 1982	5 Counters (Demonstration)	Photoelectric Beam	Solid-State to Portable Unit	No bus stop referencing	Keith West 403-268-1625
COTA Columbus, OH 1982	6 Counters 8 Signposts	Photoelectric Beam	Magnetic Tape Cassette	Match distance and signpost files	Bruce Bowles 614-275-5800
Kalamazoo Metro Transit System Kalamazoo, MI 1982	20 Counters 30 Signposts	Photoelectric Beam	Magnetic Tape Cassette	Match distance and signpost files	Charles Richards 517-322-1090
MTC Minneapolis/St. Paul 1979	44 Counters	Photoelectric Beam	None	Drivers manually record counts from display	Ray Neetzel 612-221-0930
OC Transpo Ottawa, Ontario 1978	65 Counters	Photoelectric Beam	Solid-State to Portable Unit	Schedule files matched with counts	Joel Koffman 613-741-6440
Quebec City Quebec City, Quebec 1980-1982	13 Counters	Photoelectric Beam	Solid-State to Portable Unit	No stop referencing	Pierrie Bouvier 418-627-2351
Seattle Metro Seattle, WA 1978-1983	56 Counters 250 Signposts 50 New Counters to be Purchased	Switch Mat	Solid-State to Portable Unit	Match distance and signpost files	Thomas Friedman 206-223-4705
TRI-MET Portland, Oregon 1983	50 Counters	Photoelectric Beam	Solid-State to Infrared Buffer	Match distance and signpost file; backtagging of time from receiver clock	Douglas Allen 503-238-5831

Reference: "An Assessment of Automatic Passenger Counters," Multisystems, Inc. DOT-I-82-43, September 1982.

Table I.C-5 lists firms that are currently supplying this equipment to the United States or are reportedly interested in entering the U.S. market. A data sheet for each supplier is provided that lists contact point, product description, and installation sites. This information is based on literature supplied by each firm.

Table I.C-5. Index of equipment suppliers.

Automated Passenger Counting Systems

Dynamic Controls Corporation
Etrometa BV
London Mat Industries, Ltd.
Pacena
Red Pine Instruments, Ltd.
RRA, Inc.
Urban Transportation Associates
VBB-SWECO

AVM Equipment and Signposts

AVM Systems, Inc.
General Railway Signal Company
Hani Prolectron AG

Electronic Farebox Systems

Cubic Western Data
General Farebox, Inc.

Fare Data Collection Devices*

Associated Electronics
Control System
Microsystem Design, Ltd.
Ticket Equipment Ltd.

*A number of ticket validation and pass reading devices that are being used in transit applications are capable of discriminating various fare categories and therefore are suitable as input devices for fare category counts. Most have yet to be used in an actual data collection function. Potential suppliers include AB Almex of Sweden, CAMP of France, Autelca of Switzerland, and Cubic Western of the United States.

Dynamic Controls Corporation
8 Nutmeg Road South, P. O. Box 73
South Windsor, Connecticut 06074

Contact: Ronald J. Kowalski, Sales Manager
202-528-9971

Product Description: Dynamic Controls Corporation developed and markets a complete automatic passenger counter system with the following features:

1. Switch mat sensors mounted on bus steps;
2. Microprocessor based control unit with interfaces to passenger counter sensors, electric odometer, signpost receiver antenna, door status switches, and real time clock;
3. Portable cassette data retrieval unit with umbilical cable for data transmission from vehicle; and
4. Status display unit.

The control unit can store up to 1500 records in solid state memory. Portable data retrieval unit records data from at least 8 buses on a cassette. Driver input requirements are limited. The system has a signpost interface, but signposts are not provided by Dynamic Controls.

Installation Sites:

Southern California Rapid Transit District
Seattle METRO
General Railway Signal incorporated Dynamic Controls System into its transit bus management system
Toronto Transit & South African Railways is testing the system

Etrometa B.V.
Kerkewal 49 - Postbus 132
8400 AC Gorredijk
The Netherlands

Contact: J.B. Leenhouts, Managing Director
Telephone: (05133) 3435
Telex: 46747 ETROM NL

Production Description: Etrometa currently manufacturers a mat-based automatic passenger counting system. Etrometa continues to develop and modify its system and is planning to produce a system compatible with U.S. systems.

Etrometa's system incorporates unique inductive mats. These consist of a bottom plate on which inductive proximity switches are mounted and a "floating" top plate that rests on the equivalent of leaf springs. The switches themselves are sealed but the mat upper and lower plates are not.

Etrometa's most recent system incorporates a bubble memory cartridge that provides non-volatile storage of the data from 9000 stop events. Up to 15 of these bubble memory modules can be inserted into a device called a read-out interface that transmits the data so that data transfer to the computer can take place unattended.

Etrometa also is reportedly developing a separate unit called a data converter that will assume a large part of the data screening activities prior to the transfer of the data to the computer. Etrometa's projected capabilities for the data converter include run recognition, stop identification, and file construction based on standardized software that will be built into the converter.

Installation Sites: Amsterdam, Rotterdam and Utrecht, Netherlands
Gronigan and Dusseldorf, West Germany.

London Mat Industries, Ltd.
P. O. Box 292, Station B
London, Ontario
Canada N6A 4V8

Contact: Heine Holm, Vice President
519-681-2980

Technical Description: Manufacturer of switch mat sensors for passenger counting systems marketed under the tradename, MATEX treadles. Switching mechanism in the mats is completely sealed in plastic. Simulation testing of the mats suggests a five year product life is possible.

Associated company, APC Systems, Ltd., manufacturers and markets Dynamic Controls Corporation passenger counter system outside the U.S.

Installation Sites: Seattle METRO
Southern California Rapid Transit District
Paris METRO

Pacena, Inc,
7966 Winston Street
Burnaby, British Columbia
Canada V5A2H5

Contact: Neil McClean
604-420-2023

Product Description: Pachina is developing a transit vehicle information system that can be used for passenger counting functions as well as monitor vehicle operating parameters (i.e., oil pressure or tire pressure.) The microprocessor control unit will accept signals from passenger counter sensors, odometer, clock, signpost receiver antenna, and a manual input console. The control unit can store up to 2000 stop records and 300 other records in packed format. Data transfer can be accomplished with a portable unit which stores data on 3 1/2 inch floppy disks or via bus radio for real time applications.

Several diagnostic tools are also being developed. A portable status display unit will be available for testing sensor accuracy. Each vehicle can be equipped with an additional diagnostic unit to allow drivers to monitor system functions. In addition, the Pachina system will provide a simulator for benchtesting the control unit prior to installation and a signature analyzer to assist technicians in locating problems.

Installation Sites: Awarded contract for Seattle Metro expansion.

Red Pine Instruments, Ltd.
(formerly Isaacs Associates)
RR1
Denbigh, Ontario
Canada KOH 1L0

Contact: Paul and Dianne Isaacs
613-333-2776

Product Description: Red Pine Instruments has developed and is marketing a complete passenger counter system with the following features:

1. Photoelectric (infrared) beam sensors located on vehicle stairwells;

2. Microprocessor based control unit with a clock and interfaces to counting sensors and vehicle odometer; and

3. External receiver using a portable disk or infrared data unit.

The control unit can store up to three days of data. The portable disk unit stores data on floppy disk; the infrared link temporarily stores data on buffer unit which automatically sends data to the computer. AC line operated power supply provides power supply for portable disk unit for transferring data to host computer.

Red Pine is currently developing a series of functional data collection units that may be interconnected to form a modular system. A prototype of the system is currently being tested. This system includes a microprocessor based passenger counter control unit with interfaces to counting sensors and a door switch and a microprocessor based supervisor unit with interface to passenger counter control unit and vehicle odometer. In this system a passenger counter control unit would be installed at each door with sensors so that vehicle wiring requirements are localized. Global wiring is limited to a single 4-conductor cable which links the passenger counter control units.

Installation Sites: TRI-MET
OC Transpo
Quebec City
City of Calgary

RRA, Inc.
Routeware Systems Division
3550 Hulen Street
Fort Worth, Texas 76107

Contact: Robert French, Director
817-731-2711

Product Description: RRA has developed and tested a decentralized vehicular application that involves the use of an on-board computer and software for:

- Real-time mathematical analysis of the differentially sensed vehicle dynamics to deduce the vehicle's path.

- Simultaneous map-matching to correlate the vehicle's path with a route programmed on a digital tape cassette.

In effect, the on-board computer continuously monitors the vehicle's track and superimposes it on a digital map to determine the vehicle's path and instantaneous location. Minor displacements in the computer-perceived track are compensated by matching the apparent path to the programmed route.

Installation Sites: None

Urban Transportation Associates, Inc.
7111 Hamilton Hills Drive
Cincinnati, OH 45244

Contact: Keith Armstrong
513-232-5283

Product Description: Urban Transit Associates leases and installs on-board, automatic data collection systems to transit agencies. The company also provides data processing and report generation services. The equipment used has the following features:

1. dual beam infrared passenger counter sensors;

2. microprocessor based control unit with interfaces to passenger counter sensors, electric odometer, signpost receiver antenna, and door status swtiches; and

3. portable cassette reader.

On-board data storage is accomplished with magnetic cassette tapes. Up to 14 days of data can be stored on one tape. A portable cassette reader is required to produce machine readable tapes for processing.

Installation Sites: Kalamazoo Metro Transit, Kalamazoo, Michigan
COTA, Columbus, Ohio
CTA, Chicago, Illinois

VBB-SWECO
Linnegatan 2
P.O. Box 5038
S-10241 Stockholm
Sweden

Contact: Michael Gedda, Project Manager
Telephone: 46-8-630380
Telex: 17597 SWECO S

Product Description: VBB-SWECO is an engineering consulting firm providing planning, engineering, and architectural services to public transit systems, primarily in Scandanavia but also in Europe, Africa, and the Middle East. VBB-SWECO markets a system called the Public Transit Data Collection System.

This data collection system consists of a single control box and associated sensors to record the following information on to cassette tape: date and time, distance, running time, departure time, "door-open" time, arrival time, stop time and delay time, passengers boarding and alighting, and fuel consumption. The control box, measuring approximately 12 inches by 8 inches by 8 inches, is designed to be installed behind the driver on either a bus or light rail vehicle. The unit contains a cassette tape recorder, a paper tape printer, and a 16 button keypad. Sensors for passenger counting, mileage, door monitors, and fuel consumption are connected to the control box via a multi-pole jack that is designed to make the unit itself completely portable. The current system operates on 24 volts.

Installation Sites: Oslo, Norway

AVM Systems, Inc.
5050 Mark Parkway
Ft. Worth, TX 76106

Contact: Maurice Lanman
817-625-2811

Product Description: AVM Systems, Inc. supplies signposts and signpost receiver assemblies for automated data collection systems. The signpost is a self-contained battery powered unit which is mounted on utility poles. Every 0.7 second, it transmits a unique identification code. The code can be loaded or changed in the field with a portable signpost programmer.

The signpost receiver assembly is installed on the vehicle and includes an antenna, receiver circuit boards, and cables. A low profile antenna, 20.8 inches long, 2.3 inches wide, and 2.6 inches high is installed on the roof of the bus. Two circuit boards are provided: a signpost receiver module circuit board and an error filter circuit board. The receiver circuit board provides an interface for an odometer. Typically the receiver can detect a signpost transmission 200 to 300 feet from the signpost. The signpost code, time, and odometer value are recorded when the vehicle arrives and departs each signpost area. AVM Systems also provides equipment for testing the system.

Installation Sites: Seattle Metro
Southern California Rapid Transit District

General Railway Signal Company
A Unit of General Signal
Box 600
Rochester, New York 14602

Contact: George G. Arena
716-436-2020

Product Description: The Transit Bus Fleet Management System developed by General Railway Signal (GRS) can collect data for real time applications and statistical report generation. It includes three major subsystems:

1. A vehicle and wayside data collection subsystem capable of collecting, storing, accessing and transmitting the following data on a modular basis: passenger boardings and alightings, farebox information, vehicle location and time of signpost passing, trip and vehicle identification, and alarms.

2. A two-way digital communications subsystem that transmits information from the vehicle to the central office data processing and display subsystem. The fleet dispatcher can transmit messages to vehicles and automatically control electronic vehicle destination signs.

3. A central office data processing and display subsystem consists of three components. A microcomputer is used as a preprocessor to retrieve data from the vehicle and transmit data. A minicomputer, the control processor, is used for real-time applications while a second minicomputer generates statistical reports. For real-time applications, operational data are presented on an out of tolerance "exception-type" basis.

Dynamic Controls Corporation equipment is used for passenger counting functions. Vehicle identification is accomplished with uniquely coded transponders mounted on utility poles. On-board interrogators read the code when the bus passes the transponder. The GRS system also provides software for management information report generation.

Installation Sites:

Twenty bus demonstration project at the Regional Transit Service in Rochester, New York planned for 1983-1984.

Hani Prolectron AG
Datenelecktronik
Zurcherstrasse 10
CH-9500 Wil
Switzerland

Contact: K. Koenen
Telephone: 073-22-36-22
Telex: 88-32-46

Product Description: Hani Prolectron designs, manufactures, and provides turn-key installations of computer-controlled communication and monitoring systems for public transit, primarily in Germany, Switzerland, and Austria. Hani Prolectron manufactures an on-board control unit it calls the IBIS (Integrated Board Information System).

IBIS is designed to control/monitor on-board electrical devices. The IBIS control unit contains a 22 button keyboard and a two-line display of 16 characters each plus all electronics to control/monitor the peripheral devices connected to it. The unit, measuring approximately 8 inches by 4 inches by 6 inches, is mounted in front of the driver, on or near the dashboard. IBIS is designed to provide for the centralized control of the various electronic devices on the vehicle, including overhead destination signs, taped announcements, multi-trip ticket validating devices, etc. It also is designed to accept data from weight-measuring and passenger counting units and provide the interface for the transmission of this data via radio. Special input/output connections are provided for door switches, odometer pulses, and signals from wayside signpost transmitters.

Installation Sites: Balse, Switzerland
Frankfurt, West Germany

Cubic Western Data
5650 Kearny Mesa Road
P.O. Box 85587
San Diego, CA 92138

Contact: John Hughes, Director, Marketing
619-268-3100

Product Description: Cubic Western Data has been manufacturing subway gates and ticket vending equipment for more than ten years. In 1983, Cubic began marketing its first on-board system, called the Fast Fare System.

The Fast Fare System is fare collection and data collection system the nucleus of which is an electronic, registering farebox. The system performs all the functions of a farebox, including the counting and registering of revenue deposited into the vault. Fare category counts are provided via driver-activated push-buttons located on the front panel opposite the coin inspection window. An optional magnetic pass reader can be incorporated into the unit to provide pass verification and automatic counting of pass types by category.

Installations:

A pass reading device has been tested and evaluated by San Diego Transit. Fast Fare is a new product line that is expected to be in revenue service in the near future.

General Farebox, Incorporated
4619 N. Ravenswood Avenue
Chicago, IL 60640

Contact: Norman Diamond, Vice President, Marketing
312-561-8700

Product Description: General Farebox developed, manufactures, and markets CentsaBill, an electronic registering farebox. Introduced in 1982, it has the following characteristics:

a. 4 levels of automatic fare counting and 9 levels of driver-activated passenger classifications,

b. Capability to accept and process all U.S. coins, two sizes of tokens, dollar bills, and tickets,

c. Coin inspection plate and LED digital display to indicate the amount of money (coins and bills) inserted into the farebox,

d. By-pass chute to allow the farebox to stay in service in the event of a coin mechanism jam.

e. Data port for transmitting farebox data via infrared probe to GFI's data reporting subsystem.

f. Optional driver activated route/run segmenter.

Dollar values and quantity amounts registered and stored in the farebox are cumulative totals. The run/route segmenter can compile up to 100 records. When data are transmitted from the farebox they are immediately buffered into the data system computer. Information within the computer can be concurrently transmitted to a printer and/or modem or a cassette recorder. Each data system computer can support data transmission from 4 buses simultaneously.

Installation Sites: Dallas Transit System
Pre-award tests: Utica, New York; MARTA (Atlanta, Ga.); Washington Metropolitan Area Transit Authority.

Associated Electronic Service Pty Ltd
P.O. Box 35
Norley, Western Australia 6062

Contact: Ken Gibson, Director, Marketing
Telephone: (09) 275-4611
Telex: AA92686

Product Description: Associated Electronic Services manufactures and markets a modular fare collection system with the following components:

1. A ticket cancelling machine with optical scanner to validate tickets purchased off-the vehicle. An audible signal is used with valid tickets. Microprocessor stores time, route, and fare data.
2. A conventional drop type farebox.
3. A ticket issuing machines for off-vehicle ticket purchase or on-board fare payment. A dot matrix printer is used to print tickets.
4. A console for driver input of route and fare zone data.
5. An infrared control unit to input real time and date automatically into driver console.

Data retrieval can be accomplished by portable unit or by radio.

Inatallation Sites: Perth Metropolitan Transport Trust, Australia.

Control Systems, Ltd.
The Island
Uxbridge, Middlesex
England
UB8 2UT

Contact: C.A. Bulley, Export Sales and Marketing Manager
Telephone: Uxbridge 51255
Telex: 22225

Product Description: The Autofare 3 System is implemented with two major components:

1. The solid state keyboard module records and stores data on passenger categories, revenue collected, and other identification. Fare data can be manually programmed to the 10 keys on the console or fare tables can be programmed into the memory for automatic fare calculation. The unit also contains an LED display for the driver, interface with umbilical for data transmission, and interface with other input devices such as a ticket cancelling machine. Summary printouts can be obtained from each machine. Operators are required to manually input identification data and fare categories.
2. A separate ticket issuing machine which can be positioned away from the keyboard and bus doors. High quality alphanumeric tickets are printed.

Other options available include a secure cash box, ticket validators, and VHF radio link.

Installation Sites: West Midlands PTE, Birmingham

Microsystem Design, Ltd.
Fleets Industrial Estate
Willis Way
Poole, Dorset
England BH15 3SS

Contact: R.J. Harding, Director
Telephone: POOLE (02013) 70671
Telex: 418469

Product Description: The Wayfarer is a self contained unit for issuing tickets and recording data on the number of tickets sold in each fare category and the amount of revenue collected. It is permanently installed on the vehicle and operators are required to manually input identification data and fare categories. The machine issues 3-line alpha-numeric tickets based on a preprogrammed fare structure. Fare data can be manually programmed to the keyboard with a security key or a portable plug-in memory module for automatic fare calculation can be used.

The operator keyboard contains 28 keys and allows for 8 preprogrammed fare categories and 20 preprogrammed destinations. The unit also contains an LED digital display for the driver. Summary printouts can be obtained directly from each machine. Each machine has a real-time clock calendar. Options available with the Wayfarer include ticket validator, pass reader, mileage recorder, remote ticket printer, and VHF radio link.

Installation Sites:

Test trials at Hants and Dorset Motor Services, the National Bus Company operator in Poole, Dorset.

Ticket Equipment Limited
Love Lane
Cirencester, Gloucestershire
England GL7 1YG

Contact: G. Arszelewski, Export Sales Manager
Telephone: Circencester (0285) 4161
Telex: 43120

Product Description: The microprocessor-based Timetronic ticket issuing and fare data collection system is composed of four pieces of equipment.

1. A ticket issuing machine is installed on-board each vehicle. It contains a clock, programmable keyboard, two digital displays (one for the driver and one for the passenger), ticket validator, a memory module for fare tables, interface with a distance measurement module and with the Automatic Computer Entry (ACE) Module. The machine issues 3-line numeric tickets. Individual trip or multiple trip tickets can be issued. The ticket issuing machine records and stores a daily record of opening and closing cash balances. The Timetronic can print out data stored in memory. The driver is required to input identification data and passenger categories.
2. ACE Module assigned to an individual driver, is a plug-in solid state memory module used to record and store data on the number of passengers in each fare category, revenue collected, and tickets cancelled by route during each driver's duty cycle.
3. ACE Encoder personalizes each ACE module with the driver's personal security number and maintains a file on ACE module usage.
4. ACE Reader, located in garages, is used to transfer data from ACE modules. It can provide a printout of data for each module or summary statistics from all modules at that garage. All data are read onto discs for subsequent processing.

A fare module with the complete fare structure can be plugged into the ticket machine to provide automatic fare calculation. Alternatively, up to 24 fare categories can be programmed directly onto the keyboard by transit agency staff. The driver can also use the keypoard for entering fare values.

Installation Sites:

Over 1,000 Timetronic machines and supporting equipment are being introduced at 8 subsidiaries of the National Bus Company.

I.C.4 REFERENCES

1. KLOPFENSTEIN, R.L., ET AL., "VITRO Passenger Counter Test Results." *Report No. MTR-7071,* Vol. IV, prepared for the Urban Mass Transit Administration by the MITRE Corporation (1975).
2. VOZZOLO, D., and ATTANUCCI, J., "An Assessment of Automated Passenger Counters." *Report No. DOT-I-82-43,* prepared for the Urban Mass Transportation Administration by Multisystems, Inc. (1982).
3. FRENOIS, M., and SUTTON, D., "Traffic Evaluation Methods." 43rd International Congress International Union of Public Transit, Sweden, Helsinki, *Proc.,* Vol. 5 (1979) pp. 5–36.
4. "Le Comptage des Voyageurs par Tapis Contact a la RATP." *Transport Public* (March 1982) pp. 39–45.

APPENDIX I.D

INFORMATION PROCESSING

An automated data collection system can generate a wealth of data to the point that it can rapidly become overwhelming. Perhaps the most extensive attempts at extracting management information from this type of data have taken place in Cincinnati, Ohio, and Los Angeles, California. For a number of years, the Urban Transportation Laboratory, a cooperative program involving the city of Cincinnati, the Southwest Ohio Regional Transit Authority, and the GM Transportation Systems Division, worked on developing an automatic vehicle monitoring management information system for the Queen City Metro bus system. The project is no longer active but its products were extensive. The types of reports developed continue to serve as models for the information products to be obtained from an automated data collection system and several transit properties, notably Kalamazoo and Columbus, use many of these report formats and basic routines.

The work by the Southern California Rapid Transit District (SCRTD) in Los Angeles is a continuing effort that builds on the Cincinnati experience to support its own automatic vehicle monitoring system. Several reports have been published on the design and structure of the SCRTD management information system (*1, 2, 3*).

Except for these two efforts, the data processing aspect of automated systems has tended to mirror the hardware development. The systems that have been implemented to date have been incomplete and customized to specific site needs and resources. Data collection is usually undertaken in systematic fashion, but a rigorous information program has not been established. Information continues to be gathered for special purposes or special requests, in large part because the efforts to date have had to concentrate on the hardware and data collection aspects leaving few resources available for developing an integrated information system.

As a consequence, there is little published information on the data processing requirements of automated data collection systems. The NCTRP research, therefore, includes a task in which these requirements are to be identified. The following presents the general data processing requirements and subsequently expands on these general requirements to provide greater detail on the type of output that can be produced and the ancillary information needed to generate these outputs.

In much the same fashion as previously adopted in presenting the hardware elements of an automated system, the data processing aspects of automated data collection are discussed in terms of an overall design that could, but need not be, a basis for further development. The purpose of this is twofold: first to address the requirements for data processing in an informative manner that avoids reference to particular implementations, computer languages or computer characteristics, and second to attempt to move one step closer to greater standardization.

I.D.1 SOFTWARE REQUIREMENTS

The volume of data that is generated by automated data collection systems precludes manual processing. Software is needed to sort, aggregate, and maintain data and to extract management information. The following discusses these software requirements.

On-Board Processing

In general, some on-board processing is necessary if only to achieve the appropriate format and to delineate data identifiers such as run and route number. Software is also required to avoid recording errors such as missing and/or inconsistent data. The system controller microprocessor program provides control of all data transfer operations between modules and acts as data monitor and manager for the overall system.

Processing the Data

Validation, referencing, file construction, and file merging operations take place after the data have been extracted and transmitted from the vehicle to the computer. Before any data are manipulated, the data must be screened to ensure validity and completeness. In addition, in a modular system, software is necessary to preprocess data records both to delete data that are not used by the specific transit agency and to ensure that the format is compatible with preexisting processing hardware and software.

Data records from the on-board automatic data collection system are then correlated with actual stop and trip locations. Two approaches can be taken:

1. For systems without signposts, scheduled time and distance files are matched with recorded time and distance data to identify specific counts with the appropriate bus stop.
2. For systems with signposts, signpost files are matched with signpost records and data are edited to identify vehicle trip and stop records.

Once the data and schedule files are merged, a complete master file is created which contains data observations on a trip-by-trip basis. As information is also normally required on a route-by-route basis, additional software is used to transform the master file into data files for scheduling and other applications.

External Files

Data files to support and supplement the automated data collection system must be developed and maintained. These external files, which are described in Appendix I.E, include:

1. Computerized schedule data to match time data collected from the system.
2. Computerized mileage data to correlate data counts with specific bus stops.
3. Computerized signpost data to correlate signpost records with specific signposts.
4. Computerized timepoint location and deadhead distance files for RUCUS applications.

Generating Management Information

The data on ridership activity, running times, and schedule information stored in the master file are used to produce management information reports and summary statistics. Software is required both to specify construction of the reports and to generate summary statistics desired by the specific transit agency.

Updating and Archiving of Data and Information

An often overlooked step is the activity associated with maintaining an up-to-date data base and whatever historical record is required. Off-line data storage must be planned for all data that will be retained and charges will be incurred for maintaining the data. More significantly, considerable time and effort must be devoted to establishing the procedures by which data will be periodically reviewed, updated, and archived and to maintaining a custodial role over this archive, including data retrieval and reporting from historical files.

I.D.2 THE DATA PROCESSING ACTIVITY

Figure I.D-1 illustrates the overall data processing function. Data are collected from the vehicles and subsequently transferred to a computer for initial data screening and validation. This process continues in the next step so that the bus-oriented data are appropriately referenced to identify trip, time points, and other delimiters useful to constructing route-oriented data files. Finally, the data are processed into specific files corresponding to the management information reports that will be produced. Throughout the procedure, various external files are accessed to check data validity and/or supplement information.

Transferring the Data to the Computer

The first data processing step occurs when the data are transferred from the on-board units to the computer. Typically, this is a two-stage process in which the data are first transferred to a data retrieval unit at the service island or other location that

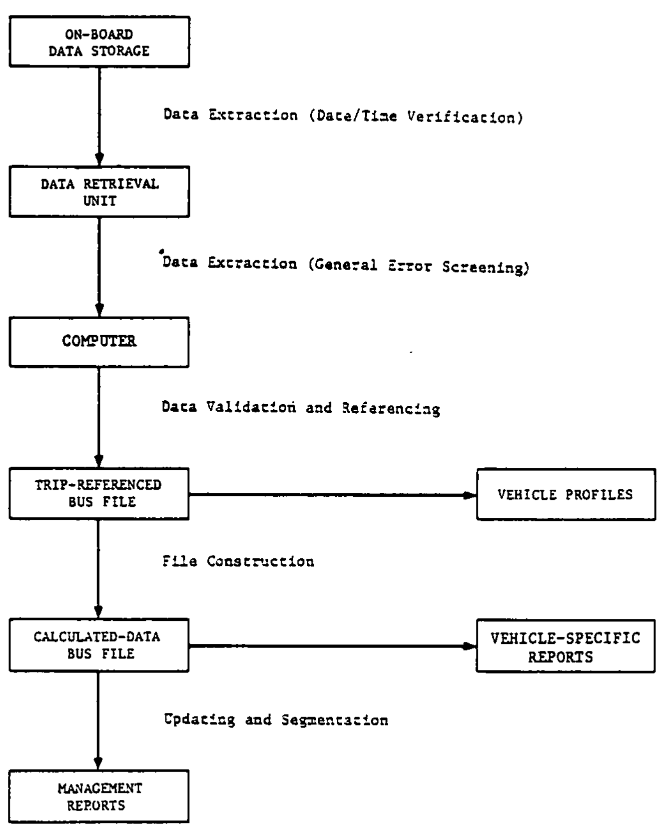


Figure I.D-1. General data flow.

provides temporary storage of the data. The transfer from this intermediate storage to the computer occurs at a later point in time—perhaps the following day.

Figure I.D.-2 illustrates the data transfer operation. The first stage of this operation, the transfer from the on-board unit to the data retrieval unit, is essentially a hardware function. The data retrieval unit requests the data and the on-board unit responds by transmitting the data. Typically, a data checking and retransmission procedure is standard, as are safeguards to ensure a positive connection and the completion of the transmission before the on-board unit is cleared. The data retrieval unit should provide an appropriate header to tag the data to indicate the time and date the data transfer was started and completed, and the time and date maintained by the on-board unit. These time/date references are required in all data systems—in clock-based systems to detect units incorrectly set and in nonclock units to provide a reference for backtagging data.

In the second stage, the transfer from the data retrieval unit to the computer, data screening, and validation begin. As in the previous stage, the data transmission monitoring is a standard hardware function. The first action in the data screening is to compare the data and time provided by the retrieval unit with that obtained from the on-board unit. If there is a discrepancy, the incident is recorded in another file called a trouble report file and processing continues using backtagged data.

The next step is to identify the bus number associated with the unit from which the data came. This is a simple look-up operation, requiring access to an external file that matches bus numbers and machine numbers (and installed dates). This file is required in all systems—even where bus number is a driver or dispatcher set feature and is recorded by the on-board unit. Whenever a file is accessed for data verification and a mismatch is detected, the incident is entered into the trouble report file and processing continues with corrected data or is halted until

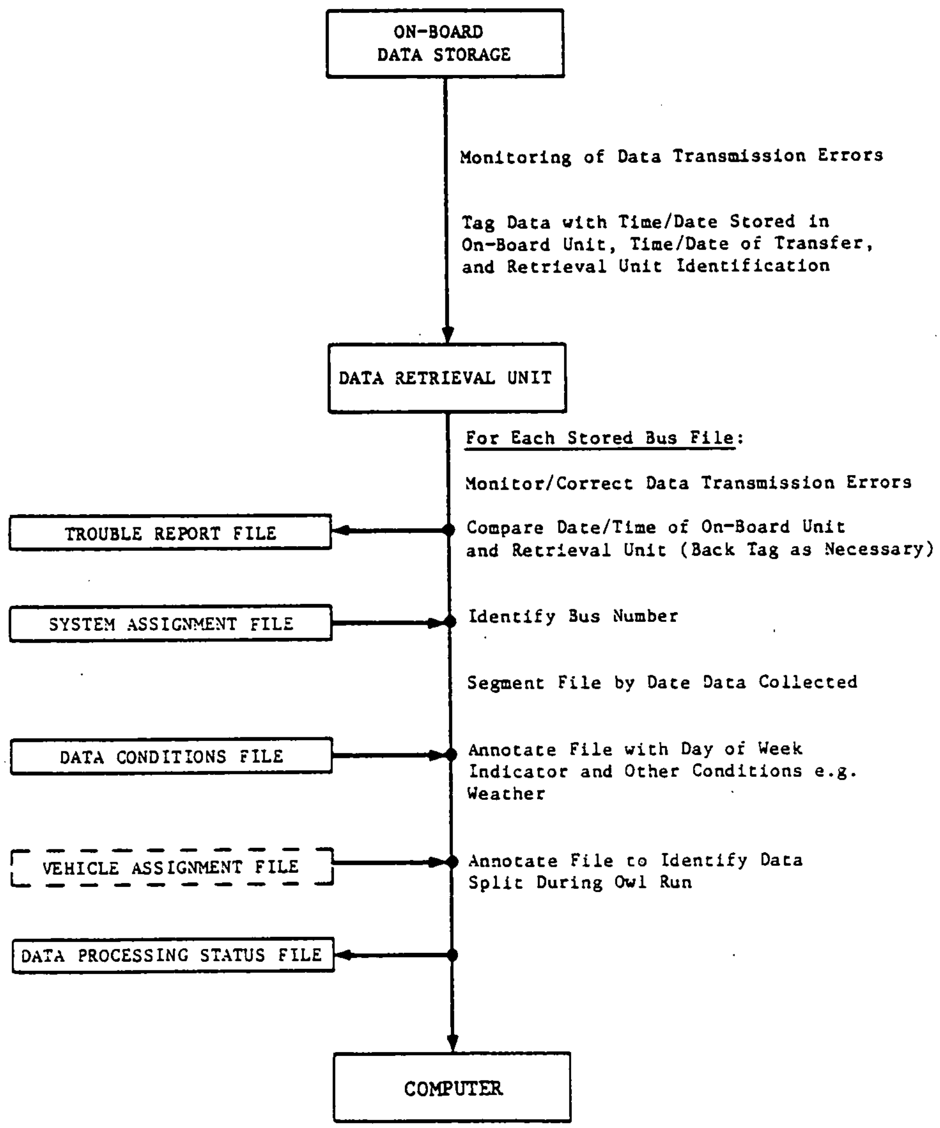


Figure I.D-2. Data transfer to computer.

the error is resolved depending on the severity of the mismatch. In the case of an incorrect bus number, the assignment file would be presumed correct and processing would continue with adjusted data.

Since a particular vehicle file may contain more than one day's data, the next step is to segment the data by date. To avoid splitting the data in a large number of owl runs, the period defining a day should not end at midnight but perhaps at 3 AM to 4 AM in the morning, and should be user definable. At this point, each segment is then annotated with additional information, such as a code to indicate the weather conditions experienced on that day and whether or not the date was a holiday, a school day, etc. This operation would be completed automatically by referencing a file called the data conditions file.

The final step in the preliminary screening process is to tag the data to indicate whether or not an owl run has been split during the segmentation of the data by date. This indicator would be used subsequently to avoid erroneous data calculations, e.g., to avoid exaggerating the number of reported trips. This annotation could be achieved by inspecting the data (via the computer) to ascertain whether or not a distinct break in the data occurred around the breakpoint. Alternatively, the computer could assess an external file to determine if a particular vehicle has been assigned to an owl run on a particular date. The former is the preferred procedure since one less piece of information must be updated.

The major product of this preliminary screening is a set of bus files segmented by date. Secondary outputs are trouble reports and status reports. Trouble reports identify data/information mismatches, while status reports identify useful processing statistics such as number of record/vehicles processed and days/dates covered by the records transferred.

Data Validation and Referencing

The next step is the most difficult. Here, the data are transformed from vehicle-oriented files to trip-oriented files. The process contains the majority of the data validation procedures and entails the most access to external files to complete this verification.

Figure I.D-3 illustrates the general procedure and Figures I.D-4 and I.D-5 provide additional detail. The process begins by identifying the first scheduled assignment as logged on a dispatcher's assignment sheet. Then, by accessing a data file defining this assignment, the route, initial time point, and other characteristics are determined in order to identify the data record corresponding to the start of the trip and likewise the end of the trip. From there, the processing continues until all trips are identified.

Figure I.D-4 illustrates the procedure where signposts are deployed at time points and trip terminals. If signposts are deployed at route terminals, the process of trip referencing is eased considerably. Supplemental cross-checks to detect and account for missed assignments, unexpected turnarounds, etc. are highly desirable to preserve the greatest amount of data. However, such could be viewed as optional features if one is prepared to accept the loss of some data.

Lacking signposts, trip referencing must rely on a combination of manual input data, time data, and distance data. Figure I.D-5 illustrates this relatively complex procedure. If drivers could be relied on to delineate accurately and reliably the start and end of a trip and enter identifying information, manual input data alone would be sufficient for trip referencing. However, such is not the case, and even if these manual inputs are available their validity must be considered suspect and verified continually. If manual input is not available, the search for the start and end of a trip depends on either time or distance referencing. Matching of time with schedule time may be even more unreliable than depending on manual input because on-time performance must be assumed. Therefore, time referencing typically takes the form of inspecting the data to determine layover periods. Distance matching is a preferred alternative, but it requires substantial data collection of its own to establish the reference file.

Whichever data referencing scheme is adopted—ideally the software should permit the user to select a combination—some data will not be usable. The trip referencing must report unidentified data and attempt to recover, so that processing can continue without manual intervention. At the end of each file processed, the user should have the ability to intervene to correct recognizable errors if so desired. As a minimum, the software must provide a report that enables the user to ascertain how successful the referencing was, and how much of the data was determined unusable and marked for discarding unless further intervention is taken.

System-Level File Construction

Having screened the data to delineate usable trip information, the next operation is to extract and maintain the data to correspond to the information needs of the transit property. This will be initiated in this step and completed in the subsequent one.

Figure I.D-6 illustrates the transformation of the previous trip-referenced bus files into three primary files:

1. Vehicle Profile Files.
2. Time Point-Trip Files.
3. System Statistics Files.

Vehicle profiles are provided to generate the type of graphic output commonly used to inspect the loading of individual buses. These files are also the primary archives of raw data. The Time Point-Trip Files contain the data and derived information relative to each trip sampled. The System Statistics Files contain the data and information that cannot generally be associated with individual trips. This file would, for example, maintain data relative to deadheading, total hours and mileage, and so on.

The same process is followed for each trip in the file. The first step is to examine the passenger load at the beginning and end of the trip. This requires stepping through all the data since the previous trip end and computing the passenger load. If either or both the trip start or trip end indicate a nonzero value, the passenger count data can be tuned to attempt to correct for known sensor counting errors. The results of this tuning are then applied to the data before proceeding.

The processing resumes at the start of the trip and at this point information pertaining to activity between trips (e.g., deadhead mileage, layover time between trips, etc.) is transferred to

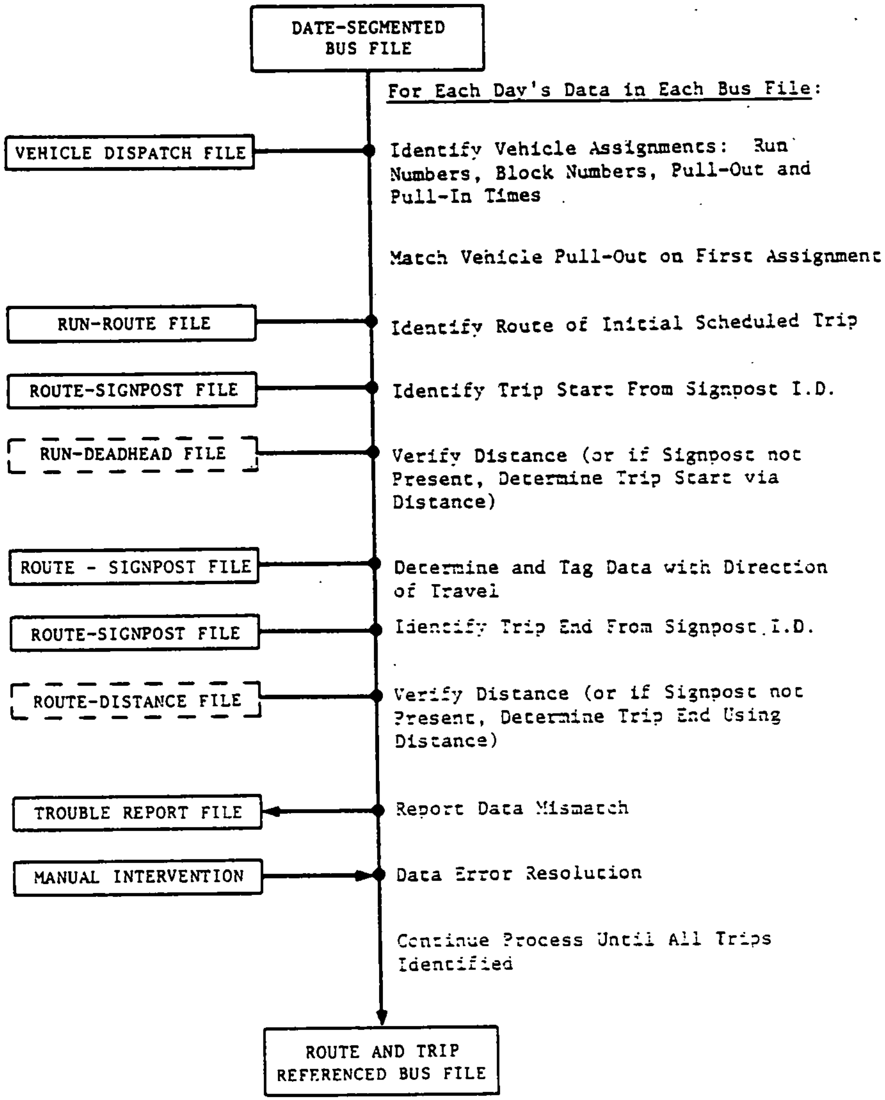


Figure I.D-3. Data validation and referencing.

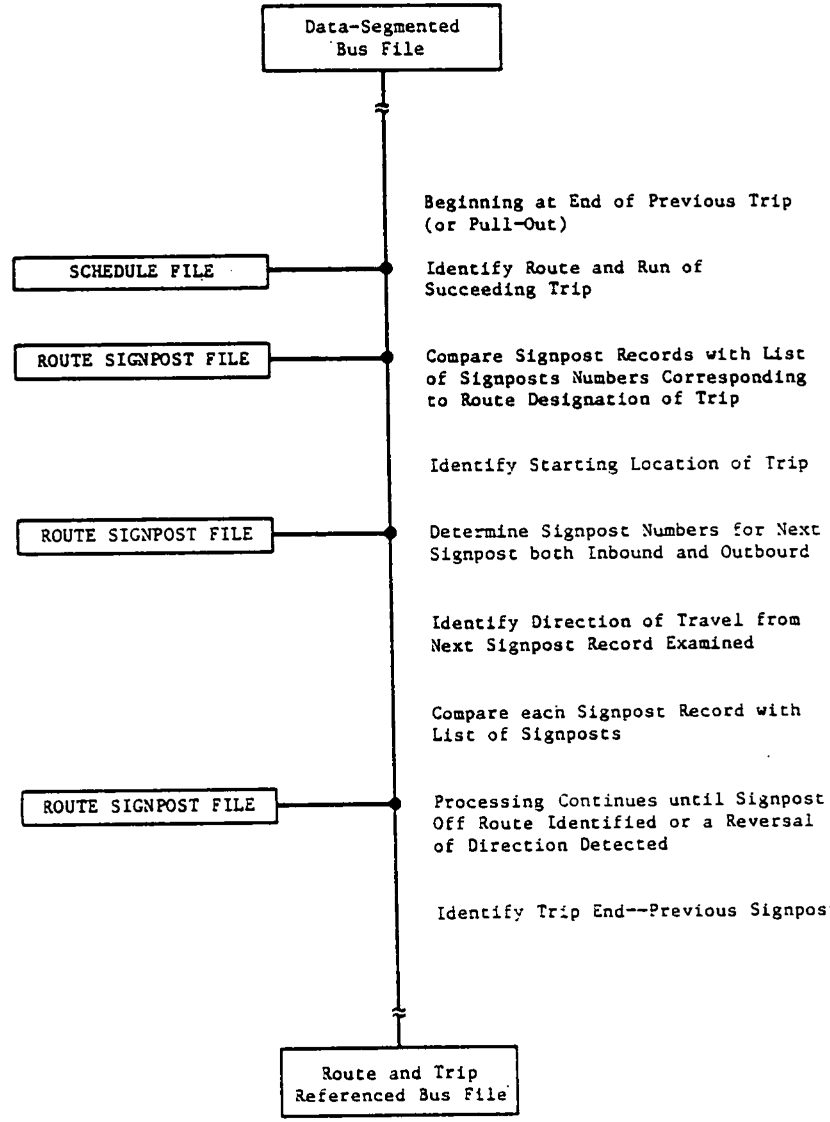


Figure I.D-4. Signpost trip referencing.

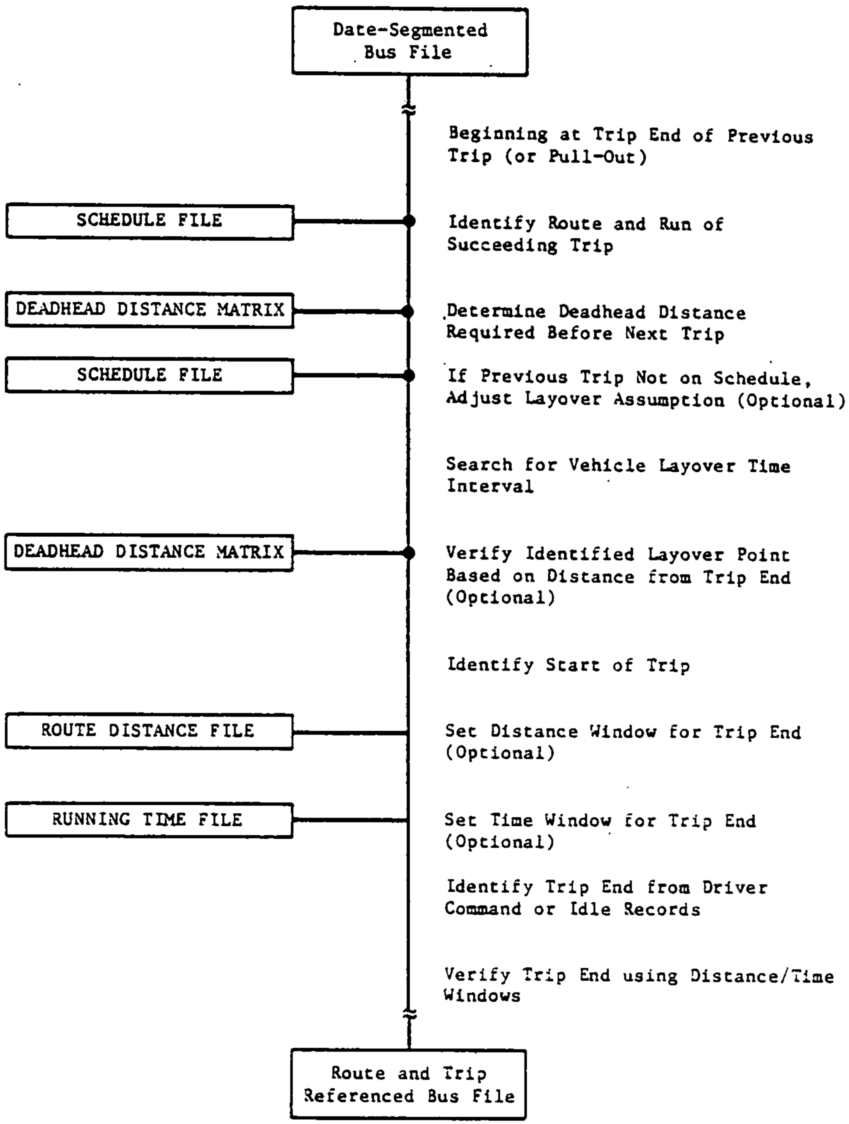


Figure I.D-5. Time and distance trip referencing.

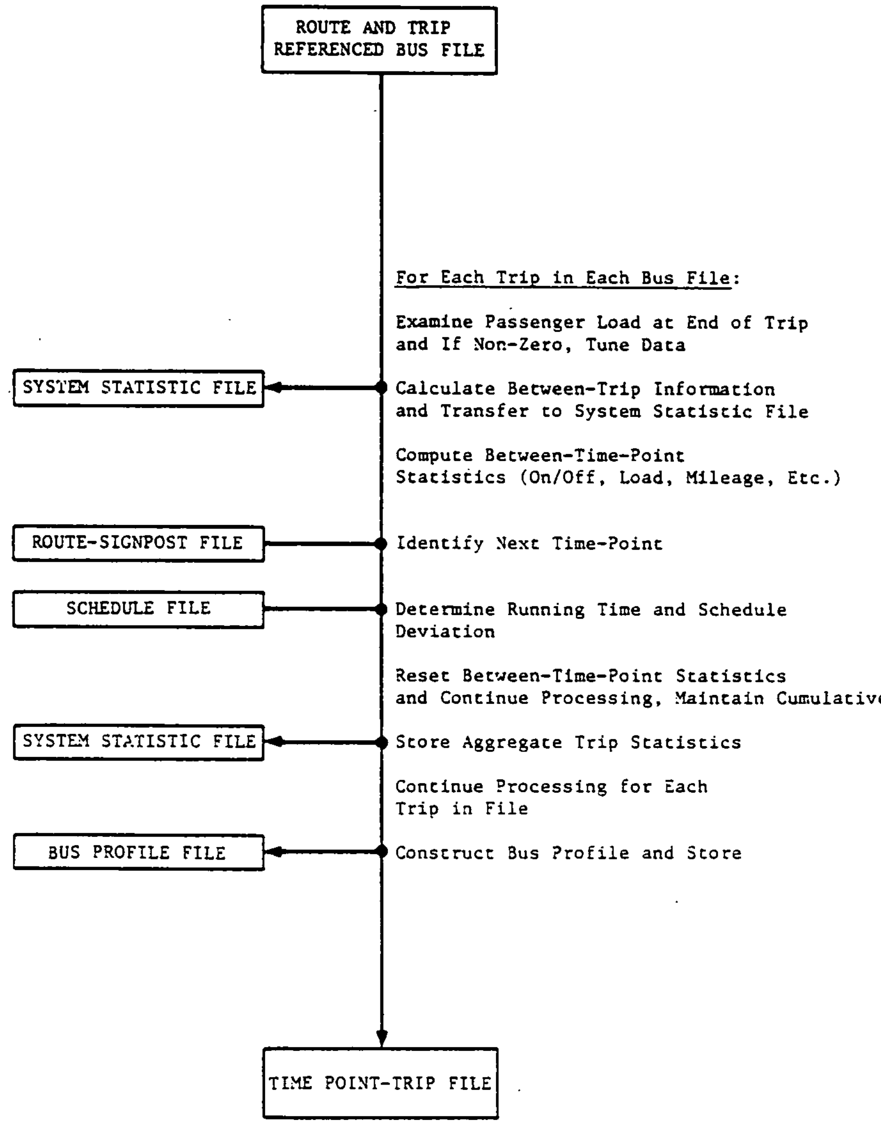


Figure I.D-6. Construction of system-level data files.

the file called the System Statistics File. Each data record is then examined sequentially until the first intermediate time point is identified. During this search, statistics for the trip segment are computed. These include information on the total number of passengers boarding and alighting since the previous time point, the maximum passenger load between time points, and the distance from the previous time point at which the maximum load was detected.

The procedure for identifying a time point location is similar to that for identifying the end of a trip. If signposts are deployed at time points, the location procedure is greatly simplified. If signposts are not used, a distance matching procedure can be used. Reference 4 details such a procedure. When a time point is identified, the data pertaining to the between time point activity become permanently associated with the time point. At this point, additional statistics such as running time and schedule deviation are calculated and the processing continues until the entire trip is segmented into time points.

At the end of each trip, additional aggregate statistics are transferred to the System Statistics File and the entire process continues until all information in a particular bus file is processed. At this point, data are still maintained in a vehicle orientation and intervening records between time points are still present. However, the final product of the step will be a time point-trip file in which intervening records are discarded. Therefore, if stop-by-stop profiles are desired or vehicle-oriented files are to be retained, files for this purpose must be created at this point. The vehicle profile provides this storage.

The three files produced in this step form the basic input to external procedures including the various management reports and other routines such as RUCUS and maintenance planning.

Report File Construction

The final step in the data processing is to use the three major files to update and maintain the specific management information needed. Individual files are created for each of the management reporting functions desired. Figure I.D-7 illustrates this process for one of the management reports—running time.

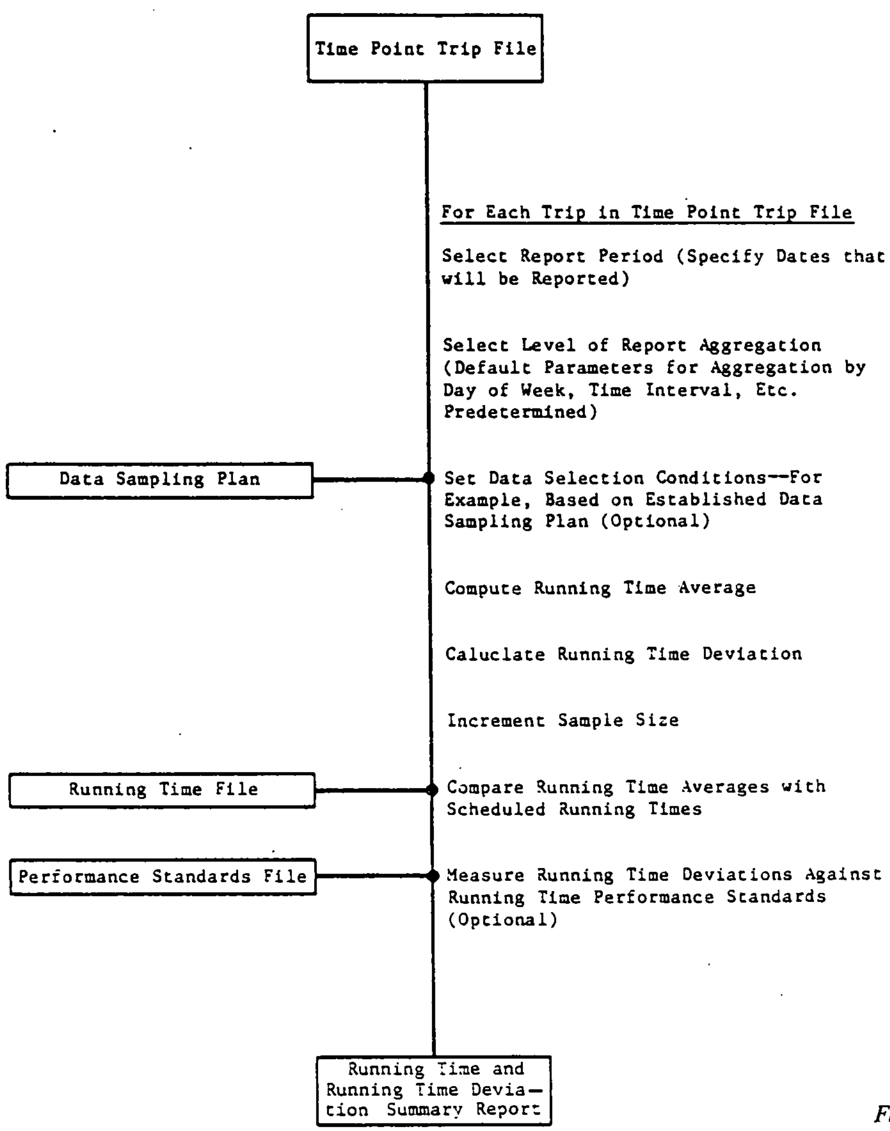


Figure I.D-7. Running time summary report.

Data are appended to each management report file directly from the Time Point Trip File by stepping through the latter file and extracting the appropriate and relevant information. The first stage in this process is to determine whether or not the data supplied by the particular trip conform to the sampling plan and therefore maintain the random integrity of the information. This is an important step in that it ensures that data transferred to the management reports do not introduce a bias that will undermine the random nature required in the sample. Depending on the type of data, this screening may be extremely rigorous or very general. For some route-level statistics, such as ridership and passenger mileage, it may be important to exclude certain trips because they would introduce a bias. For other statistics, such as the running time between points during specified time periods, a significant bias may not be introduced by accepting all the data if the time intervals are of sufficiently short duration and only averages are sought.

Once the trip data have been examined and determined appropriate to the management information, it is a routine operation to update the management report file. In the case of the example shown, running times from the trip are used to compute new averages and the sample size indicator is incremented.

I.D.3 REFERENCES

1. LUDWICK, J. S., JR., "Management Information Reports from Automatic Vehicle Monitoring System Data." *WP-79W00738*, The MITRE Corporation (Jan. 1980) 67 pp.
2. LUDWICK, J. S., JR., "Meeting UMTA Section 15 Reporting Requirements with Automatic Vehicle Monitoring System Data." *MP80W28*, The MITRE Corporation (July 1980) 21 pp.
3. LUDWICK, J. S., JR., "Detailed Design for a MIS for the Southern California Rapid Transit District." *MTR-80W84*, The MITRE Corporation (Oct. 1980) 103 pp.
4. DEIBEL, L. E., and RAVENEL, F. G., "Bus Stop Identification Using Odometer Data." *WP11088*, The MITRE Corporation (June 1975) 44 pp.

APPENDIX I.E

EXTERNAL DATA FILE DESCRIPTIONS

The more significant external data files referenced in Chapter I.3 and Appendix I.D are described here, in alphabetical order. Descriptions, which include the purpose of the file and the definition of its contents, are presented for the following:

1. Data Conditions.
2. Deadhead Distance Matrix.
3. Performance Standards.
4. Route-Distance.
5. Route-Signpost.
6. Running Time.
7. Schedule File.
8. System Assignment.
9. Time Point-Trip.
10. Vehicle Dispatch.
11. Section 15 Summary File.

Other files have similar data contents and structures to these files.

DATA CONDITIONS FILE

Purpose

The Data Conditions File is used to characterize the conditions under which the data were collected e.g., weather conditions. The file serves two purposes.

1. The file is used as a reference file to annotate other data files with information describing the conditions on the date of the data collection. For example, date-of-the-week labels and school day or holiday indicators would be provided by the data conditions file.

2. The file also serves as an index and status file. It provides information indices that can be used to facilitate data access and retrieval and can be used to inspect the conditions under which data have been collected. For example, the file could be used to characterize the data set and identify data conditions that need additional emphasis.

File Contents

For each date in the data collection period:

Calendar Date
Day of the Week Label or Code
Weather Condition Code
School Day Code
Holiday Code
Trips Sampled

File Construction and Maintenance

The complete file is constructed prior to each data collection period. Data elements that cannot be supplied at the time of file construction i.e., weather and trips sampled, would remain blank to indicate that they have not been entered. At the beginning of each computer session, the computer compares the sign-on date and queries the user for the codes for prior unassigned dates. Data pertaining to the number of trips sampled is computer generated during the data processing.

DEADHEAD DISTANCE MATRIX FILE

Purpose

The Deadhead Distance Matrix contains the between-route terminal travel distance for all deadheading. The file is used to help identify the starting points (and records) in the absence of signposts. For route changes between trips, the file identifies the distance between the previous trip terminal point and the layover location of the succeeding trip. Where the route does not change between successive trips, the matrix contains an appropriate code to indicate whether or not the terminal points for the trip start and trip end are identical locations to help avoid errors caused by intervening data records.

File Contents

For Each Route:

For Each Terminal (and Turnaround Point):

Code Characterizing Terminal

Distance to Each Other Terminal

The file contains a matrix of distances in which the diagonal consists of the code identifying the type of movement between trip end and trip start on the same route and ostensibly the same terminal.

File Construction and Maintenance

The file requires considerable effort to develop since it requires collecting data on distance between all terminal points. It should be considered an embellishment and incorporated only if excessive data errors are encountered in trying to detect trip ends via procedures employing only time and route distance.

PERFORMANCE STANDARDS FILE

Purpose

This file is used to maintain site-specific performance standards used in various reports as measures of efficiency and effectiveness. Passenger loading standards are typical of the types of standards contained in this file (the file contents described pertain to these standards). However, the file would contain all relevant quality of service and productivity standards that would be used in the reporting process.

File Contents—Passenger Loading

For Each Type of Vehicle in The Fleet:

For Each Time Period (or Other Defining Parameter):

- Vehicle Type Code
- Time Period Code
- Load Standard

File Construction and Maintenance

In general, the file has a one-time set-up and is relatively easy to establish and maintain.

ROUTE DISTANCE FILE

Purpose

The Route Distance File contains the measured distance from the terminal of the route to each time point along the route to the opposite terminal. The file is essential to distance matching procedures to identify vehicle location.

File Contents

For Each Route:

- Route Number
- Terminal or Time Point Sequence Number
- Cumulative Distance to Time Point

File Construction and Maintenance

The file requires considerable effort to construct and requires significant data processing to use reliably.

ROUTE SIGNPOST FILE

Purpose

The Route Signpost File identifies the location of all signposts deployed on the system. Its primary use is to reference data to location on a route. However, it also can be used to verify vehicle assignments, to denote direction of travel, and to verify and correct odometer data.

File Contents

For Each Route in The Transit System:

- Route Number
- Signpost Identification Number
- Type of Signpost (Terminal, Turnaround, etc.)
- Schedule Reference (Time Point Number)
- Location Label
- Distance to Next Signpost (Optional)

Special data records would be used where signposts are deployed at garage or service island locations.

File Construction and Maintenance

A significant initial effort is required to construct the initial data file, particularly if distance measurements are entered into this file. Subsequent efforts to maintain the file are minimal if signposts are programmable so that if a signpost is removed it can be replaced with one that will transmit the same identification number. Route restructuring, however, will require file revision.

RUNNING TIME FILE

Purpose

The Running Time File serves two purposes:

1. It maintains the running times that were used in constructing the schedule. As such, it provides the base for the comparison of actual running times and scheduled running times.

2. In time and distance-based trip referencing procedures, the file can be used to estimate the time of arrival at the end of the trip and thereby aid in the identification or verification of the end of the trip.

File Contents

For Each Route:

For Each Time Period:

Time Point Number
Scheduled Running Time Between Time Points

File Construction and Maintenance

File contents are available from current schedule. Changes to the file occur only when different running times used in schedule construction. Ultimately, if running time averages were used to construct schedule running time, file updating and maintenance could become automatic.

SCHEDULE FILE

Purpose

This file is the primary means by which the data is linked to the route, run, and trip. It is the most extensive external file in that it contains the arrival and departure times at each time-point and trip terminal broken down according to vehicle block. The file is used to segment the data into the trip-oriented data required by the Time-Point/Trip File and to determine schedule deviations.

File Contents

Multiple files are maintained—one for each schedule e.g., weekday schedule, Sunday schedule, etc. Each file consists of multiple records broken down by vehicle block number and within vehicle block by run number and trip.

For Each Vehicle Block in a Particular Schedule:

Header record indicating pull-out time, initial run and initial route, and scheduled pull-in time.

Multiple records defining scheduled trips (one per trip) each consisting of the following data elements:

Scheduled Deadhead Time (if applicable)
Scheduled Arrival Time at Terminal
Route Designation for Trip
Run Designation for Trip
Relieving Run during Trip (if applicable)
Relief Point Designation
Scheduled Departure Time
Schedule Time at Time Point i
Scheduled Time at Time Point i + 1 (and All Remaining Time Points)
Scheduled Arrival at Trip Terminal

Ending Record has same format as a trip record except that pull-in time is indicated.

File Construction and Maintenance

File contents are available from current schedule.

SYSTEM ASSIGNMENT FILE

Purpose

The System Assignment File identifies the vehicles (and the corresponding installation dates) to which each data collection system has been assigned. The file serves multiple functions.

1. The file is used to reference the data to the vehicle on which the data were collected. The serial number of the data system and the date of the data recording are used in combination to identify the vehicle number.

2. The file provides a general history and an overall system status. Special codes are substituted for vehicle numbers to indicate systems in inventory but not in use--units being repaired held as spares, etc.

File Contents

For Each Data Collection System:

- For Each Installation (or Change in Status):
  - Data System Serial Number
  - Vehicle Number (or Code)
  - Installation (or Change) Date

Three fields per record. Records arranged chronologically by data system.

File Construction and Maintenance

Input to file provided by copies of work orders where appropriate. Entry of updates would be through keyboard from the work orders using a special edit routine that would locate records by date and system number.

TIME POINT-TRIP FILE

Purpose

This file contains separate records for each trip sampled and provides the basic input for all subsequent information processing activities.

File Contents

For Each Calendar Date:

- For Each Route Direction:
  - For Each Trip:
    - Run Number
    - Bus Number
    - Time Point Number
    - Time
    - Schedule Deviation
    - Passengers on Between Time Points
    - Passenger Off Between Time Points
    - Passenger Load
    - Maximum Passengers Between Time Points
    - Stop Number for Maximum Load

File Construction and Maintenance

This is output file generated automatically by the computer.

VEHICLE DISPATCH FILE

Purpose

The Vehicle Dispatch File maintains the records of the vehicle assignments made by the dispatcher to vehicle blocks (or to driver runs at vehicle pull-out). It is one of the most important of the external files and can be used both to schedule assignments and to record assignments.

1. As a scheduling tool, the file can be used to provide the dispatcher with a list of the vehicle blocks or driver runs that need to be covered on a particular date. A printed form could be generated to enable the dispatcher to enter only the vehicle number and the pull-out time when the assignment is made. The form would identify vehicle type when appropriate.

2. Completed dispatcher logs would be used to enter into the permanent file the vehicle assignments. These would be used in subsequent processing to tag the data with data indicating the work assignment based on knowing the vehicle number.

File Contents

For Each Date that Data are Collected:

Calendar Date
Division or Garage Code
Vehicle Block or Driver Run Number
Type of Vehicle Code
Vehicle Number Assigned
Pull-Out Time
Status or Error code

File Construction and Maintenance

Vehicle block assignments would be made and entered into the computer system and this schedule would be transmitted to the dispatcher. As vehicles are assigned, the dispatcher would note directly on this schedule the bus number and the pull-out time. The completed form would be returned for data entry.

SECTION 15 SUMMARY FILE

Purpose

This file is used to maintain the passenger ridership information required in UMTA Section 15 reports. The day-of-the-week intervals are those defined by UMTA: Weekdays, Saturday, and Sunday. Time-of-day intervals are preset as AM Peak, Mid-day, PM-Peak, and Night. Aggregate values are obtained for successive levels up to the system-level.

File Contents

For Each Route in The Transit System:

For Each Route Direction of The Route:

For Each Day-of-the-Week Designated:

For Each Time Interval Designated:

Passengers Boarded
Bus-trip-distance
Passenger Miles
Bus-trip-time
Passenger Minutes
Capacity Miles
Seat Miles
Bus Trips (Sample Size)

File Construction and Maintenance

File generated automatically from the Time-Point-Trip File.

APPENDIX I.F

ISSUES RELATED TO ESTIMATING EQUIPMENT REQUIREMENTS

This appendix provides additional background and information relevant to estimating equipped bus requirements for on-board automatic data collection systems to supplement Chapter I.4. Four major topics are addressed:

1. Site-specific factors that may affect equipped bus requirements.
2. Procedures for estimating data variability.
3. Procedures for determining the confidence level of route data.
4. Alternative approaches to statistically based sampling.

I.F.1 SITE-SPECIFIC ISSUES AFFECTING ON-BOARD EQUIPMENT REQUIREMENTS

The number of buses to be equipped with on-board, automatic data collection hardware will be influenced by several site-specific factors. These are summarized in Table I.F-1 and discussed briefly below.

Table I.F-1. Site-specific issues affecting on-board equipment requirements.

ISSUE	IMPACT ON EQUIPPED BUS REQUIREMENTS
Data Sampling Scheme	
Higher Confidence Level	+
Lower Tolerance Level	+
Greater Data Variability	+
Multiple Data Collection Periods	+
Transit Agency Operating Characteristics	
Bus Dispatching Procedures	0
More Operating Divisions/Garages	0
More Types of Vehicles	0
Less Flexibility in Vehicle Rotation	0
More Interlining and Trippers	0
Data Collection System Implementation Philosophy	
Comprehensive Sample Coverage	+
Special Study Requirements	+
Utilization of Peak Load Counts	-
Technology Constraints	
Increased Equipment Reliability	-
Increased Counter Accuracy	-

KEY:
+ = Increases the number of equipped buses required.
0 = Could increase the number of equipped buses required.
- = Decreases the number of equipped buses required.

Data Sampling Scheme

Gathering data on all trips on all routes every day is generally not feasible or necessary. Nor is it necessary to saturate a route with equipped buses for a short period of time. Statistically reliable inferences about passenger levels, schedule adherence, and fare collection can be made from a representative sample of bus trips selected randomly. The determination of an appropriate sample size involves trade-offs between acceptable accuracy and cost. Larger samples typically result in greater accuracy but cost more in terms of equipment and data processing.

Any number of mathematical equations which include the variables—population size, confidence level, tolerance level, and variability of the population data—can be used to determine the appropriate sample size. To implement these equations, the values for these variables must be selected or estimated.

The population size refers to the total number of one-way bus trips operating during the data collection period. The population can be categorized in many ways to reflect the data needs of a transit agency—systemwide, operating division, route, and/or time period. The size of the population can be easily determined by counting the number of scheduled one-way bus trips each data collection period for the appropriate category.

The confidence level of a statistical calculation defines the proportion of the sample size which may be expected to contain the true value of the data being evaluated. The tolerance level indicates the desired accuracy of results. It indicates the range around the observed value in which the true value is likely. For example, suppose a transit property chooses to measure average peak load at a tolerance level of 5 percent and a confidence level of 10 percent. If the measured average peak load is 60, there would be 90 percent probability that the true value is 60 ± 3 or between 57 and 63 passengers.

The confidence and tolerance level is selected by transit agencies to reflect the accuracy desired. Route level data gathered at the 90 percent confidence level is recommended because these data can then be used to estimate systemwide totals for Section 15 reporting that will meet UMTA's 95 percent confidence level requirements (*1*, pp. 41–45).

The tolerance level selected by a transit agency should reflect the data item being measured, the type of route (i.e., capacity constrained, evening service, etc.), and the time of day being analyzed. Guidelines for selecting the appropriate tolerance level, which have been adopted in other data analyses being pursued by UMTA, can be used in this analysis (*1*, *2*). Recommended tolerance levels are provided in Table I.F-2.

Peak periods and capacity-constrained routes require higher confidence and tolerance levels and will require more equipped buses than other time periods. This is because a higher proportion of the system's resources is assigned here and because this represents the primary management opportunities for decision-making (*1*). Therefore, in determining automatic data collection system equipment requirements, it is only necessary

Table I.F-2. Recommended tolerances for basic data needs.

Data Item	Time Periods	Route Type	Recommended Tolerance
Route Level			
Load, Bus Arrival Time, Total Boardings, Revenue	Peak	Capacity Constrained	±10%
	Peak	Not Capacity Constrained	±15%
	Midday	All	±15% to ±20%
	Evenings, Owl & Weekends	All	±30% to ±50%
Boardings (revenue) by fare category	Peak, Midday Midday	All	±20%
	Evenings, Owl & Weekends	All	±20%
Boardings and alightings by stop	All	All	±50%
Systemwide			
*Unlinked passenger trips, *Passenger-miles Linked passenger trips	All		±10%*

*Required by Section 15 (at 95% confidence level); if route level data are obtained at the tolerances recommended here, systemwide tolerance will generally be within ±10%.

SOURCE: Attanuci, J., I. Burns, N. Wilson. "Bus Transit Monitoring Manual: Volume I, Data Collection Design." Report No. UMTA-IT-09-90008-81-1. Prepared for the Urban Mass Transportation Administration by Multisystems, Inc. and ATE Management Service Co. (1981) p.42.

to focus on covering weekday peak hour sampling requirements. It may be assumed that if there is enough equipment to sample these trips, there will be adequate equipment to cover midday, night, and weekend service.

Data variability refers to the fluctuations in passenger levels that can result from many factors: time of day, day of week, weather, traffic conditions, driver habits, etc. Patterns of within-day variations have generally led transit planners to stratify data collection by time period, i.e., AM peak, midday, PM peak, evenings, and weekends. But even for these time periods, ridership may vary from day to day. For example, AM peak ridership on a rainy Thursday before a holiday can be considerably less than the previous Wednesday. The more variation between days, the more days must be sampled to obtain an "accurate" estimate of average daily ridership.

To estimate data variability, it is necessary to have some prior knowledge about the variance of the data. Ideally, the variance is estimated mathematically using previously collected data on total boardings and passenger loads. Additional information on data requirements and procedures for estimating data variability is provided in Section I.F.2.

The data collection period refers to the time frame in which the sample of bus trips is to be completed. The data collection period can be defined by the calendar (i.e., quarterly, semiannual, annual, etc.), seasonal service changes, or driver sign-up changes. Since a complete sample should be obtained for each data collection period, the number of days in the data collection period will have a direct impact on the number of equipped buses needed. For example, quarterly data collection will require twice as many buses as semiannual collection.

Transit Agency Operating Characteristics

Of the five transit agency characteristics given in Table I.F-1, the ability to assign and dispatch equipped vehicles to specific vehicle blocks for data collection purposes is the most critical component of an effective automatic data collection program. Where this capability does not exist, transit agencies may be required to equip additional buses and/or to change dispatching procedures. In particular, transit agencies accustomed to dispatching vehicles on a first-driver/first-bus routine from a lineup in the garage will have difficulties in ensuring that data collection on individual routes is adequate. Because the order of the vehicles is determined by hostler activities, it may be difficult to assign equipped vehicles to a specific vehicle block. The lineup would have to be carefully controlled or the number of equipped buses would be determined by the number of lanes available. Ten lanes could easily require a 20 percent fleet installation even if only two vehicle types are involved. In this case, dispatching would require larger amounts of data collection and more equipped buses to ensure adequate route level sampling, and special software would have to be used to extract the appropriate route level data from all of the data collected.

Because equipped buses are assigned to a vehicle regardless of the route, run, or trip, dispatching equipped vehicles by vehicle block may not result in true random sampling. If successive runs by the same driver are included in the sample data for a route, the data may be biased by driver performance. However, transit agencies may not perceive this as an urgent problem.

For a given fleet size, the number of divisions or garages will generally have a small impact on overall equipment requirements. A greater number of buses will have to be equipped compared to simple sizing across the entire fleet. However, each division represents a smaller operation and the total typically will not be significantly greater. Nonetheless, it is advisable to consider each garage as an independent operation because, in most cases, vehicles cannot be rotated between divisions.

General fleet characteristics, such as the types of vehicles in the fleet and the restrictions governing their assignment to routes, can have varying impacts on system sizing. In most instances, having more than one type of vehicle, e.g., standard 40-ft coaches and articulated buses, will not increase the total number of buses, provided the number of types is small and the number of vehicles of each type is sufficiently large to permit a reasonable sampling program to be adopted. In this case, system sizing can be segmented in a manner similar to that used for multiple garages with the number of buses of each type being determined independently. Under some circumstances, however, fleet and operating characteristics could have a major impact. If certain types of vehicles must be assigned to specific routes, these routes should be considered independently from the remainder of the fleet and separate equipment requirements developed.

Other operating issues affecting the equipment and its deployment include interlining and trippers. Interlining tends to be viewed as a problem in that it potentially increases the number of buses needed to survey a particular route simply because a lesser number of trips by a particular bus on the route is available for the sample and therefore one or more additional vehicle blocks must be included in the sample. Each additional vehicle block would indeed represent an additional equipped vehicle but only when sampling is viewed on a route basis. In a systemwide data collection program the data collected by a single vehicle block contains information appropriate to each of the routes within that block. "Off-route" data should not be viewed as unnecessary because it provides data that likely have to be collected anyway. In fact, interlining could be considered an unanticipated benefit in an overall sampling scheme because it tends to reduce the number of consecutive trips on the same route in the data sample.

Interlining may increase overall equipment requirements to some extent, but it is believed that these effects can be held to a minimum by careful equipment allocation and judicious use of the data made available from the surveys by vehicle block. It is not believed that a significant bias would be introduced if assignments for the more critical routes were established first on the basis of requiring some minimum threshold of trips per vehicle block on that route and then assigning units to other routes on the basis of filling in the data not provided by the effects of interlining. In this manner, data could be salvaged to the maximum extent possible and system size ramifications kept to a minimum.

Trippers are potentially a more significant problem than interlining. These short pieces of work occurring typically in the AM or PM peak cannot be ignored. Although assigning equipped buses to cover these operations seems unproductive, precisely the opposite is the case. In much the same manner that a bus is removed from service when it is not needed to satisfy demand, data collection units not needed to satisfy specific data needs should be removed from service. This is not to say that drivers, for example, should be allowed to turn units on and off; rather, it means that artificial attempts to achieve maximum unit productivity should be avoided as being unproductive. Data needs during peak periods are more critical and deserve greater sampling. One way to avoid the processing and storing of the data is to not collect it and perhaps the most reliable means of achieving this is to consider trippers as legitimate vehicle blocks for data sampling.

Automatic Data Collection System Implementation Philosophy

A transit agency has many options available regarding implementation and operation of its automated data collection system. While the majority of these choices are related to module and hardware selection, in some cases management preferences regarding system operation and implementation can increase equipped bus requirements. Among the most important considerations are sample coverage, special study requirements, and use of supplementary point checks.

Some transit managers perceive it is necessary to sample an entire route or corridor during one time frame (i.e., 1 to 3 weeks) in order to obtain an accurate picture of ridership and schedule deviations or to obtain input for RUCUS applications. This perception is not entirely accurate inasmuch as concentrating data collection into one time period can lead to an unrepresentative sample. For example, if particularly bad weather occurs during the collection period, the data collected on that route or corridor would not necessarily reflect true ridership or running time patterns.

Not only does ensuring that the data are representative become a problem, but also the number of equipped buses required will increase significantly if a transit agency attempts to sample an entire route at one time. Covering an entire corridor would require even more equipped buses. Since the equipment requirements are significant, most transit agencies that have implemented automated systems have abandoned this concept recognizing that random sampling is a more effective and less expensive approach for ensuring collection of representative data.

Similarly, some transit agencies may desire to have the ability to undertake special studies with the automated data collection system. In order to do so, more equipment than is required for a fixed sampling schedule may be necessary.

Finally, transit properties may choose to reduce the amount of automated equipment required by supplementing the automated data collection effort with peak load counts undertaken by manual checkers. There are several circumstances where manual point checks might be cost effective:

1. Transit systems with a radial route structure which do not require extensive route level boarding data can reduce equipment requirements with manual peak load counts. In a radial system, there are likely to be points at which a number of routes converge, enabling a single checker to collect data at one time. Collecting the same data with an automated system would require equipped buses on all bus trips (*1*, p.34).
2. Transit properties that currently employ checkers can use this staff to undertake point checks in lieu of other options (promotion, retraining, etc.)

Technology Constraints

Although reliability, maintenance requirements, and accuracy have been generally acceptable to transit properties that have implemented automated data collection systems, the reliability of the technology options selected will have an impact on the amount of spare equipped buses required to ensure adequate coverage. As reliability and sensor accuracy increase, spare equipped buses and spare parts decrease.

The availability of data collection equipment will be dominated by three factors:

1. Vehicle breakdowns or accidents.
2. Passenger counter sensor malfunctions.
3. Fare collection equipment malfunctions.

Although a rigorous analysis of the availability of data collection systems has not been undertaken, an indication of equipment availability can be obtained from the experiences in current applications of automated systems. These transit agencies report that only 85 to 90 percent of the equipment is in working order at any given time. At Seattle METRO, for example, 90 percent of the units are reported to be in working order on any given day (*2*, p.34). When bus breakdowns are taken into account, equipment availability is likely to be in the 85 percent range.

For those transit agencies that intend to implement fare category counter modules, equipment reliability problems are likely to cause more difficulties. Fare collection equipment malfunctions are particularly significant because the bus is taken out of service until repairs can be made. At transit properties that have implemented electronic registering fareboxes, equipment reliability has tended to be low initially, improving over time (*4*). The potential impact resulting from the nonavailability of the fare element is not known, but it is reasonable to assume that it is close to that for passenger counters and therefore could inflate total equipment requirements by as much as 10 percent.

The accuracy of the passenger counter sensors is generally acceptable to the transit properties using them because patterns of counter errors can be identified (i.e., boarding counts tend to be more accurate than alighting counts; sensors tend to undercount rather than overcount). Software filters and reasonableness checks can be employed to screen out inconsistent data and thus improve the accuracy and utility of the data. Some data must be discarded because of counter inconsistency or the inability to adequately correlate bus stop records with specific stops. In Seattle, for example, approximately 20 to 30 percent of the data was discarded from the system prior to signpost installation (*2*, p.34). Signposts are expected to significantly improve data utility. Expert judgment suggests that where signposts are installed data usability may improve to approximately 90 percent.

I.F.2 PROCEDURES FOR ESTIMATING DATA VARIABILITY

Ridership and running times on a given route may fluctuate because of time of day, day of week, weather, traffic conditions, driver habits, etc. An estimate of the amount of fluctuation (variance of the data) needs to be obtained because the variance affects the sample size required to obtain reliable estimates. As the variance increases the sample size requirement increases. Unfortunately, estimating data variability is not an easy task. Many factors cause passenger levels to fluctuate and it is difficult to isolate the impact of any one. In addition, prior knowledge of passenger behavior is required. The depth of this information determines the reliability of the estimate.

Before an estimate of the variance can be obtained, the analyst must determine: (1) the level of stratification to be used. (2) the data resources to be used, and (3) the method to calculate the variance.

Level of Stratification

A stratification scheme that takes into account the ultimate use of the data and the available data resources must be selected. The level of data stratification selected will have a significant impact on the estimated variance. Generally, more aggregation is associated with less data variability. For example, ridership totals on a specific route during the PM peak will fluctuate more than systemwide daily ridership. Since data variability affects the amount of sampling required to obtain reliable estimates, stratifying the data will require more sampling.

Data can be stratified in space and time. For transit purposes, spatial classifications are systemwide, corridor, route, route segment, trip, or bus stop. The spatial classification selected should reflect the use of the management information.

Time-oriented stratifications include: time of day, day of week, week, month, quarter, etc. Generally, time of day, and day of week are used to stratify transit data collection because observable patterns of ridership at this level of detail have led transit planners to develop schedules on this basis. Broader stratifications can be easily developed from these data.

The minimum desirable stratification for estimating equipped bus requirements is by route and by time of day. This level of stratification should lead to reasonable equipment estimates. Smaller stratifications (i.e., peak period trip level data by day of week) would be more accurate and should be considered if data are available. Broader classifications (i.e., systemwide or weekly ridership) may result in very small equipment estimates.

Data Resources

Ideally, estimation of the variability of passenger behavior would be undertaken for each route by time period using at least 3 days of data on total boardings per trip (*1*, pp.49–51). At this level of analysis, estimates of the coefficient of variation for each route and each time period would be very reliable.

Unfortunately, not all transit agencies have these data readily available or the resources to undertake extensive data collection to determine sample size requirements in order to estimate equipped bus fleet size. In the absence of detailed data, transit agencies may consider using other resources such as route revenue counts or less detailed information that may be available. These may include:

1. Peak passenger loads per trip.
2. Route revenue accounts per day.
3. Total route ridership per time frame.
4. Route revenue accounts per time frame.
5. Total route ridership per day.
6. Expert judgment.

Admittedly the estimates of data variability may not be as precise if these alternatives are used. However, they should represent relative fluctuations in passenger behavior. Disadvantages of these data resources are discussed below.

Use of peak load data may result in larger sample sizes than would result from total boarding data because peak loads fluctuate more (*1*, p.50). While route revenue accounts may not be complete because they do not include pass usage, the accounts should reflect relative differences between trips or routes.

As the time and spatial stratifications become broader (i.e., items 3, 4, and 5), the fluctuations in passenger behavior become less evident and sampling needs are minimized. For example, if daily systemwide ridership for the system is used, only a few days of counting for each data collection period may be required to obtain reliable results. Similarly, use of weekly or monthly ridership data per route would probably result in even smaller sample requirements.

Expert judgment can be an excellent source of ridership variability estimates that should not be overlooked in the absence of hard data. While the estimates are not verifiable, experienced schedulers and planners often have a fairly accurate perception of ridership patterns.

Calculating Measures of Variation

Several statistical measures of data variability are available. The standard deviation and the coefficient of variation are the measures used to estimate data variance in computing sample size requirements. Use of the coefficient of variation is recommended in this manual because it offers several advantages and it is used in other related UMTA research (*1, 3*).

The coefficient of variation is calculated by taking the standard deviation of the data and dividing it by the overall mean of the data. By dividing by the overall mean, it is possible to normalize the scale of each variance to enable comparisons among time periods, routes, or other data items.

Statistical handbooks offer numerous options for calculating the coefficient of variation depending on the number of causal factors to be included and error correction terms (i.e., number of data points, number of days of data collection) that are included. An inexpensive programmable calculator can be used to estimate the coefficient of variation with the following equation:

$$\text{Coefficient of variation} = \frac{\sqrt{\frac{\Sigma(X-Xm)^2}{n-1}}}{Xm}$$

where:

X = the value of individual data points (i.e., total passengers per trip, peak load per trip, etc.);
Xm = the average value of the individual data points; and
n = the number of data points used to make the estimate.

The "Bus Transit Monitoring Manual" (*1*) provides worksheets for calculating between-day and within-day coefficients of variation which includes more error correction terms. Estimates obtained from these procedures would tend to have smaller values than the estimates from simplified equations.

Table I.F-3. Estimating confidence level of data for individual routes.

1.	Enter total number of peak direction trips in largest peak period on one day for the route.	______
2.	Enter the number of weekdays in the data collection period.	______
3.	Determine the total number of trips that will occur in the data collection cycle (N). Multiply line 1 by line 2.	______
4.	Enter the number of days of data desired.	______
5.	Determine the sample size (n). Multiply line 1 by line 4.	______
6.	Enter tolerance error (E). See Table I.F-2. Default: 0.10	______
7.	Enter coefficient of variation (V). See Section I.F-2. Default: 0.45	______
8.	Calculate the value of Z. $Z = \frac{E}{V}\sqrt{\frac{Nn}{N-n}}$	
9.	Estimate confidence level of data. Compare line 8 with Table I.F-4.	______

I.F.3 PROCEDURES FOR DETERMINING THE CONFIDENCE LEVEL OF ROUTE DATA

Table I.F-3 can be used to provide an estimate of the confidence level of route data. If confidence level of the data for an individual route is less than desirable, transit agencies can increase the sampling for that route.

In analyzing route level data accuracy, keep in mind that the value of Z is very sensitive to the value of N. Routes with a small number of peak direction trips per day may require large amounts of sampling to obtain data that are statistically reliable. The practicality and need for sampling a large number of scheduled trips should be kept in mind when analyzing the adequacy of route level data.

I.F.4 ALTERNATIVE APPROACHES TO STATISTICALLY BASED SAMPLING

Some transit agencies may elect to use a statistically based data collection program because of the improved accuracy of the resulting route level estimates. In a statistically based sample, a sampling plan for each route, by time period, would be developed reflecting the variability of ridership. Some routes would require a few days of data collection, other routes would be sampled more extensively. An approach for developing route sampling plans based on between day ridership variance and time-of-day ridership variance has been developed (*1, 2*). A computer package of this work written on UCSD (Apple) Pascal was developed for the Capital District Transportation Authority (CDTA) in Albany, New York, and is available to interested transit agencies from the TIME Support Center, Rensselaer Polytechnic Institute (*5*).

Several opportunities exist for streamlining this approach to reflect the objective of this manual—i.e., to determine equipped bus requirements. Any or all of these could be taken in developing equipment estimates without seriously affecting the results. These include:

1. Limiting the analysis to peak-hour sampling requirements for each route.
2. Evaluating only the impact of within day variance for the peak hours.
3. Clustering the routes by type assuming similar coefficients of variation for routes with similar characteristics.

Limiting the analysis to peak hour sampling would reduce the amount of calculations required and still result in reasonable equipment estimates. Because of the higher confidence level and lower tolerance generally desired for peak hour data and the fact that most system resources are used during the peak hour, it can be reasonably assumed that peak hour sampling will require the largest number of equipped buses. If enough equipment is available to meet peak-hour sampling needs, sufficient equipment will be available for off-peak data collection.

While ridership does vary from day to day, within-time-period variations in passenger behavior are substantially greater than between-day variation. Recent empirical studies of transit agency data found that 80 percent of the time, ridership is similar across weekdays with Friday showing the most variability (*3*, p.35). Furthermore, it is extremely difficult to estimate between day variances (*3*, p.21). This analysis suggests that consideration of weekday variation may not be essential.

Table I.F-4. Z values for selected confidence levels.

Confidence Level*	Z
99%	2.576
95%	1.960
90%	1.645
75%	1.152
68%	1.000
50%	0.674

*UMTA requires systemwide data collection for Section 15 reporting to be collected at the 95% confidence level. When route level data collected at the 90% confidence level is aggregated to estimate systemwide totals, UMTA's accuracy requirements will be met (p. 41-45).

If the analysis of equipped bus requirements is based on these assumptions, sampling requirements for a route could be easily estimated with a hand calculator. The following equation may be used (*7*):

$$n = \frac{NZ^2V^2}{NE^2 + Z^2V^2}$$

where:

n = the number of trips to be sampled;
N = the total number of scheduled one-way bus trips per route in the data collection period (largest peak period);
Z = the confidence factor;
E = the maximum relative error (percentage expressed in decimals) tolerated in the estimate; and
V = within-day coefficient of variation for peak period.

Z values for confidence factors are provided in Table I.F-4. Recommended values for E are provided in Table I.F-2.

Clustering routes can further simplify the analysis (*1,* p.90). Route classification schemes group routes according to similar data variability characteristics and may be based on several factors:

1. Functional type of route (i.e., feeder, express, shuttle).
2. Route length.
3. Headway.
4. Total boardings.
5. Peak load factor (e.g., percentage of available seat capacity).

Evidence obtained during the development of the "Bus Transit Monitoring Manual" and other research suggest that data variability is related to route headway (*1,* p.47; *6*). Examples of route classification schemes based on route headway that can be used include:

1. Less than or equal to 10 min (i.e., routes with heavy demand for which passengers do not necessarily schedule their trips to coincide with a particular bus).
2. Between 10 and 30 min (i.e., routes with moderate demand for which passengers generally schedule their trips to catch a particular bus).
3. Thirty minutes or greater (i.e., routes with policy headways for which service frequency is not determined by demand).

The boundaries for each headway classification could be adjusted based on local conditions. For example, for peak period analysis 5-min, 10-min, and 15-min categories may be appropriate.

I.F.5 REFERENCES

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APPENDIX II

TECHNICAL SPECIFICATIONS

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CHAPTER II.1

INTRODUCTION

Two principles guided the development of this automated data collection system. First, it assumes a modular approach through which a transit agency may design an on-board, automatic data collection system which meets its passenger, schedule, and fare information needs by selecting only those functional units (modules) that are appropriate to these needs. This has two significant advantages: (1) it enables each transit agency to select only those functions that serve their specific needs without requiring a customized design; and (2) it enables updates of the system by replacement of modules as new components are developed, as new technology becomes available, and as the agency's needs change.

Second, the system design was based on a particular standardized computer bus (a set of address, data, control, and power circuits arranged in a standardized manner and operating under a strict set of data communication rules) known as STD BUS and associated standard hardware. (The STD BUS is supported by multiple sources including the STD Manufacturers Group (STDMG). STDMG has prepared and makes available to interested parties, a document titled, "STD BUS, Specification and Practice." STD BUS is recognized as a defacto industry standard without any trademarks, copyrights, or patents restricting its use. STD BUS also provides the foundation for a proposed Institute of Electrical and Electronics Engineers (IEEE) Standard P961. The STD BUS term is used throughout the report because this term will remain more widely recognized, at least, until the IEEE standard is fully developed and adopted.) This approach also has two significant advantages: (1) costs are kept down by avoiding the use of custom-manufactured parts; and (2) parts and modules are easily replaced as a result of the standard plug-in feature of the STD BUS systems.

By using the guidelines contained in Appendix I, transit managers will be able to evaluate the capabilities of various technology options and implementation schemes, and work effectively with equipment suppliers to ensure that their agency goals are satisfied. By using the technical specifications to procure their system, the agency will be able to keep costs at a minimum as well as to enhance flexibility.

Chapter II.2 describes the functional units of the modular system; Chapter II.3 details the overall functional requirements for the system; and Chapter II.4 contains the specifications for each of the 13 modules. Data format and storage requirements associated with the data collection system are presented in Chapter II.5. General rquirements are discussed in Chapter II.6.

CHAPTER II.2

SYSTEM OVERVIEW

An on-board automatic data collection system consists of a set of functional units that are joined together to form different system configurations depending on the units selected. In a modular, standardized approach, each transit agency selects only those functional units or modules needed to support its particular needs.

Thirteen modules have been identified for the proposed modular system. These modules and their functional characteristics are defined in Table II-1. Figure II-1 shows the overall relationship of the various modules. The modules provide the electronic means to gather passenger, fare, and schedule data,. and the data necessary to identify records by time and location.

The nucleus of the proposed modular on-board automatic data collection system is a microprocessor-based unit (called a system controller). The system controller and all circuitry to interface with other modules are contained in a single enclosure located on the vehicle.

Each module consists of appropriate sensing devices, electronic circuits to record data from the sensors, and necessary cabling connections. The design philosophy of the modular system requires each module located on the vehicle to contain an independent plug-in component that is inserted into the system central control unit.

Table II-1. Functional characteristics of the modular system.

MODULE DESIGNATION	FUNCTIONAL DESCRIPTION
1. System Controller	Microprocessor located on the vehicle that accepts, monitors, and controls the data collection and data transfer functions of all other modules. In addition, it includes a clock and calendar with back-up battery. Also accepts data from odometer and driver door control switches.
2. Passenger Counter	Sensors that detect the number of passengers boarding and alighting at each bus stop.
3. Fare Category Counter	Fare collection equipment that detects the number of passengers per fare category. Maintains cumulative value of revenue received.
4. Memory*	Stores data on the vehicle. At least 64K of non-volatile memory is provided.
5. Memory Expansion	Provides additional memory where needed.
6. Signpost Receiver	Signpost transmitter installed along routes transmits an encoded identification number to an antenna mounted on the bus roof.
7. Manual Input	Console for driver to enter data reference information such as bus number, farebox number, farezone identification, etc.
8. Door Status	Additional door switches that can be used to detect and count the number of passengers boarding and alighting at each door.
9. Status Display	Portable data transfer equipment that allows transit personnel to monitor counter accuracy and perform other system diagnostic checks.
10. Data Transmission	On-board data communications device for transferring data from memory to the external data receiver.
11. Expansion Module	Provides the capability to add other data collection functions. For example, the destination sign could be used to automate route/trip information.
12. Power Supply	Converts, conditions, and filters primary bus voltage to provide power to the data collection system.
13. External Data Receiver	Data retrieval unit used to receive data from the vehicle and send it to the computer for processing.

*If solid state memory is not used, this module would serve to house the electronics to an external cassette recorder or similar device. Memory modules may also be deleted entirely in certain real-time data collection systems.

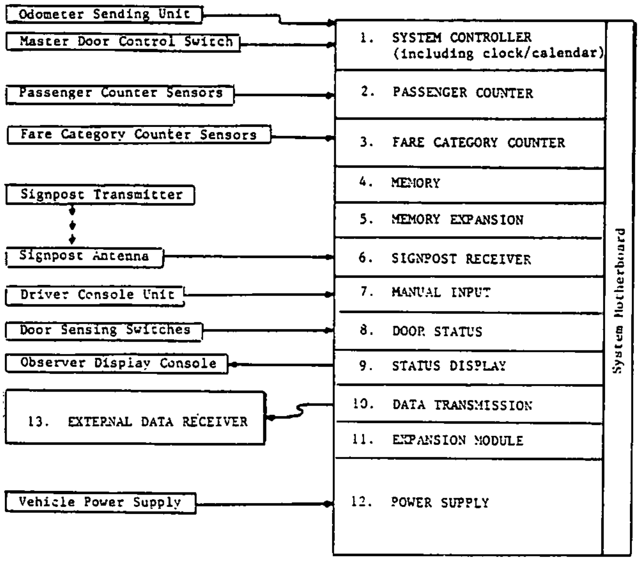

Figure II-1. Structure of the modular system.

CHAPTER II.3

SYSTEM REQUIREMENTS

The on-board automatic data collection system consists of 13 modules and associated sensors and electronics. Twelve of the modules interface with and connect to a STD-BUS assembly. The interface electronics of each module are separately packaged and inserted into a single enclosure, the system central control unit. The thirteenth module is a data retrieval unit (referred to as an External Data Receiver) that is used to retrieve the data from the on-board unit and transfer it to a host computer for processing. The following details the overall functional requirements for the system.

3.1 SYSTEM CONFIGURATION

The interface electronics for twelve of the modules shall conform to the standard known as STD BUS and shall, to the extent practical, use available STD BUS hardware. The interface electronics shall be assembled within a single enclosure, with each plugging directly into a STD BUS motherboard at the rear of a STD BUS rack contained within the system central control unit.

Figure II-2 shows the placement of the interface electronics units within the central control unit and designates the position each shall have in the assembly. The STD BUS assembly shall

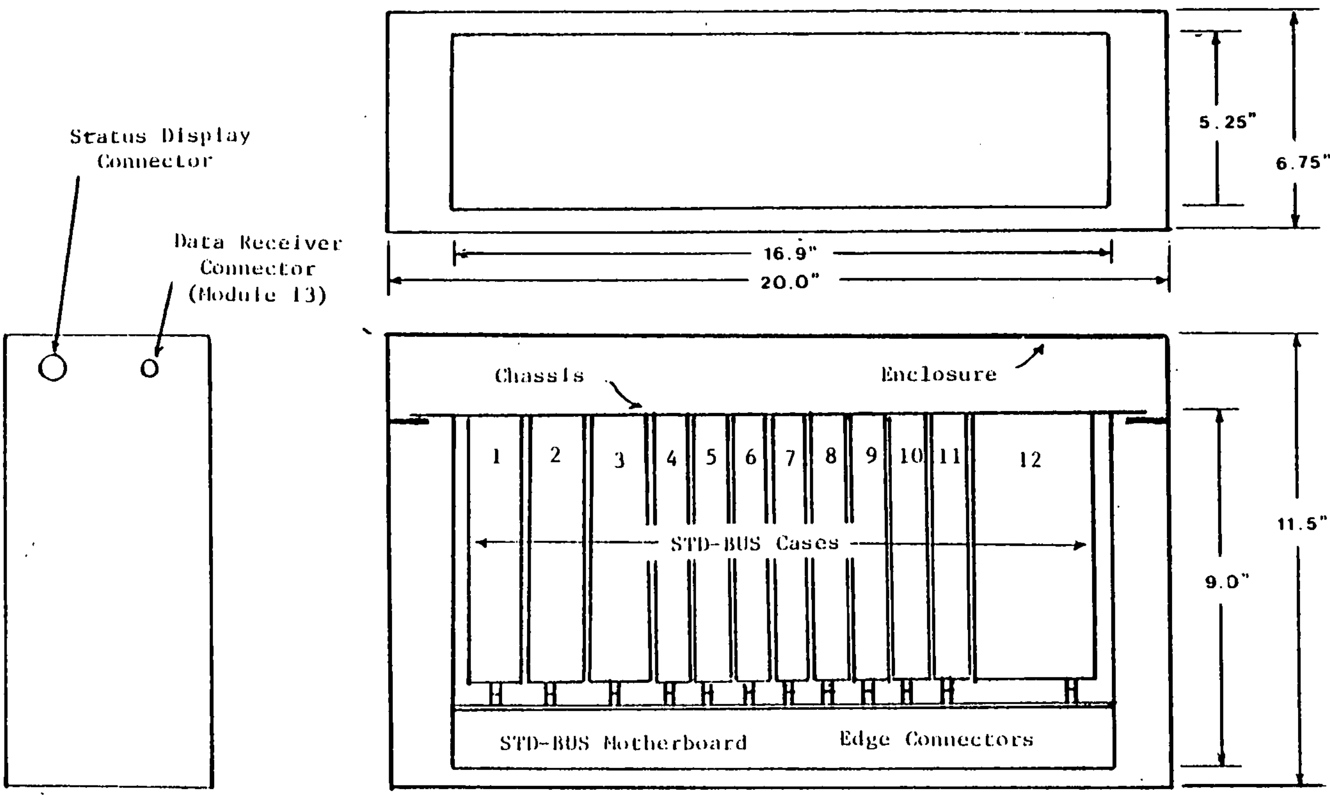

Figure II-2. Placement of interface electronics within system central control unit.

consist of a mounting frame measuring approximately 5.25 in. high, 9.0 in. deep, and 19.0 in. wide suitable for mounting a variety of module widths. A total of 12 modules shall be accommodated as specified below and shown in Figure II-2. Module enclosures shall be standard card cases designed for insertion into a module rack. A strip cutout rear panel shall be used for passing circuit board edge connectors through the back of the enclosure. Units 1 through 3 (see Fig. II-2) shall be 1.65 in. wide. Units 4 through 11 shall be 1.05 in. wide. Unit 12, containing the power supply, shall be 3.0 in. wide. Printed circuit cards within individual enclosures shall be STD BUS compatible cards (4.5 in. wide and 6.5 in. long with a 56-contact, edge connector on one of the 4.5 in. sides).

The assembly shall be mounted within an enclosure as shown by Figure II-3. The size of the enclosure and positioning of the chassis within the enclosure shall provide adequate room for all connectors and cabling so that cabling will run above the top of the chassis and so that individual electronics units can be easily disconnected and removed. The enclosure shall be hinged on the top and secured by a keyed lock. Specifications pertaining to fabrication and installation of the enclosure are provided in Chapter II.6.

3.2 SYSTEM INTERFACE REQUIREMENTS

Each module shall be considered as an independent unit that wholly fulfills its function without reference to or connection with other modules except through the specified, plug-in, STD BUS connection. Where an individual module incorporates remote sensors, for example, the passenger counter, sensors shall be connected directly to the front panel of the associated electronics unit via connectors with bayonet coupling. Where sensors or other remote devices require power, the contractor may choose either to provide for separate connection directly to the vehicle power supply or to use the power supply that is provided by the STD BUS connection (see Chapter II.4). In neither case shall power requirements exceed that specified in Section 4.12 in Chapter II.4.

Figure II-4 depicts the preferred locations of the central control unit and the several remotely located sensors. The contractor may propose alternative locations. Final locations for each unit within the data collection system shall be determined by the transit agency, and the contractor shall examine each vehicle type to ensure the correct and proper location of all data collection subsystems and cabling.

3.3 DATA COLLECTION REQUIREMENTS

The system shall be capable of generating 10 types of records as defined by Table II-2. The records actually generated by a particular system shall depend on the configuration of the system and certain user-specified conditions. The system shall automatically generate those records corresponding to a particular module, e.g., manual input and signpost, whenever that module is part of the system configuration. The addition (or removal) of such modules shall not require changes to the system to generate the appropriate data records. In addition, the user shall be able to specify which of the three designated types of stop

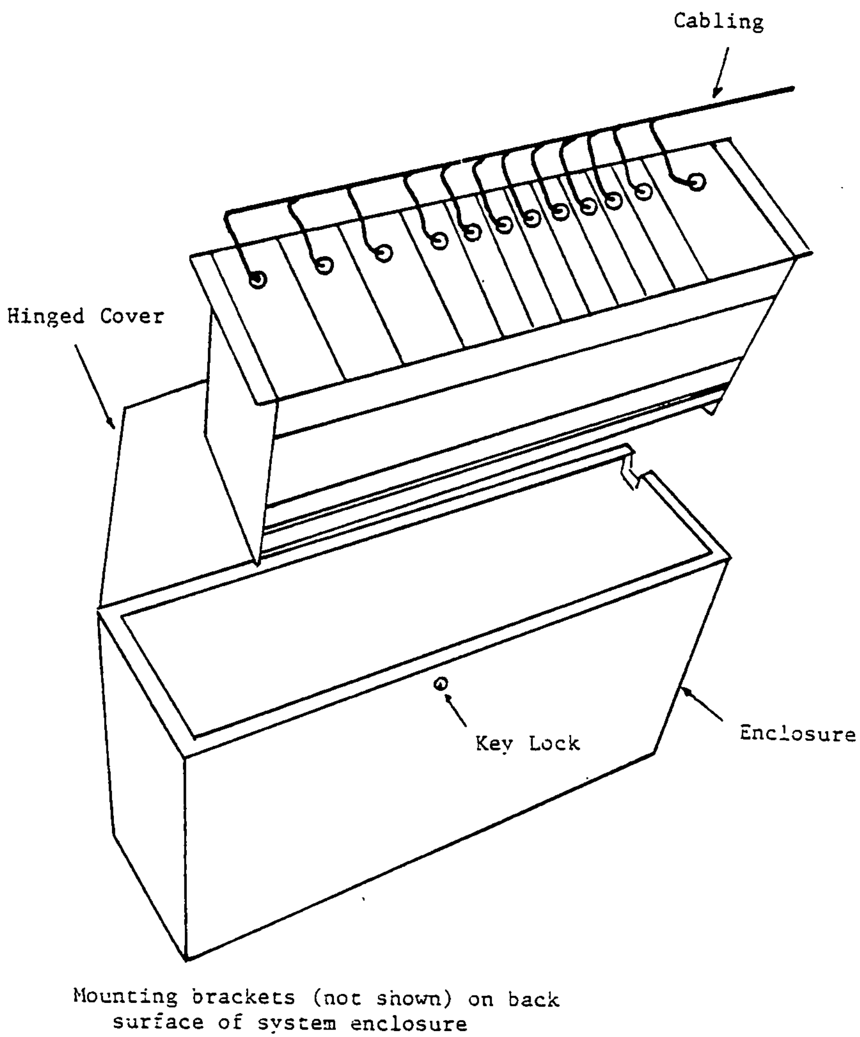

Figure II-3. System assembly and enclosure—central control unit.

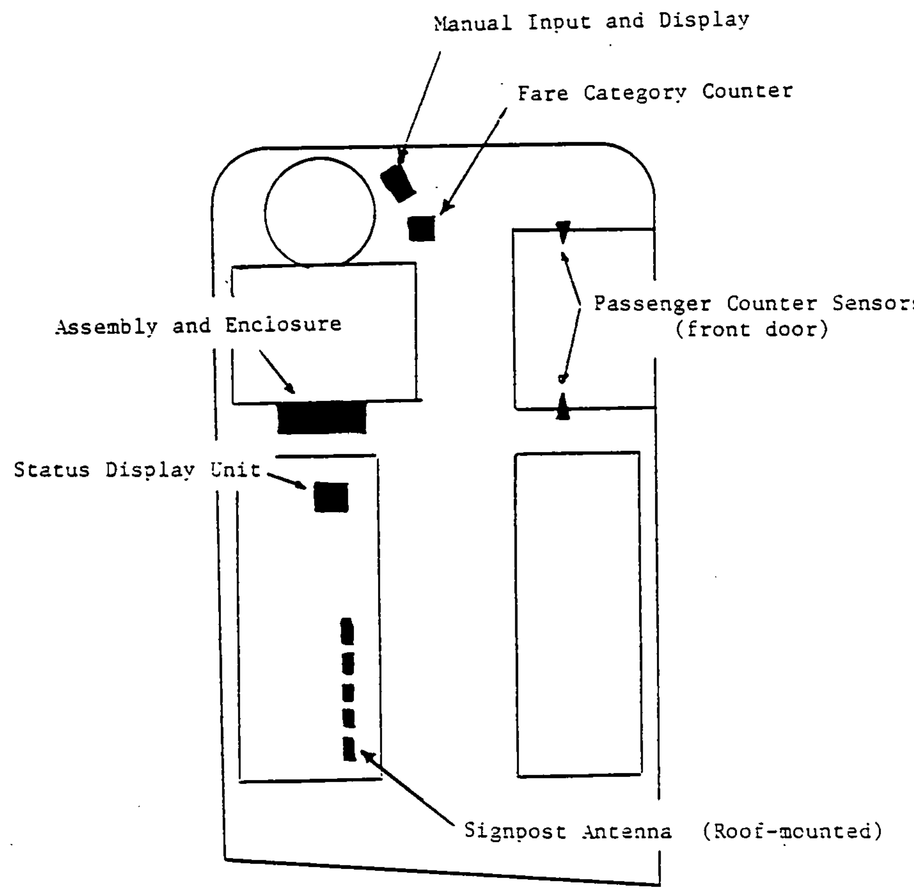

Figure II-4. Desired location of system components.

records will be generated and shall be able to select the time interval associated with record type 6 (idle start record) and the distance interval associated with record type 8 (distance record). These user-specified parameters shall be factory preset at the time of delivery but shall be changeable by the user without requiring program modification. (The use of switches mounted on the system controller board is acceptable.) Data supplied and retained by each module are described in Chapter II.4; data specifications and record formats are contained in Chapter II.5.

Table II-2. System data record types.

		DATA ELEMENTS				
Type	Data Record	Passenger Counts	Fare Category Counts	Distance	Location I.D.	Other Data
0	System Initialization: Dual Function 1. At Power-On 2. Following Data Transmission	--	--	--	--	All Manual Data
1	Error Detection: Dual Function 1. Error Detected 2. Power-On (Loss of Power Indicator)	--	--	--	--	All Manual Data
2	Driver Command: Driver-activated Record Command (from Manual Input Module)	All Data	All Data	Cumulative Distance	Signpost Number	All Manual Data
3	Stop Record Type I: Data storage at Door Closure	All Data	All Data	Cumulative Distance	Signpost Number	Time: Door Open and Door Close
4	Stop Record Type II: Data Storage Based on Movement Following Door Closure	All Data	All Data	Cumulative Distance	Signpost Number	Time: Door Open and Door Close
5	Stop Record Type III: Data Storage at Door Opening (Previous Stop Data Recorded)	All Data	All Data	Cumulative Distance	Signpost Number	Time: Door Open and Door Close
6	Idle Start Record: Data Stored if no Movement Within Specified Time Interval (Time is User-Selectable)	--	--	Cumulative Distance	Signpost Number	Time
7	Idle Stop Record: Data Storage When Movement Detected After a Mode 6 Recording	--	--	Cumulative Distance	Signpost Number	Time
8	Distance Record: Data Storage After Specified Distance With No Stop Event (Distance is User-Selectable)	--	--	Cumulative Distance	Signpost Number	Time
9	Signpost Record: Data Storage at Signpost Entry/Exit (from Signpost Module)	--	--	Cumulative Distance	Signpost Number	Time

[1] A data record identifying code corresponding to the type of record shall be stored along with each record.

CHAPTER II.4

MODULE SPECIFICATIONS

Specifications for the 13 modules contained within the on-board automatic data collection system are presented below. The specifications for certain optional modules (e.g., the fare category counter, manual input, and status display) represent typical or preferred configurations and therefore presume certain predefined functions and characteristics. They should not be interpreted as defining the only form the module can take. Individual modules may perform different functions or the manner in which certain functions are performed may be specified differently provided such differences do not interfere with or affect the design of other modules or the overall system. For example, the manual input module specified assumes a driver console through which the driver enters route number as one data input. This particular function, i.e, the input of route number, could be specified as an automatic input from the vehicle destination sign if so desired without changing the overall specification. The intent of the modular system is to allow individual modules to be tailored to particular needs.

4.1 SYSTEM CONTROLLER MODULE

The system controller module is the nucleus of the system in that it performs the control and data management functions of the system. The module consists of a microprocessor, various data input and output circuitries to accommodate the interface electronics of the other modules, and a programmable read-only memory (PROM) to control the system. The microprocessor program provides control of all data transfer operations between modules and acts as data monitor and manager for the overall system.

Microprocessor and Program. The system controller shall contain a microprocessor and sufficient program memory to fulfill all the control and data management functions required by the on-board automatic data collection system. Program instructions shall be contained in PROM to facilitate system customization for special purpose applications. However, the microprocessor and its associated program shall be designed to satisfy the minimum requirements defined in this specification without reprogramming.

Interface Unit Recognition. The system controller shall be programmed to recognize automatically the presence of each of the input modules contained in the data collection subsystem. Data records stored shall be determined based on the presence or absence of these various input modules. That is, the system controller shall recognize that a particular module is installed and contains accessible data. Depending on commands received for data recording, the controller shall access the data contained in the appropriate modules and initiate appropriate reset action (see Section 4.1.4).

4.1.1 Real-Time Clock

The system controller module shall include a real-time clock providing military (24-hour) time (hours; minutes; seconds) and date (month; day). The clock shall include an internal power source that will maintain its operation when the system is disconnected from the primary source or in the event of any malfunction of the primary source.

If the internal power source is a long life battery, it shall have a minimum life expectancy of 18 months. If a rechargeable battery is used, it shall be able to power the clock without recharge for a minimum of 8 days. Provisions shall be made in the system diagnostics for battery check. A voltage reading on a long life battery will be sufficient. A voltage reading on a rechargeable battery must be in a form where the battery is disconnected from the recharge source and has an impressed load. Batteries must be easily accessible and replaceable.

Clock setting shall be accomplished by two methods: (1) the clock/calendar shall be set to correspond to the clock/calendar values in the external receiver unit each time data are retrieved (see Section 4.13), and (2) the clock shall be settable via the driver console within the manual input module (see Section 4.7).

4.1.2 Distance Measurement

The system controller shall provide for the direct connection of an odometer and shall incorporate the necessary electronics to measure distance traveled by the vehicle in statute miles in increments of 0.001 miles. The controller electronics shall provide for the accumulation and data retention of the cumulative distance measured and shall also initiate a data recording whenever that vehicle travels a specified distance without intervening data recordings.

Sensing Unit. Any sensing device appropriate to the distance measurement function may be used provided it satisfies all conditions contained in this specification. The sensing unit shall be a permanent attachment to the bus. Its design shall permit installation by a transit mechanic in 30 min or less. It shall not interfere with normal servicing routines, such as tire changing and balancing, nor shall a failure of the sensor pose any hazard to bus operation.

The distance measurement sensor shall have demonstrated an inherent accuracy in excess of 99 percent. That is, exclusive of external operating conditions such as variations in tire inflation pressure, tire slippage, aging and tread wear, and vehicle loading and speed, the sensor shall be capable of measuring distance within ± 1 percent of its true value. The sensor shall have demonstrated an accuracy in excess of 95 percent in actual revenue service while subject to the external conditions referred to above.

Power to the sensing unit, if required, shall be supplied directly by the vehicle power supply or by the electronics unit within the distance measurement module. (Refer to the section entitled "Power Supply" for a description of the power supply requirements of interfacing electronics units.)

Electronics Unit. The electronics associated with the distance measurement shall be placed on the same P.C. board as the system controller. It shall provide a fully compatible interface between the sensing unit and the on-board data collection control unit. The distance measurement electronics shall be supplied by the same vendor supplying the system controller and shall be integrally mounted with the system controller. No external wires or other electrical contacts other than those provided by the system controller shall be required.

The electronics shall accept signals from the distance measurement sensor and perform such processing as is necessary to measure distance in increments of 0.001 statute miles. All distance regardless of direction shall be recorded.

The electronics shall accumulate and retain two separate distance measures: cumulative distance and incremental distance. Cumulative distance shall be the accumulated distance traveled subsequent to a general system initialization condition. Cumulative distance data shall be reset to zero only upon system initialization. Data storage of cumulative distance shall permit accumulated values up to 999.99 miles. Incremental distance shall be the distance traveled by the vehicle following the recording of a data record of any type. A special data recording shall be initiated whenever the bus travels the user-specified interval without intervening data records. This interval shall be selectable in 0.5-mile increments from the value of 0.5 miles to 4.0 miles.

4.1.3 Door Control Switch

The system controller module shall also provide for the direct connection of a door status monitor that indicates a simple ON/OFF condition to correspond to door OPEN/CLOSE states respectively. The door open and close signal for this purpose will normally be taken from the door control switch operated by the vehicle driver. However, the connection shall allow alternative signal services to be incorporated provided the condition presented at the connection with the controller consists of an ON signal of + 12 VDC to represent a door OPEN state and an OFF state of 0 VDC to indicate the closed state. Contact current shall not exceed 500 mamps. Any other representations of door open/closed states shall be incorporated into the system via the special door status module (see Section 4.8).

4.1.4 Data Control and Reset Operations

The system controller shall access data maintained by the various modules and on completion of the data transfer to memory shall effect a reset of data provided by those modules in accordance with the reset activity list defined in Table II-3.

Of the data elements listed, seven shall be maintained directly by the system controller and handling of these data elements shall be contained as part of the resident program. These data elements are:

Table II-3. Data reset function list.

DATA ELEMENT	Recordings* Causing a Data Reset (Other than Mode 0 & 1)**	Other Reset Conditions
Passengers Boarding	3,4,5	None
Passengers Alighting	3,4,5	None
Fare Revenue	None	None
Fare Category Counts	3,4,5	None
Cumulative Distance	None	None
Incremental Distance	All	None
Signpost Number	None	None
Manual Input	None	None
Clock Time	None	None
Calendar Date	None	None
Idle Time	3,4,5,7	If Movement Detected
Door Open Time	3,4,5	None
Door Closed Time	3,4,5	None

*Refer to Table II-2 for definition of Record Types.

**Modes 0 and 1 automatically effect a data reset.

1. Cumulative Distance.
2. Incremental Distance.
3. Clock Time.
4. Calendar Date.
5. Idle Time.
6. Door Open Time.
7. Door Close Time.

Idle time is defined as the elapsed time from a Type 3, 4, or 5 data recording, i.e., a stop-even record, or from the last detected movement of the vehicle. Idle time shall be reset to zero whenever one of those recordings takes place or whenever vehicle movement is detected. Whenever this elapsed time exceeds the user-specified interval, a Type 7 recording (see Table II-2) shall be executed and idle time shall be reset to zero. This time interval shall be selectable in 0.5-min increments from 0.5 min to 4.0 min.

4.2 PASSENGER COUNTER MODULE

The passenger counter module shall consist of passenger sensing devices and an associated electronics unit to detect and count the number of passengers boarding and the number of passengers alighting the vehicle. The electronics unit shall contain both the logic to detect and differentiate between bidirectional passenger movements, and the electronics to count and retain accumulated values for both boarding and alighting passengers. The passenger counter module shall be capable of sensing and counting eight separate channels of movement, i.e., capable of counting streams of passengers boarding and alighting more than two doors, some of which may have more than one bidirectional passenger stream.

Passenger Sensors. Any passenger sensing device may be used provided no active participation by either the passenger or the driver of the vehicle is required and provided all other conditions in this specification are satisfied. The sensing devices shall not impede or restrict the flow of passengers and shall not protrude into or occupy an area associated with normal passenger, driver, or service activity. Their design shall minimize passenger awareness of the devices. Electrical connections shall be designed so that there is no hazard to the passenger in the event of accidental or deliberate contact.

Passenger sensors shall be semipermanent installations intended to remain on the bus for extended durations. Consequently, sensors shall be capable of withstanding the vehicle environment, including prolonged storage, and cleaning and maintenance activities.

Power for the sensors, if required, shall be supplied directly from the vehicle power supply or by the passenger counter electronics unit from the standard power supplies available to all interface circuitry through the system controller module. (Section 4.12 describes power supply.)

Electronics Unit. The passenger counter electronics shall be located in the system central control unit, interfacing with the system controller module through the STD-BUS motherboard. The unit shall be powered directly from the power distributed to all interface circuitry by the motherboard.

The electronics unit shall accept signals from the passenger counter sensors, differentiate between bidirectional passenger movement, and count the number of boarding and alighting passengers. This counting function shall be active only during a "door open" condition, indicated by the presence of an appropriate signal from the driver door control switch or from the door status module, if present.

The electronics unit shall separately accumulate and store two types of counts: the total number of passengers boarding and the total number of passengers alighting. The unit shall accumulate and maintain counts of up to 999 passengers in each category. Data in both categories shall be retained until accessed, retrieved, and reset by command of the system controller following each bus stop (see Table II-3). Data shall also be reset whenever a system initialization signal is received from the system controller.

Passenger Counter Accuracy. As a minimum, the passenger counter shall demonstrate the following accuracy for a series of data recording events where such event is defined as a complete stop cycle, i.e., one or more doors are opened followed by all doors being closed:

1. For 70 percent of all recording events, both the count of boarding passengers and the count of alighting passengers shall be exactly that determined by manual ride checkers.
2. For 85 percent of all events, neither the boarding count nor the alighting count shall be in excess of ± 1 of the corresponding manually determined counts.
3. For 95 percent of all events, neither the boarding count nor the alighting count shall be in excess of ± 2 of the corresponding manually determined counts.

A valid test of the foregoing conditions shall contain a minimum of 500 consecutive events with the following minimum characteristics:

1. The average number of boardings per event (based on manual data) shall not be less than 2.
2. The median number of boarding or alighting passengers (based on manual data) shall not be less than 2.

In addition, the passenger counter shall generate data of sufficient accuracy to enable the calculation of the total ridership on the bus within ± 10 percent of actual ridership as determined by manual rider checkers. Such accuracies shall be achieved for at least 95 percent of all events. All accuracy tests shall be conducted during revenue service.

4.3 FARE CATEGORY COUNTER

The fare category counter shall consist of appropriate fare category detection devices and associated electronics. The electronics shall accept signals from the detectors and shall accumulate and store counts of the number of users within each specified fare category.

Two types of fare category counter modules are defined by this specification:

1. A "standard" fare category counter consisting of a single detection device, such as an electronic farebox, and an associated electronics unit capable of counting up to 6 user categories.
2. An "expanded" fare category counter consisting of multiple fare media detection devices, e.g., a farebox, a pass-reader, and a ticket validator, and a single electronics interface unit capable of recording up to 12 user categories.

The interface electronics units of both the standard and the expanded module shall conform to the STD-BUS system defined in this specification and shall be compatible with the system controller, i.e., hardware or program modifications shall not be required to use either type of fare category counter.

Fare Category Sensors. Any fare category detection devices may be used including those requiring driver or passenger participation. Acceptable devices include:

1. Driver-actuated push-buttons located on a farebox or driver console.
2. Passenger-activated reading devices for multi-ride tickets and/or passes.

Six data inputs corresponding to six distinct fare categories for each fare media (e.g., cash transfer, pass, senior citizen, etc.) shall be provided. Six fare categories for each device are considered typical of the intended applications; however, devices providing lesser or greater numbers of categories shall not be precluded by the system design.

If driver-actuated push-buttons are used, physical separation between the buttons shall be sufficient to minimize accidental activation of unintended category counts. If passenger-activated devices are used, the determination of the fare category to be counted shall be made from the medium (ticket or pass) itself and shall not rely on the passenger to make this determination.

Electronics Unit. The on-board automatic data collection system shall permit either of two fare category counter interface electronics units to be used. The "standard" electronics unit shall accept signals from a single fare category device and store category counts in six separate classifications. The "expanded" unit shall accept signals from up to three fare detection devices and shall accumulate and maintain counts in each of 12 categories. The unit shall retain counts of up to 99 passengers in each category until accessed, retrieved, and reset by command of the system controller. The unit shall be active, i.e., capable of counting fare categroeis, at all times including periods of data access and retrieval by the system controller. An appropriate buffer shall be used to ensure that counts occurring during data access and resetting operations in the system are not lost. The point of data reset is a selectable option residing in the system controller and depends on the nature of the fare collection system being used. (Pay-on-Entering, Pay-on-Leaving, and Self-Service fare collection techniques each require a different record/reset strategy to allocate fare category counts to logical data records.)

The fare category counter electronics shall also accept signals from an electronic farebox to accumulate and maintain a record of the total revenue received. This total shall not be reset by the event reset signal (see system controller for definition); it will only be reset by a system initialization command from the system controller. The unit shall be capable of storing total revenue of up to 9999.99.

4.4 MEMORY MODULE

The on-board automatic data collection system shall consist of a plug-in memory module that provides the basic solid-state memory for the system. The memory module shall contain 64K-bytes. Memory shall be nonvolatile.

The memory module will contain a system power monitor that will detect power loss, or other malfunctions, and automatically disconnect from system power. The power monitor will continue to monitor and automatically reconnect power when it is back to normal. If nonvolatile memory is battery backed, the module shall include a circuit that monitors the battery and indicates when it is low.

4.5 MEMORY EXPANSION

Space shall be allocated in the STD-BUS rack for a second memory module. The memory expansion module shall be identical to and interchangeable with the memory module defined in Section 4.4.

4.6 SIGNPOST MODULE

The functional requirement on the signpost module is to provide location reference information to the data collection system at several locations along the bus route. The module shall consist of self-contained radio transmitter units in fixed installations at selected locations along the transit route, a vehicle-mounted antenna, and interface electronics to detect, discriminate and store the RF encoded locations identification number transmitted by the signpost. Clock or system time and distance shall be read on receipt of the signpost signal and stored along with the location ID.

Signpost Transmitter. The signpost transmitter shall be a self-contained unit consisting of an RF transmitter, data encoder, and internal battery power supply. The signpost transmitter shall be designed for installation at selected locations along the bus route—typically a street light or traffic signal pole—and as such shall be hermetically sealed and capable of surviving this exposed environment. Installation mounting hardware shall minimize loss due to theft and vandalism, yet shall be such that installation can be completed in less than 15 min—not including site access time. The signpost transmitter shall operate regardless of whether mounted on metal or wood pole.

The signpost shall continuously transmit an RF-encoded three-digit identification number. This identification number shall be selectable either by the use of switches within the unit or by an external or remote device.

Signpost Accuracy. Signal strength shall be such that code discrimination is possible at distances of at least 100 ft from the transmitter and not greater than 500 ft from the transmitter.

The following location accuracy requirements must be met.

1. Eight-five percent (85%) of the time, the system must be capable of locating a bus within 100 ft of a line perpendicular to the street where the signpost is located.
2. Ninety-five percent (95%) of the time, the system must be capable of locating a bus within 150 ft of a line perpendicular to the street where the signpost is located.
3. That is, for every 100 times that a bus passes one or more signposts, at least 90 times the location of the bus must be detected correctly within 100 ft of a line perpendicular to the street where the signpost is located, and at least 99 times the location of the bus must be detected correctly within 150 ft of a line perpendicular to the street where the signpost is located.

The signpost transmitter shall contain internal batteries capable of continuous transmitter operation for not less than 4 years in all climatic conditions (i.e., lithium batteries). Batteries shall be replaceable without removal of the transmitter from its installed location. Battery change-out shall be accomplished in less than 10 min after site access.

Alternate signpost transmitters may be used provided a cost advantage can be shown.

Signpost Antenna. The signpost antenna shall be considered a semipermanent installation on the bus. Its design shall preclude damage during normal bus operation including passage through automatic washers. Antenna installation shall be such that the antenna is replaceable wholly from the bus exterior and shall not require the removal of wiring or other changes to the signpost module.

Interface Electronics. The interface unit shall be located in the system central control unit, interfacing with the system controller through the STD-BUS motherboard.

The interface unit shall initiate a "Type 9" data record when it enters and when it leaves the transmission range of the signpost. These data commands shall be initiated under the following circumstances:

1. Change of signpost code from zero state (i.e., no code being received) to a code state (i.e., signpost identification number being received). This generates a signpost entry record.
2. Change of state from a code state to a zero state. This generates a signpost exit record.

The interface unit shall, in either case, transfer the identification number of the detected unit, i.e., zero state codes shall not be transmitted. The interface unit shall be programmed so as not to generate false data due to intermittent signal loss in the fringe area of a transmitter. That is, it must generate only one entry record and one exit record at any signpost.

4.7 MANUAL INPUT MODULE

The manual input module shall consist of a manual input and display console and an interface electronics module.

Input/Display Console. The console shall provide the following:

- Display of selected information, including:
  Time
  Date
  System operation status
- Input of driver-settable data, consisting of:
  A four-digit run number identification code
  A three-digit route number identification code
  A four-digit driver identification code
  A two-digit zone or type of service identification code
- Input of service-settable data consisting of:
  Setting of clock and calendar
  A four-digit code settable to indicate bus number, farebox, or other data as defined by the user
  A two-digit code to provide additional user-defined data such as division or garage codes.

The input/display console shall be located so as to provide ready access by the bus driver. The input console shall have a push-button or similar device to initiate the recording of summary data. This control shall be inhibited during periods when such a command would lead to erroneous recordings.

Two indicator lights shall be provided on the input console. A READY light shall be lit continuously whenever the system is operational, i.e., whenever all subsystems are connected and the system is able to accept data and recording commands. A second indicator shall be illuminated whenever information is being recorded.

If the console is designed to be mounted on the dash of the transit bus, it shall not obstruct the drivers' view nor shall it interfere with normal driver movements.

All input devices shall be conspicuously labeled, and all visual displays shall be clearly visible in sunlit conditions. Access to nondriver settable input devices shall not require the removal of the unit from the bus dashboard.

Time and data information provided by the clock and calendar on the system controller module shall be displayed on the manual input console. Hours and minutes shall be displayed continuously; seconds shall be displayed only when setting the time. The manual input console shall allow for the correct time to be set conveniently by service personnel. Power shall be applied to the clock at all times. The display need not be illuminated during the period the data collection system is not in use.

All elements including driver control and system indicators shall connect to the interface circuitry through a single cable.

Electronics Interface Unit. The electronics shall interface with the system controller through the STD BUS motherboard. The interface unit shall accept inputs from the console and provide all necessary data management functions for local data storage and for the transfer of the data to central memory (under control of the system controller). Changes of manual input data shall be inhibited during the times the system controller is accessing these data.

It is desirable that the interface electronics automatically identify the amount of data provided and thereby permit different manual input modules to be deployed without firmware modification. However, reprogramming for specific record lengths is permissible if required.

4.8 DOOR STATUS MODULE

The standard mode of monitoring door status shall be through the door control switch (operated by the transit vehicle driver) with the interfacing electronics located in the system central control unit. The door status module provides an alternative (optional) method of monitoring door status. This module uses sensing devices located at each vehicle doorway that indicate the actual physical status of each door and is used to provide more door status information than would be provided by the door control switch. Depending on the type of transit vehicles in use and the data needs of the transit system, it could be the preferred mode.

The door status module shall perform the following functions:

1. Monitor the opening and closing of all doors to define the beginning and end of passenger boarding and alighting activity (see definition below).
2. Generate a single digit code corresponding to door cycles during a particular stop event (for example, "1" to indicate that only the front door opened).

Signals from each of the door sensors shall be input to the door status module interface unit and used to generate two distinct status indicators to the system controller:

1. Condition "A": any door opens following a state in which all doors had been determined to be in the closed condition.
2. Condition "B": all doors return to the closed position following a Condition "A" state.

Condition "A" shall be used by the system controller to define the time of door opening; condition "B" shall be used to denote the time of door closing. Neither status signal in itself shall prompt a data recording because this shall be a function dependent on the data mode selection in the system controller.

4.9 STATUS DISPLAY MODULE

The status display module is an external device that permits an observer to monitor preselected functions of the system. The purpose of the module is to enable accuracy and diagnostic checks of the on-board automatic data collection system to be performed.

Display Unit. The display unit shall be a hand-held device consisting of a six-digit display and associated electronics to select and display any of several data read-outs as specified herein.

The six digits shall be divided into three groups with a minimum separation between groups of 1 inch. The display unit shall contain three switches: one a push-button switch controlling display modes and two 12-position thumbwheel switches or similar devices to select data for display. Table II-4 describes the function of each switch and the data intended for display.

Table II-4. Status display unit switch function.

Switch 1

"Off" — display shows data as selected by Switch 2
"On" — display shows time-of-day in hours/minutes/seconds

Switch 2 & 3

Switch 2 Position	Switch 3 Position	Information Displayed: Left Two Digits	Middle Two Digits	Right Two Digits
0	1	Passengers Boarding	"00"	Passengers Alighting
0	2	Cumulative Distance		
0	3	Cumulative Revenue		
0	4	Signpost Number		
x	y	Fare Category x	"00"	Fare Category y

The display unit shall also provide a reset switch to clear the display and shall contain an indicator (such as a flashing light) to indicate that a signpost transmission signal is being received by the system. Alternative status display module configurations including the use of multiple line alphanumeric displays and the use of keypads are permissible provided the specified data requirements are met.

Interface Electronics. The interface electronics for the status display shall be contained in the central control unit and shall provide all control required for the communication between the controller and the display unit. It shall not interfere with system operation in any way and shall not interrogate, i.e., access data, unless the display unit is physically connected. Interface circuitry is expected to be a semipermanent installation in all systems providing this feature; display units, however, will be connected and used only when required to monitor and/or test the system. Consequently, interface circuitry to fulfill the status display function shall be kept to a minimum; the display unit itself shall contain, to the extent possible, all circuitry required of the status function.

4.10 DATA TRANSMISSION MODULE

The data transmission module is the on-board data communications module for transferring data from the on-board automatic data collection system to the external receiver module. It consists of a data transmission unit connected directly (via standard microcomputer bus) to the system controller; cabling as required; and an output device for sending the data to the external receiver module. The output device specified herein is the female portion of an umbilical connector to accomplish data transfer via the physical connection of the receiver module. However, alternative output devices such as an RF transmitter, ultrasonic or infrared sending units, or similar noncontacting device shall be capable of being used with the system with appropriate changes to only the data transmission module.

Data Transmission Characteristics. Data shall be transmitted synchronously at a rate of 9600 baud and shall conform to requirements for RS232C serial data transfer in accordance with a recognized data communications protocol such as bisynchronous or HDLC. Data transfer shall be accomplished in not more than 60 sec.

Data Control and Protocol. The data transmission module shall initiate data transmission on receiving an appropriate command from the external receiver module and shall continue transmission until all data stored in memory since the last data retrieved is transferred. An appropriate "end-of-data" message shall be transmitted to indicate to the external receiver that all data have been transmitted. On receiving a verification signal from the receiver module, the system controller shall reset the memory module, i.e., clear the data stored in system memory.

Output Device. The typical output device will be a female connector. The device may be located as part of the system central control unit. However, other locations such as in a separate enclosure mounted near the farebox or even on the vehicle exterior shall be anticipated. Cable lengths of up to 25 ft shall be accommodated. The connector shall be rugged and of a quick connect nature providing a positive physical indication of its "seated" position.

4.11 Expansion Module

Space for a spare module shall be provided in the central control unit (the chassis holding all interface electronics) for expansion of the system. This module provides for the addition of new functions into the automatic data collection system by the insertion of a plug-in STD BUS printed circuit board containing the electronics of the new functions. Reprogramming of the PROM in the system controller is expected whenever the expansion module is incorporated.

4.12 POWER SUPPLY MODULE

The power supply for the automatic data collection system shall be located in the 12th slot of the STD BUS chassis. It shall be contained in an enclosure that is $3.00 \times 4.62 \times 6.69$ in. outside dimensions and shall be mounted on a 4.50×6.50 in., series 7000 STD BUS p.c. card with a 56-contact edge connector.

The power supply will be a DC-DC switching converter unit working off the transit vehicle's DC electrical system and will provide regulated power of approximately 100 watts consisting of + 5 VDC at 5.0 amp for computer logic, + 12 VDC at 5.0 amp for event sensor power, and auxiliary power of − 5 and ± 12 VDC at 0.5 amp each. The power supply will be designed to automatically adjust for its power source being either 12 VDC or 24 VDC and either positive or negative ground.

4.13 EXTERNAL DATA RECEIVER MODULE

The external receiver module may be provided in either of the following two configurations:

1. A portable data retrieval unit, such as a portable cassette recorder, portable disk unit, or solid-state memory, that stores

data retrieved on an interim medium such as magnetic tape, i.e., interim to that which will be used by the host processor.

2. A direct connection via modem to the host processor that will perform the data analysis.

The basic design of both units shall permit direct interfacing with a variety of potential host processors including microcomputers, minicomputers, and mainframes.

If a portable unit is employed, sufficient storage capacity shall be provided on each medium, e.g., cassette tape, to contain at least five complete sets of data, i.e., data from at least five buses, without changing the media. The portable unit shall also monitor the remaining capacity and provide an indication of whenever remaining capacity is insufficient to handle another complete data set as defined by the characteristics of the system. Both types of retrieval devices shall provide a visual indicator that data receiving/transmitting is occurring and a separate indicator to denote data transfer has been completed and the unit is "ready" for additional retrieval operations.

CHAPTER II.5

DATA SPECIFICATIONS

Ten data record types were specified for the system in the system controller module specification. Table II-5 defines the specific data to be recorded for each. Data shall be stored in the binary coded decimal (BCD) format.

5.1 SYSTEM DATA STORAGE

Individual data records shall include an appropriate "end-of-record" limiter and data shall be stored without intervening spaces.

5.2 DATA FORMAT REQUIREMENTS

Irrespective of the method of data storage in the system, the intended end product of the on-board automatic data collection system is a transit-bus-oriented data file suitable for subsequent automatic data processing. Consequently, the system shall provide the necessary conversion of data to create this data file—either prior to data transmission via the data transmission module or subsequent to data transmission, e.g., within the external receiver module. This conversion shall include the assignment of specific data elements to specified data fields and the incorporation of appropriate character separators, if required. Table II-6 illustrates the field assignments desired and the form certain data elements shall take. Where certain data elements are not available through certain configurations, data field assignments shall be adjusted to eliminate intervening space since user data processing will be tailored to recognize data based on user's system characteristics.

Table II-5. Data storage requirements.

DATA ELEMENT	Storage Format	DATA RECORD TYPE 0	1	2	3	4	5	6	7	8	9
Data Record Type	Single Digit		x	x	x	x	x	x	x	x	x
Machine Identification Number	Four Digit Number		x	x	x						
Manual Input Data	Variable		x	x	x						
Date	Mo./Day		x	x	x						
Time	Hr/Min/Sec		x	x	x						
Time of Door Opening	"					x	x	x			
Time of Door Closing	"					x	x	x			
Passengers Boarding	Three Digit No.					x	x	x			
Passengers Alighting	Three Digit No.					x	x	x			
Revenue	$/¢				x	x	x	x			
Fare Category Counts	Two Digit Numbers					x	x	x			
Distance	Miles Hundreds				x	x	x	x	x	x	x
Signpost Number	Three Digit Number				x	x	x	x	x	x	x

Table II-6. Data field identification and sequence.

Data Field	Type 0,1 Records		Type 2 Records		Type 3,4,5 Records		Type 6,7,8,9 Records	
Sequence	Data Element	Field	Data Element	Field	Data Element	Field	Data Element	Field
1	Record Code	1	Record Code	1	Record Code	1	Record Code	1
2	Machine ID	2-5	Machine ID	2-5	Door Openg*	2-9	Time*	2-9
3	Run Number	6-9	Run Number	6-9	Door Closg*	10-17	Distance***	10-15
4	Route Number	10-12	Route Number	10-12	Passengers On	18-20	Signpost ID	16-19
5	Bus Number	13-16	Bus Number	13-16	Passengers Off	21-23		
6	Zone Number	17-18	Zone Number	17-18	Revenue**	24-30		
7	Additional	19-20	Additional	19-20	Fare Cat. 1	31-32		
8	Date	21-24	Date	21-24	Category 2	33-34		
9	Time*	25-32	Time	25-32	Category 3	35-36		
10					Category 4	37-38		
11					Category 5	39-40		
12					Category 6	41-42		
13					Category 7	43-44		
14					Category 8	45-46		
15					Category 9	47-48		
16					Category 10	49-50		
17					Category 11	51-52		
18					Category 12	53-54		
19					Distance***	55-59		
20					Signpost ID	60-63		

*Time representation occupying 8 fields e.g. 11:24:17
**Revenue representation occupying 7 fields e.g. 1731.25
***Distance representation occupying 6 fields e.g. 214.31.

CHAPTER II.6

GENERAL REQUIREMENTS

This chapter sets out the general requirements for the on-board automatic data collection system with regard to operating environment, design features, security, reliability and maintenance, identification, and safety.

All on-board equipment shall be designed specifically to operate in typical urban transit bus environment, subject to long periods of continuous use and periodic abuse, and shall not require special or unusual maintenance skills for its routine servicing and repair.

6.1 OPERATING ENVIRONMENT

6.1.1 Temperature

The equipment shall operate without any degradation of performance over an ambient air temperature range of 0 C to 45 C. Any system components that are not in the passenger compartment and are exposed to outside ambient conditions or may receive significant amounts of heat from the vehicle (engine compartment, brakes, transmission, etc.) shall be able to operate without any degradation of performance over an ambient air temperature range of −20 C to 55 C.

6.1.2 Thermal Shock

Data collection equipment shall be able to withstand sudden temperature changes due to operating conditions. Equipment shall be capable of operating under temperature shock conditions of 3 C per minute over any 6 C portion of the specific operating temperature range.

6.1.3 Vibration

All equipment is intended to operate for its full service life under the vibrating conditions typically found on transit vehicles. It shall operate without any degradation of performance when subjected to sinusoidal vibration of ± 0.5 g cycled from 5 to 200 to 5 Hz in 12 min along each of three mutually perpendicular axes. If vibration or shock isolators are included in the design, they shall be considered part of the equipment and subject to the specifications.

6.1.4 Mechanical Shock

Data collection equipment shall be capable of surviving drops on hard level surfaces in the unpacked, nonoperating condition, or a kick or punch from an average male adult while the equipment is operating. Therefore, fare collection equipment shall be capable of surviving acceleration pulses of 5-g peak value with an approximate duration of 10 msec along each of three mutually perpendicular axes.

6.1.5 Relative Humidity

All equipment shall be capable of operation in relative humidities from 5 percent to 95 percent over the temperature range specified in Section 6.1.1. This shall include short periods of condensation.

6.1.6 Exposure to Water

Equipment shall not sustain permanent damage from exposure to rain for brief periods such as may occur during change out of failed units in the field. In addition, equipment mounted on the interior of vehicles shall be resistant to permanent damage due to accidental or malicious water exposure such as may occur when the vehicle's exterior or interior is washed.

6.1.7 Sand, Dust, and Ash

Equipment shall not suffer any degradation in performance when exposed to sand, dust, or volcanic ash conditions, whether caused by external conditions, by on-board conditions, or by vehicle cleaning and vacuuming operations.

6.1.8 Fuels, Solvents, and Fumes

Any circuitry or equipment which is mounted such that it will be exposed to the following substances shall not suffer any degradation in performance as a result of that exposure:

- Any vehicle oils and additives.
- Brake, power steering and transmission hydraulic fluids.
- Engine coolants.
- Diesel fuel.
- Freon and degreasers.
- Soap, steam, and washing solvents.

6.1.9 Sunlight

Radiant heating from and exposure to direct sunlight shall not degrade the performance of data collection equipment operation, nor shall it damage the finish of any enclosures.

6.1.10 Electromagnetic Interference

Data collection equipment shall meet performance and reliability requirements while under the influence of radiated and/or conducted interference from the vehicle and/or the external environment and/or the data collection system self-generated environment. In addition, the data collection system shall conform to appropriate FCC standards for electromechanical radiation.

6.1.10.1 Vehicle Environment

Data collection equipment may be mounted on various types of transit vehicles. Therefore, all equipment and power and control circuits shall have the necessary shielding and grounding to operate on any bus, trolley bus, or light rail vehicle. Probable sources of on-board electromagnetic interference include:

- Power collectors.
- Propulsion system (cam, chopper, or variable frequency AC control).
- Electrical system (lighting, solenoids, relays, etc.).
- Communication equipment (public address, radio).
- Ignition system.

6.1.10.2 External Environment

Data collection equipment shall operate satisfactorily when located near external sources of electromagnetic interference, such as:

- Other vehicular traffic.
- Sixty-cycle power lines (overhead or buried).
- Industrial or high rise buildings.
- Light rail or trolley bus transit power lines.
- Light rail or other signalling systems.
- Radio/TV circuits or transmitters.

6.1.10.3 Internal Environment

Electrical circuitry within the data collection system shall be separated and shielded from potential sources of interference such as wiring for event sensors that may carry surges of relatively heavy electrical currents.

6.2 NONOPERATING ENVIRONMENT

6.2.1 Temperature

Data collection equipment shall be able to withstand an ambient air temperature range of −35 C to 65 C without subsequent degradation of performance. The nonoperating temperature test shall consist of three temperature change cycles alternating between 65 C and −35 C with 12 hours at each temperature for each cycle, thus a total of 72 hours of test time at temperature. The rate of change of temperature shall be at the maximum rate attainable by the test chamber but shall not exceed 10 C (18 F) per minute.

6.2.2 Thermal Shock

Data collection equipment shall be exposed to the temperature change cycles in paragraph 6.2.1 without subsequent degradation of performance.

6.2.3 Vibration

The data collection system shall be able to withstand, without failures and without subsequent degradation of performance, exposure of ± 1.5-g sinusoidal vibration cycled from 5 to 200 to 5 Hz at 12 min per cycle for 7 cycles (84 min) along each of the three mutually perpendicular axes.

6.2.4 Mechanical Shock

Each component or module of the data collection system shall be capable of surviving drops on hard, level surfaces in the unpacked, nonoperating condition without subsequent degradation of performance, without physical failures, and without physical distortion that would prevent proper assembly into the system. The component drop test shall consist of three drops from a height of 36 in. onto a concrete floor. In one of these drops, the component must land flat on one of its largest surfaces. In the other two drops the component must land on a corner. Each STD BUS electronics package, each sensor, the manual input console and the status display unit, shall all undergo this test.

The STD BUS chassis with all electronics installed shall be subject to the following bench handling test: with the rack on a work bench with a solid wooden top at least 1⅜ in. thick, lift one edge of the rack 4 in., using the opposite edge as a pivot, and let the rack fall. Perform 4 times lifting a different edge each time.

6.2.5 Other Nonoperating Environments

All other environments in the nonoperating modes are less than or equal to the operating environments.

6.3 DESIGN FEATURES

Design and construction of data collection equipment shall fully consider its intended use in various transit environments. The contractor's responsibilities regarding design shall include, but shall not be limited to, the following:

1. The design of equipment and appropriate mountings and enclosures in order to:
   a. Reduce the adverse effects of vibration, shock, and environmental conditions.
   b. Discourage vandalism, thefts, and break-ins.
   c. Prevent unauthorized access to internal components.
   d. Facilitate access by authorized personnel.
   e. Promote operational simplicity.
   f. Ensure safety.
2. The design of interconnections between units of the system to include:
   a. Meeting functional requirements.
   b. Necessary cabling and connectors capable of meeting expected environmental conditions.
   c. Concealment of connections to prevent safety hazards and tampering.
   d. Necessary circuit protection.
   e. Mistake-proof fastening brackets for all units.
3. The design of onboard equipment to operate directly from the vehicle power system during all normal operating conditions without interfering with the operation of the vehicle.

The external materials and finishes of the equipment shall be such that the wear and punishment of continuous public exposure and regular cleaning with strong detergents shall not adversely affect the appearance or functions of the equipment. This public exposure shall include both normal and abusive use. The enclosure shall discourage vandalism, and the finish shall resist corrosion.

6.4 SECURITY

Data collection equipment shall be designed to minimize losses or damage due to vandalism. The equipment shall be inoperable except when switched on by the driver. It shall be secure against unauthorized entry or removal, and shall be designed so as to give the least invitation to malicious attention.

6.5 HUMAN FACTORS

Particular emphasis is to be given in system design to factors concerning the safety, convenience, and operational simplicity of all elements at the man/machine interfaces. Sound human engineering principles shall be reflected by the equipment design and shall include, but shall not be limited to, the following:

1. The location of all equipment in such a manner as to not present obstruction to normal passenger activities, driver access to the driver area, and driver vision of roadway and surrounding passenger activity.
2. The design and installation of all electronic equipment, cabling, and connectors to minimize the possibility of electrical shocks in the event of deliberate or accidental misuse or equipment malfunction.
3. The design of all displays so as to be clearly visible in sunlit conditions and readily readable by its intended user.
4. The location of all controls so as to be easily reachable and operable from normal duty positions.
5. The design of all components that will be accessed or removed for servicing accessibles with adequate space for tools and with the weight not to exceed 22 lb (10 Kg mass).
6. The design of subsystem connections to facilitate a mistake-proof system hookup and installation.

6.6 RELIABILITY

All equipment shall be designed from reliable components. The contractor shall identify critical subsystems and components and shall design for their reliability in light of these priorities and the impact of a failure on system operation.

Guidelines for mean time between failure (MTBF) are as follows:

	Years
Passenger Counter Sensor Beams	4
Passenger Counter Sensor Mats	1
Fare Category Counter	2
Distance Measurement Sensor	3
Signpost Transmitter	1
System Controller	2
Manual Input Console	2

The contractor shall perform a reliability analysis of each subsystem and the complete system. He shall ensure that subsystems and components are readily replaced to minimize downtime.

6.7 MAINTAINABILITY

The contractor shall establish a three-echelon maintenance plan that will permit the transit property to minimize downtime of the equipment.

First-echelon maintenance will permit the service personnel to identify the malfunctioning subsystem without necessitating its removal from bus or service island. The contractor shall ensure that all test points are readily available and diagnostic procedures are established to complete this check in 15 min.

Second-echelon maintenance will include preventive maintenance and repair of failed subsystems. Appropriate test points and procedures shall be established to isolate defective components within 30 min by a skilled technician. Repair shall be completed by replacement of module components. The contractor shall also establish a preventive maintnenace program for all subsystems.

As part of maintenance, the contractor shall provide third-echelon support to repair equipment not within the capability of the transit property. Such repairs shall be completed by the contractor within one week.

6.8 INSTALLATION

The on-board portion of the system will be installed on conventional urban and suburban transit coaches. Buses of both U.S. and foreign design are typical, including, but not limited to, all models General Motor's RTS, Flxible's 870, "New Look" coaches manufactured by GM of Canada, Flyer Industries, Neoplan, and Gillig and the various articulated buses manufactured by Crown Ikarus, Neoplan, and MAN.

The contractor's responsibilities regarding installation shall include, but shall not be limited to, the following:

1. The mounting of all equipment to:
   a. Reduce the adverse effects of vibration.
   b. Prevent vandalism.
   c. Prevent unauthorized access to appropriate components.
   d. Facilitate access by authorized personnel.
   e. Promote operational simplicity.
   f. Maintain safety.
2. The appropriate connection of all subsystems including the:
   a. Necessary cabling and connectors capable of meeting expected environmental conditions.
   b. Concealment of cabling to prevent safety hazards and tampering.
   c. Necessary circuit protection.

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