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TCRP Synthesis 34

Data Analysis for Bus Planning and Monitoring

A Synthesis of Transit Practice

Transportation Research Board
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Synthesis of Transit Practice 34

Data Analysis for Bus Planning and Monitoring

PETER G. FURTH
Northeastern University
Boston, Massachusetts

TOPIC PANEL

PETE DONNER, *Port Authority Transit, Pittsburgh*
PETER JANAS, *Toronto Transit Commission*
ANTHONY PALMERE, *Sacramento Regional Transit District*
TOM PALMERLEE, *Transportation Research Board*
ROSS PATRONSKY, *Chicago Transit Authority*
DAVID H. SEMENDINGER, *Washington Metropolitan Area Transit Authority*
DAVID VOZZOLO, *Federal Transit Administration*
NIGEL WILSON, *Massachusetts Institute of Technology*

Transportation Research Board
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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions*, published in 1987 and based on a study sponsored by the Federal Transit Administration (FTA). A report by the American Public Transit Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of vice configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academy of Sciences, acting through the Transportation Research Board (TRB), and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at anytime. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end-users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. TCRP results support and complement other ongoing transit research and training programs.

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The members of the technical advisory panel 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 panel, they are not necessarily those of the Transportation Research Board, the Transit Development Corporation, the National Research Council, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel 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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PREFACE

A vast storehouse of information exists on many subjects of concern to the transit industry. This information has resulted from research and from the successful application of solutions to problems by individuals or organizations. There is a continuing need to provide a systematic means for compiling this information and making it available to the entire transit community in a usable format. The Transit Cooperative Research Program includes a synthesis series designed to search for and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in subject areas of concern to the transit industry.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to transit agency managers, their schedule and operations planning staff, and others who are responsible for information about system operations and ridership. It will also be of interest to others who interact with transit agencies in the reporting of operations data in order to support regular scheduling and operations planning activities for monitoring trends, and for reporting to oversight agencies.

This synthesis reviews the state of the practice in how data are analyzed. It addresses methods used to analyze data and what computer systems are used to store and process data. It also covers accuracy issues, including measurement error, and other problems, including error in estimates.

Administrators, practitioners, and researchers are continually faced with issues or problems on which there is much information, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered or not readily available in the literature, and, as a consequence, in seeking solutions, full information on what has been learned about an issue or problem is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to the available methods of solving or alleviating the issue or problem. In an effort to correct this situation, the Transit Cooperative Research Program (TCRP) Synthesis Project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common transit issues and problems and synthesizing available information. The synthesis reports from this endeavor constitute a TCRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to a specific problem or closely related issues.

This document from the Transportation Research Board addresses agency experience with different data collection systems, giving attention to management error, the need for sampling, and methods for screening, editing, and compensating for data imperfection. Sample reports from selected U.S. and Canadian transit agencies are reproduced in this synthesis.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, available information was assembled from numerous sources, including a number of public transportation agencies. A topic panel of experts inthe subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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DATA ANALYSIS FOR BUS PLANNING AND MONITORING

SUMMARY

Transit agencies have a constant need for information about system operations and ridership in order to support their regular scheduling and operations planning activities, for monitoring trends, and for reporting to oversight agencies. Building on a recently published Transit Cooperative Research Program (TCRP) synthesis that described passenger counting technologies and procedures, this synthesis reviews the state of practice in how data are analyzed. In addition to passenger data, attention is also given to operations data (e.g., running time, schedule adherence). The main analysis issues addressed are (1) what methods are used to analyze the data and (2) what computer data systems are used to store and process the data. This report also addresses accuracy issues, including measurement error and other measurement problems, and sampling error in estimates.

A survey of medium- and large-sized U.S. and Canadian transit agencies was undertaken, as well as a review of the literature. Follow-up interviews with a majority of the responding agencies were conducted to get more detail on aspects of data analysis programs in which agencies were advanced or had valuable experience. Agency staff shared their experiences with various data collection and analysis methods and submitted sample reports that would illustrate the types of analyses now being applied to ridership and operations data. Many of these reports are reproduced in this synthesis.

Experience with different data collection systems is reviewed, giving attention to measurement error, the need for sampling, and methods of screening, editing, and compensating for data imperfection. Striking differences among agencies in the reliability of certain types of data—farebox passenger counts, load observations from point checks, and automatic passenger counter (APC) data—were found. Successful efforts to control measurement error for each of these data types are documented. Examples of the role of analysis methods used for screening, interactive editing, and filling in for missing values are also documented.

Attention is given to the ability of data collection systems that automatically locate vehicles to provide accurate data for off-line analysis of operations. Typical off-line analyses include determining running time variability, schedule adherence, and traffic delays. Three types of automatic data collection systems are examined: (1) automatic vehicle location systems, whose primary purpose is to relay vehicle location in real time to central control; (2) automatic passenger counters, whose main purpose is to identify stops and to record passenger movements and time elapsed; and (3) trip time analyzers, whose main purpose is to track vehicle location and record events such as doors opening and closing for later trip time analysis. Locational accuracy and recording needs for off-line analysis are contrasted with those of real-time monitoring, highlighting the significant gap between typical automated vehicle location (AVL) capabilities and those of APCs and trip time analyzers in supplying the data needed for off-line analysis.

System-level ridership and passenger-mile estimation methods are reviewed, including count-based and revenue-based methods. At many agencies, separate ridership estimation techniques are used for National Transit Database reporting and for internal management. Attention is given to sampling techniques used and to whether the precision of ridership estimates is specified or calculated. Sampling and estimation methods for system-wide schedule adherence are also reviewed.

A large number of analysis methods applied at various levels of geographic detail are reviewed. Most of these methods apply at the route level, though some apply jointly to data from several routes that share stops or operate in a common area. These methods include analysis of ridership by route and by area, analysis of run time and schedule adherence by route, and route economic performance analyses. Thirty sample reports are included, illustrating the analysis techniques used by different agencies.

The types of computer systems used to process, store, and organize ridership and operations monitoring data are reviewed. A wide variety of data systems are used, based in part on differences in data collection systems, analysis needs, and resources devoted to the development of data systems. Relationships between data systems and the data collection methods and analysis techniques they support are examined. Particular attention is given to efforts to integrate data from several sources into a single database.

The primary conclusions of this synthesis include the following:

- *With proper attention measurement error can be controlled.* For each type of data collection system, example agencies were found that reduced measurement error to acceptably small levels. Errors stemming from operator failure—primarily a problem with electronic farebox counts—can be controlled if data are regularly screened, feedback is given promptly within the standard channels of discipline and retraining, and there is cooperation from the managers in transportation and maintenance departments. Errors stemming from equipment malfunction—primarily a problem with APCs, but with other devices as well—can be controlled with automated screening of data and responsive hardware and software maintenance. Errors in observing loads in point checks can be controlled by regular testing with feedback and retraining.

- *Automated data collection holds the key to doing statistically valid analyses of running time and route-level schedule adherence.* Most agencies are forced to rely on very small samples to estimate necessary running time and to monitor schedule adherence, and decisions made on these estimates are quite subjective. In contrast, agencies that automatically collect running time and punctuality data are able to perform statistically valid analyses of performance that guide improvements in scheduling, operations control, and traffic engineering. The large samples necessary for a statistically valid analysis are impractical without automatic data collection.

- *Automatic vehicle location systems do not usually provide the same quality of performance data as automatic passenger counters and trip time analyzers.* Because off-line analysis of running time and schedule adherence is less glamorous than real-time displays of vehicle location, its importance for scheduling and operations monitoring is often overlooked in designing AVL systems. Unfortunately, many existing AVL systems were not designed to record data for off-line analysis, and adding this capability to existing systems is often impractical. Furthermore, the location needs of off-line trip time analysis—time at given locations and time and location for various events—differ from the demands of realtime monitoring. Agencies desiring to use AVL as a data source for analyzing operations data must ensure that this capability is part of the system design. In contrast, APC systems usually provide more useful data, because they almost always record arrival and departure time at each stop. Their main drawback is that, due to their cost and maintenance burden, they are usually installed on only a fraction of the fleet, limiting sample size. Trip time analyzers, which are usually designed exclusively for off-line analysis and installed fleetwide, provide the most useful operations data. With proper design, however, any of these systems can provide the locational accuracy and event data needed to support off-line analysis of running time and punctuality.

- *Statistical treatment of estimates has not spread far beyond federal mandates for National Transit Database (NTD) reporting.* The statistical precision of most ridership and operations estimates made by transit agencies is unknown. Statistical sampling is rarely practiced except for making NTD estimates. Many decisions are based on estimates made with statistically invalid sample sizes.

- *Industry practice is not yet mature in its development of data systems for planning and service monitoring data.* There are still in use a large number of small, informal data systems, such as spreadsheets, which require extensive manual data input and intervention. Many report formats are hard to read and fail to convey the information in the most useful way. Transfers between data systems and analyses that rely on data from different sources often entail a good deal of manual labor. In addition, many decisions are being made without adequate information.

- *The industry is migrating to general purpose database packages for data analysis.* Almost all of the recent developments in data analysis software at transit agencies have involved the use of general purpose, commercially available database packages on personal computers, often networked. The database packages are customized to the agency's needs either by planning department staff or by consultants. Custom analysis software remains only as a relic of the mainframe era and is being replaced. Proprietary analysis packages that are supplied to support specific devices (fareboxes, AVL, APCs, and hand-held units) have limited capability, being difficult to customize and update, and making it difficult to integrate data from different sources.

However, adapting general purpose database software for receiving and analyzing transit data requires expertise that is not available at many transit agencies. No examples have been observed of one agency's software being shared with another agency.

- *Although route-level analyses are well developed, network-level and geographic analysis methods are still in their infancy.* Database structures in which data are organized by route are simple and common, making analyses at the route level easy. In contrast, network analyses and analysis methods based on geographic areas require a far more complex database structure. New software modules with geographic capabilities that accept transit operations and ridership monitoring data have recently been introduced and may open up new possibilities for analysis.

- *Commercially available data systems for transit ridership and operations data analysis may play a role in advancing industry practice in data analysis.* New software products that are not tied to particular data collection devices are being developed by suppliers of scheduling software and by university research centers. These new products have strong database capabilities, and some have geographic capabilities that permit higher levels of data integration and analysis. These products may prove useful to agencies that lack the expertise to develop their own modern data system or who desire geographic analysis capability without developing their own custom modification of a geographic information system.

Finally, further research is recommended in three areas. The first is with data definitions and interfaces to further simplify data integration. With improvements in automated data collection systems and software for analyzing data, there is increasing value in having different systems being able to "talk" to one another. Research can help highlight where standardization would be beneficial and suggest standards that might be acceptable industrywide.

A second area involves detailed case studies of a few of the more advanced data systems that have recently been developed by transit agencies. Their experience would be a valuable guide to other agencies.

A third area identified for future research concerns the uses and benefits of trip time analyzers with data supplied by event recorders. Operations data have tended to be seen as a fringe benefit of both APC and AVL systems and have gotten little attention in its own right. An examination of the value of having automatic, detailed data on every trip operated for off-line analysis may reveal that it is well worth the cost of a trip time analyzer.

CHAPTER ONE

INTRODUCTION

Transit agencies constantly demand information about system operations and patronage in order to support their regular scheduling and operations planning activities, for monitoring trends, and for reporting to oversight agencies. The recently published Transit Cooperative Research Program (TCRP) Synthesis 29, *Passenger Counting Technologies and Procedures (1)*, provides a critical review of how passenger data are used and the methods by which the data are collected. The present report builds on Synthesis 29 by examining how the data, once collected, are analyzed. In addition to passenger data, attention is also given to operations data (e.g., running time, schedule adherence). The main analysis issues addressed are what methods are used to analyze the data and what computer data systems are used to store and process the data. Also addressed are accuracy issues, including measurement error and other measurement problems, and sampling error in estimates.

INFORMATION NEEDS

The monitoring information needed by transit agencies can be divided into two categories: information about ridership and information about operations. It is also useful to distinguish information needs for upper management and external reporting from the needs of departments such as planning, scheduling, and service monitoring. Upper management and external reporting information needs are almost exclusively at the system level, focusing on ridership and revenue information to support strategic planning, budgeting, and fare policy analysis. Traditionally, they have not required operations data, although some agencies have begun to monitor and report system-wide schedule adherence.

Departments responsible for planning, scheduling, and service monitoring need both operations and ridership information at varying levels of detail. Geographically, information is needed for various purposes by route, route segment, and stop, and for geographic areas served by more than one route. Likewise, information is needed for different levels of time detail. Sometimes information is needed for standard periods, such as planning periods (e.g., a.m. peak, midday) or scheduling periods (periods of constant running time or constant headway, which may vary from route to route); sometimes an analyst will want information on a customized period or an individual trip.

The most common ridership measure used in standard analyses at both the system level and at detailed levels is boardings (unlinked passenger trips). Linked trips (also called revenue passengers) are monitored by some agencies as well, usually at the system level only. At the route and sometimes route-segment level, the number of boardings is a necessary input to the regular economic or performance analysis now followed by most transit agencies in which routes and route segments are compared in terms of ratios such as cost per passenger or passengers per vehicle-hour. Route-segment and stop-level boardings information is also used as needed by operations planning for analyzing service changes or prioritizing stop-level amenities. The ridership measure most needed to support scheduling, at least on routes where the service frequency is determined by passenger load, is passenger load at a route's peak point. Because peak points can change, it is helpful to have an up-to-date profile of load all along the route. Load profiles are helpful for analyzing service changes as well. Ridership information linking several routes, such as transfer patterns and origin-destination matrices, are helpful for various analyses, but are not commonly available.

The two main operations measures needed are punctuality, also called schedule adherence or on-time performance, and running time. Detailed running time information is needed to support scheduling. Punctuality is monitored in some agencies at the system level to give a general indication of performance. Tracking punctuality at the route/period level is helpful as a means to identify needs for better control or schedule revision. Running time analysis, in which trip time is divided into time spent in motion, at stops, delayed in traffic, and so on, is a further level of detail in operations data, and is useful for various scheduling purposes.

System-level information for upper management needs and external reporting is collected, analyzed, and reported routinely at every transit agency. Nevertheless, methods and data systems used for system-level analyses vary considerably between agencies because of differences in data sources available and reporting needs. Even more variability exists among agencies with respect to the type and quantity of detailed ridership and operations data collected. Not surprisingly, methods and data systems used for detailed analyses also vary widely.

DATA SOURCES

One of the primary reasons for differences in analysis methods and data systems is the result of differences in data sources. As reported in TCRP Synthesis 29 *(1)*, the primary sources of passenger data are electronic fareboxes, automatic passenger counters (APCs), and manual counts made by traffic checkers and operators. Sources of operational data include APCs, automatic vehicle location (AVL) systems, ride checks, and point checks. This report also considers a common European source of operations data called trip time analyzers.

Three issues related to data sources are examined in this synthesis. The first is measurement error. Experience at various transit agencies indicates that measurement error with some data sources can be so great as to render the data unusable, whereas at other agencies the data are considered very reliable. Attention is paid to successful efforts taken to improve measurement accuracy, including screening and editing automatically collected data.

A second issue related to particular data sources is data storage. Data storage systems are often tied to the data collection technique; for example, electronic fareboxes, APCs, and hand-held devices usually come with their own data systems. These data systems influence later analysis. The availability of these data systems is certainly an advantage; however, they do not always offer the analysis capabilities needed, and higher level data systems are often needed to integrate the data from different sources. Another data storage issue examined concerns how long data are stored.

Third, some data sources typically yield daily counts on all trips, whereas others yield only samples. Even with daily counts, adjustments are often still needed for occasional missing data or miscounts. When the data represent a sample, estimation methods should account for sampling error.

ANALYSIS METHODS

Analysis can be seen as the process by which useful information is drawn from data. This includes both different ways to estimate a given measure and different measures and displays that illuminate various aspects of the data. Analysis usually results in a report.

One purpose of this synthesis is to summarize the types of service monitoring analyses used in transit agencies. This synthesis includes a large number of sample reports drawn from examples submitted by the surveyed transit agencies. A critical review is given of the analysis methods used.

Particular attention is given to methods used to estimate system-level ridership and passenger miles. Statistical accuracy of methods involving sampling is addressed as well.

DATA SYSTEMS

We use the term data system to refer to the hardware and software that allows data to be stored, organized, and analyzed. Collectively, transit agencies have experience with many types of data systems. These include data systems developed as a support to a particular data collection system, large-scale database systems on mainframes and personal computers (PCs) that integrate data from various sources and perform sophisticated analyses, and simple spreadsheets and databases used with simple data structures and/or analysis needs. Part of the purpose of this synthesis is to describe the state of the practice in data systems used, with a critical analysis of how different data systems support different information needs, data sources, and analysis methods.

REPORT ORGANIZATION

Chapter 2 provides a brief review of the literature and a description of the survey of the transit agencies taken as part of this study. A number of references to the literature are given in later chapters as well, as appropriate to the context.

Chapter 3 reviews data sources. It includes a general description of the sources and the type of data they capture. It also discusses measurement error and efforts taken to control it, and issues related to data completeness and sampling. Data systems particular to the data sources are also described.

Chapter 4 discusses analysis methods used for estimating system-level ridership and passenger miles. Key issues examined include data sources, mathematical models, and computer systems used in analysis and reporting. The accuracy of the estimates is also discussed.

Chapter 5 describes analysis methods related to service monitoring and planning data. A large number of sample reports are presented to illustrate the methods. The data systems used in performing these analyses, and their relation to the data sources, are also described.

Chapter 6 contains conclusions and recommendations for future research.

CHAPTER TWO

SURVEY OF TRANSIT AGENCIES AND THE LITERATURE

LITERATURE REVIEW

As mentioned earlier, this synthesis builds on TCRP Synthesis 29, *Passenger Counting Technologies and Procedures (1).* Synthesis 29 describes the state of practice with regard to passenger counting. It covers technical issues, resource requirements, and implementation issues related to many of the data collection methods discussed in the present synthesis. It includes a good review of uses for passenger data. It also offers a brief summary of data processing and reporting experience that may be thought of as the precursor to the present synthesis. A TCRP synthesis of practice with regard to AVL systems *(2)*, a data source outside the scope of Synthesis 29, was also reviewed. It describes different AVL technologies and configurations and ways in which AVL data are used off-line in running time and schedule adherence analysis.

Literature on Data Systems

Hickman and Day *(3)* report on a survey of California transit agencies with regard to information systems and technologies. Thirty agencies, both large and small, responded. The authors found widespread use of data systems for schedule and farebox data. They report that most agencies keep ridership data in an electronic format, but do not further elaborate on the data systems except to mention a scope ranging from simple spreadsheets to sophisticated systems. They found that although it was common for certain types of data to be used by several departments at the same agency, a minority held their data in a single database accessible across the agency. Various means were being used to transfer files from one department to another. Schedule data were the most common data type to be shared across the agency, being useful for all the functions studied (operations management, service planning, performance monitoring, and traveler information).

Cummings *(4)* also describes innovative efforts at a transit agency to develop and integrate data systems, this time in Atlanta. A single relational database has been developed that incorporates farebox, APC, and rail faregate data.

A recent TCRP Report *Understanding and Applying Advanced On-Board Bus Electronics (5)* summarizes the state of the practice in integration of on-board data devices. New buses have many electronic systems and sensors, and may have as many as 11 computers (microprocessors) managing various systems. The focus of most of this electronics, however, is running the bus in real-time, not providing data for off-line analysis. Agencies can design systems in which data from different devices, such as operator's console, radio, farebox, destination sign, annunciator, and door switches are integrated with each other and with a computer called the vehicle logic unit (VLU) in a local area network called a vehicle area network or VAN. The VLU can hold schedule information, which may be updated at each pullout using the radio system, and can store data for later analysis. To make integration easier, a transit industry working group has developed the J1708 family of standards for communication in a vehicle area network *(6,7).* Although development of VANs is still in its infancy, many suppliers advertise that their devices are J1708 compliant, paving the way for further development. At the present time, on-board computers that run APC systems are the most developed as VLUs, combining data from passenger counters, door sensors, odometer/ transmission, and location devices to generate data on not just passenger counts but vehicle trajectories as well. On-board computers developed to run AVL systems similarly integrate data from many sources, but data storage for off-line analysis is not always a design feature. The computers in electronic fareboxes store data for off-line analysis, but without integration with other data sources.

Hickman et al. *(8)* evaluated the benefits and liabilities of open interface standards for information systems in the transit area. A survey of suppliers found that many are using open interface standards to allow their data to be more easily integrated with other data systems. However, many reasons for continuing to use proprietary standards were also cited, including financial security (for fareboxes in particular) and customization. It should be noted, however, that most of the visible work in information systems integration for transit, such as traveler information systems, advanced fare media, and real-time monitoring of vehicle location, relates to areas outside the scope of this report. Comparatively little attention is given to providing ridership and performance data for off-line analysis.

Furth *(9)*, summarizing a Transit-IDEA report, describes ways by which the value of farebox data can be enhanced by its integration with other data sources. It discusses measurement error issues related to fareboxes and describes how a link with the destination sign can reduce dependence on operator intervention and thus improve data accuracy.

Literature on Analysis Methods

Transit agencies have always monitored ridership and performance, which involves some analysis of counts, revenue, and observations. In the last two decades, demand for improved performance, increased accountability, and attention to quality have led to the development of more refined measures and standards, scientific sampling and estimation methods, and accuracy standards.

Attention was first focused on system-level ridership monitoring. In 1979, the Federal Transit Administration (FTA) began to require that most U.S. transit systems use statistically valid sampling and estimation methods to determine annual system boardings and passenger miles for the National Transit Database (NTD). Research on typical levels of variation led to the publication of two sampling and estimation methods for annual system-wide boardings and passenger miles. The first, appearing in updated form as FTA Circular 2710.1A *(10)*, is based on direct expansion of sample means in a two-stage sampling framework. The second, Circular 2710.4 *(11)*, is based on estimating the ratios of boardings and passenger miles to farebox revenue, and using those ratios to expand annual system-wide farebox revenue. Under current regulations, transit systems may use the method of Circular 2710.1A without further analysis; alternatively, they may use the method of Circular 2710.4 or a customized method if a statistician certifies that it will yield estimates whose precision (margin of error) at the 95 percent confidence level is ±10 percent or less. A few alternative methods of sampling and estimation have been published *(12-15)*, including estimation methods using ratios or conversion factors, for example, to estimate peak load from boardings or boardings from peak load. A sampling method developed expressly for use with APCs has also been developed *(16)*.

Another line of analysis was the definition of performance measures—typically ratios such as boardings per vehicle-hour—to monitor efficiency, effectiveness, and economy. This movement began at the system level, but then turned its focus to the route and route/direction/period level, which is the critical level for most planning and monitoring purposes. For example, Wilson and Gonzalez *(17)* emphasize the need for a regular data collection program with regard to boardings, peak load, and running time to provide feedback for service planning and scheduling. An FTA published manual *(18)* suggests how statistical sampling and estimation methods can be used with route/direction/period-level data collection.

Benn *(19)* and Perk and Hinebaugh *(20)* summarize current practice in route-level performance monitoring and design standards. Most performance monitoring schemes rely on simple ratios, such as boardings per vehicle-hour, demanding only the simplest analysis of ridership or operations data. However, it has created a demand for integrating ridership data with schedule and operations data so as to more easily calculate and report the desired ratios. Increasing attention is being given to estimating and reporting on-time performance. Bates *(21)* offers a preliminary survey of industry practice, while Jackson and Ibarra *(22)* describe a service reliability program that relies on considerable data collection and analysis. Additional information of note in this area comes from a 1998 study by Strathman et al. *(23)*, which provides an example of using data from AVL bus dispatch systems for analysis of performance and schedules.

The literature also includes descriptions of many special purpose analysis methods for service planning, such as predicting the growth trend of new services, designing short-turn and zonal routes, and comparison of ridership to population in a route's service area. Such special purpose analysis methods are beyond the scope of this report, except inasmuch as they emphasize the point that there may always be unexpected uses for good, accessible data. Some of these methods also emphasize the value of integrating ridership data with geographic data and with traditional long-range planning models.

SURVEY OF TRANSIT AGENCIES

A survey of selected large and medium-sized transit agencies was conducted to gain insight into the state of the practice with regard to data analysis. Questions were asked regarding data sources, data systems, and estimation methods. To build as much as possible on the information obtained from the Synthesis 29 survey, all 33 of the respondents to the Synthesis 29 study were surveyed, which made it unnecessary to repeat a number of the questions. Four other agencies were also surveyed.

Responses were received from 20 of the 37 surveyed agencies. They range in fleet size from about 150 to about 2,000. Four are Canadian. Table 1 presents a list of the responding agencies with key characteristics. As the table indicates, the responding agencies vary considerably in size and in data collection technologies. The responses received from the Synthesis 29 survey were also reviewed in detail.

The questions, along with a summary of responses, are found in Appendix A.

Follow-up interviews were conducted with 11 of the responding agencies, as well as with agencies identified in the literature, to clarify responses and to get more detail on aspects of data analysis programs that were advanced or unique.

TABLE 1
KEY CHARACTERISTICS OF RESPONDING AGENCIES

Agency	Central City	Bus Fleet (Approximate)	Fleet With Electronic Fareboxes (%)	Fleet With APC (%)	Fleet With AVL (%)	Systematic Ride Check Program*	Systematic Point Check Program*
MBTA	Boston	1,000	100	—	—	Y	
Calgary Transit	Calgary	750	—	3	1		Y
CTA	Chicago	2,000	100	1	< 1	Y	Y
RTA	Cleveland	700	100	—	—	Y	Y
DART	Dallas	750	100	—	100	Y	Y
Houston METRO	Houston	1,200	100	—	—	Y	
KCATA	Kansas City	250	100	—	100		
MDTA	Miami	600	100	—	100		
MTS	Milwaukee	550	100	—	90	Y	Y
TTDC	Norfolk	150	100	—	75	Y	Y
AC Transit	Oakland	700	100	3	—		Y
LYNX	Orlando	200	100	—	2		Y
OC Transpo	Ottawa	800	—	1	100		
PAT	Pittsburgh	900	100	—	—		Y
Sacramento RT	Sacramento	200	100	—	—	Y	
Metro	Seattle	1,000	100	12	100		
Pierce Transit	Tacoma	192	100	—	—	Y	Y
TTC	Toronto	1,500	—	—	100	Y	Y
WMATA	Washington	1,300	100	—	—	Y	Y
Winnipeg Transit	Winnipeg	500	—	—	—		Y

*Excluding samples taken primarily for NTD (Section 15). Y = Yes.

MBTA = Massachusetts Bay Transportation Authority; CTA = Chicago Transit Authority; RTA = Regional Transit Authority; DART = Dallas Area Rapid Transit; METRO = Metropolitan Transit Authority of Harris County, Texas; KCATA = Kansas City Area Transportation Authority; MDTA = Metro-Dade Transit Agency; MTS = Milwaukee Transport Services; TTDC = Tidewater Transit District Commission; AC Transit = Alameda-Contra Costa Transit District; LYNX = Central Florida Regional Transit Authority; OC Transpo = Ottawa-Carleton Regional Transit Commission; PAT = Port Authority Transit; RT = Regional Transit; TTC = Toronto Transit Commission; WMATA = Washington Metropolitan Area Transit Authority.

CHAPTER THREE

DATA SOURCES

FAREBOX COUNTS

Electronic fareboxes can be an excellent source of ridership data because of their ability to register passenger boardings by fare category. Some registrations are done automatically. Tokens are counted automatically as a single fare, and fareboxes are normally programmed to recognize the standard fare and register each series of dropped coins that matches (or exceeds) the standard fare as one boarding. With various attachments, fareboxes can also read magnetic fare media, such as passes and magnetic transfers, lessening reliance on operator intervention. Other registrations, including passengers with discounted fares and nonmagnetic passes, require the operator to push a button corresponding to the appropriate fare category. In addition to tallying boardings, electronic registering fareboxes, like mechanical registering fareboxes, count revenue. Data are stored in the farebox during operation and, in systems in use today, are uploaded to a dedicated PC at the garage as part of the regular process of retrieving revenue from the vehicles.

All 16 of the U.S. responding agencies—and none of the responding Canadian agencies—have electronic registering fareboxes. Twelve of the U.S. agencies use fareboxes as their primary source for determining system ridership, and 10 further use them as their primary source for determining route-level ridership. In most cases, agencies are using boarding counts as ridership counts (perhaps with adjustment for undercount); in a few cases where boarding counts are not reliable, agencies are using revenue counts and converting them to estimated boardings using an average fare factor. Four responding U.S. systems do not use their electronic registering fareboxes as a primary data source for operations planning or monitoring.

The fareboxes of the responding systems all tally boardings by fare category as well as revenue. At certain moments, those tallies are recorded in a permanent storage medium and reinitialized, a process called segmenting the data. The more frequently the data are segmented—the most frequent level being for each trip—the greater the detail of the retrieved counts. Of the 12 responding agencies that use farebox counts as a primary data source, 7 segment by trip, giving the finest level of detail (which can, of course, be aggregated to route or period levels). Three agencies segment by route. One agency, the Chicago Transit Authority (CTA), segments by hour, which has the advantage that segmenting is done automatically, and, because this agency has very little interlining, allows for analysis at the route and period (but not trip) levels. One of the 12 agencies segments their data by day only.

A recent development is fareboxes that store transactional data. Instead of making a record only at the end of each trip or other segmentation point, these fareboxes create a permanent record of every boarding, or at least every fare transaction. Typically, the record includes time of day, fare category, payment medium, and identifiers such as route number. Transactional data can be aggregated to the same levels of detail as traditional farebox data provided that the necessary identifiers (e.g., trip number) are recorded. Transactional data also make new analyses possible. For example, by including the pass number in each pass transaction, linked trips and individual travel patterns can be analyzed. Effects of fare promotions using magnetic media can similarly be analyzed. If location data are recorded with each transaction, one can track boardings (but not alightings) by stop. Furth *(12)* describes a means of estimating passenger volumes and passenger miles based on an analysis of boardings by location.

Sampling and Missing Data

Farebox systems provide daily data on nearly every trip, because every bus is normally equipped with a farebox; therefore, there is no need for sampling. However, because of the effort needed for editing the data, at least one agency makes roughly a 25 percent sample, analyzing 1 week's data each month and expanding the results to the month.

There is usually enough missing data due to hardware malfunctions and other problems to make some kind of adjustment for missing data desirable. However, if data reliability is considered critical, operating procedures can be adjusted to better monitor data quality, and additional features can be added to farebox system design to improve reliability. For example, at Foothill Transit, Montebello Transit, and Culver City Transit in Southern California, revenue from prepaid passes is allocated among the agencies according to passenger use. With agency revenue thus dependent on passenger counts, a transactional farebox system was designed to include redundant memory and other features that minimize the amount of lost data.

Sources of Measurement Error

Measurement error can be a serious problem with farebox data for several reasons, primarily the need for operator intervention for nonautomatic registrations and segmentation. Responding agencies identified five sources of measurement error:

1. The operator fails to register a boarding, presses the wrong key, or fails to clear the coin box after a nonstandard fare.
2. The operator doesn't properly sign on (e.g., enter badge number and run number) or segment the data (e.g., enter trip number at the start of each trip).
3. Maintenance staff do not probe the fareboxes each day, allowing data to be assigned to the wrong date or to be lost because of storage buffer overflow.
4. The assignment of keys to fare categories (the "fareset") is either ambiguous or incomplete, so that operators sometimes don't know how to register a boarding.
5. Hardware and software problems due to manufacture or to inadequate maintenance.

A 1985 study done at Alameda-Contra Costa Transit District (AC Transit) *(24)* is an example of measurement problems. At the time, about 25 percent of their farebox readings were found to either not match a bus number, not be distributed by fare type, or to be unreasonably high or low. In a comparison of 16 vehicle-day summaries with manual counts, 4 of the summaries were discarded as unreasonably high or low; the remaining 12, although showing an average undercount of only 6 percent, ranged from a 21 percent undercount to a 19 percent overcount. It was found that undercounts increased systematically with the level of pass and transfer use and with fare; no explanation was offered for the overcounts.

Minimizing Measurement Error

Ensuring good quality data demands a concerted effort on several fronts on the part of transit agencies. Agencies were asked to rate the level of attention given to ensuring the quality of ridership data from their fareboxes. Seven of the responding agencies reported that the farebox data are reliable enough to be used by analysts, although five of these seven stated that analysts must still be wary because bad data occurs frequently. The other nine responding agencies report that data quality are so bad that the data are either unduly burdensome to use or are simply too unreliable. Except for one agency, whose fareboxes were supplied by a manufacturer no longer in business, the differences in data quality are not due primarily to hardware, but rather to differences in the institutional commitment to farebox data quality, a commitment that cuts across many departments. Key efforts made to maintain data quality are listed here according to how frequently they were cited (shown in parentheses):

- Feedback, with possible discipline and retraining, for noncompliant operators (10);
- Having personnel committed to regular (daily or monthly) data monitoring (7);
- Periodic checks for consistency and for gross operator neglect (6);
- Tracking the degree of undercount (3);
- Having personnel dedicated to farebox maintenance (including preventive maintenance) and close coordination with farebox maintenance staff (3);
- Having a semi-automated screening and editing program (3);
- Investing in technology (e.g., magnetic card readers) to reduce the burden on operators (2);
- Comparing with traffic checker or APC data (2); and
- Requiring trip-level segmentation only on selected routes (1).

Advanced technology can reduce the need for operator intervention, thus reducing one source of error. More and more agencies are installing magnetic pass and transfer readers to reduce reliance on operator intervention. At least one agency—Pace in suburban Chicago—has worked with farebox and destination sign suppliers to reduce the problem of operators failing to segment the data at the end of each trip. They developed a simple electronic link so that the operator controls the destination sign from the farebox keypad *(9)*. Because of the destination sign's visibility to the public, the operator has a strong incentive to key the change of trip into the farebox. The link also reduces risk of injury from operating the (usually overhead) destination sign controls. If vehicle area networks develop as expected, real-time checks on operator sign-on, route, and trip will become possible, data segmentation may become automatic, and data quality should improve.

Interestingly, the two responding agencies that gave themselves the highest rating for farebox data quality were the smallest, the Tidewater Transit District Commission (TTDC, Norfolk, Va.) and the largest, the CTA. Experience suggests that smaller agencies often have good farebox data for a variety of reasons, including lower passenger volume (allowing operators to give more attention to farebox operation), a tradition of regular passenger counting by operators, and the greater accountability that usually comes with a smaller number of operators. However, smallness alone is not enough to guarantee good quality data. At TTDC, farebox reports are screened monthly, to search for missing or inconsistent data. Missing operator inputs are traced to the operator, who is thus informed (along with his or her supervisor), and corrections are made. Screening checks also look for inconsistencies from month to month.

At the other extreme, the CTA experience indicates that the obstacles to getting good farebox data can be overcome at a large agency as well, though not without a good deal of effort. Like many other large agencies, the CTA found that their farebox counts were effectively worthless during the first few years of operation. At that time they made the strategic decision to invest in improving the quality of their farebox data. CTA worked with the vendor to have software adjustments made so that the data are segmented by hour (based on an internal clock), removing dependence on the operator for data segmentation. They simplified their faresets. They also developed software that partially automates the tasks of screening and editing the data. Each day's data are screened, edited if necessary, and downloaded to a customized database, with a turnaround of about 5 days. Finally, they instituted a regular checking program to monitor the remaining level of undercounting (less than 5 percent overall).

A commitment throughout the organization, beginning with upper management, is needed to attain a level at which farebox counts are reliable. Agencies with unreliable farebox counts sometimes describe a vicious cycle in which analysts won't use the data until its reliability improves, yet find it difficult to enlist the cooperation of operators and maintenance personnel who know that the farebox counts are not being used and who are under pressure because of competing priorities. Because of the significant effort needed, some agencies with other good data sources have chosen not to invest in farebox count data. For instance, Seattle Metro has made the strategic decision to invest its effort into the quality of APC data rather than farebox counts.

Screening and Editing Methods

Because farebox data are being collected every day on every bus, good estimates of passenger use can still be obtained even if there is missing or bad data, provided the bad data can be identified and either corrected or discarded. Houston METRO (the Metropolitan Transit Authority of Harris County) is one of the responding agencies with a semi-automated screening and editing program for farebox counts. To reduce the level of effort needed, data from 1 week per month are selected for analysis. Data from the sampled week are first extracted to a special purpose database. This database is linked to the operator timekeeping system to detect erroneous sign-on information (e.g., wrong block number). If no further errors are detected in a day's data for a bus, the sign-on information is corrected automatically; otherwise, the error is reported for manual correction. Operators with three or more sign-on errors in the sample week are reported to the Operations Department and to training instructors.

Outliers are then identified by comparing the 5 weekdays. In an interactive process, outliers can be removed and automatically replaced with the average of the remaining weekdays. Weekend outliers are identified using simpler range checks.

Next, three adjustment factors are applied. First, a run omission adjustment is generated for each route as the ratio of operated trips to trips with valid data. Second, an undercount adjustment, described later, is applied to all the counts. Finally, a revenue adjustment factor is applied to make the counts representative of the month from which they were drawn. This factor is the ratio of mean revenue per day for the month to mean revenue per day for the sample week.

Two reports illustrate Houston METRO's screening and adjustment process. Table 2 is an automatic corrections report listing discrepancies in operator sign-on data between the farebox and timekeeping systems that have been automatically corrected to match the timekeeping data. Table 3 presents historical values of adjustment factors used for undercount and for differences between sampled week revenue and average monthly revenue.

Adjustment Factors to Correct for Undercount

Of the 16 responding agencies with fareboxes, 7 report a systematic undercount of boardings with fareboxes, with estimates ranging from 1 to 6 percent (except for one agency, which reports a 30 percent undercount and, not surprisingly, does not use the farebox counts as a regular data source). Undercount most frequently occurs with noncash fares, when revenue collection alone requires no interaction with the farebox, for example, for flash pass users and free passengers such as young children. Fare evasion and operator failure to register discount fares also contributes to undercounting. Three responding agencies report no systematic undercount.

Three agencies report using expansion factors to adjust their boardings totals for undercount. Sacramento Regional Transit applies a daily adjustment factor, the ratio of counted cash revenue to calculated cash revenue based on registrations of cash boardings. This factor is applied to boardings in all categories, not just cash boardings. The other two, CTA and Houston METRO, have a dedicated checking program for estimating adjustment factors. At both agencies, boardings are counted manually on a sample of trips and compared, by fare category, with the farebox counts for the same set of trips. The ratio of the total of the manual counts to the total of the corresponding

TABLE 2
AUTOMATIC CORRECTIONS MADE TO OPERATOR SIGN-ON DATA IN FAREBOX DATABASE TO RECONCILE WITH TIMEKEEPING SYSTEM

Passenger Counting System Electronic Registering Farebox 01/08/96 Through 01/12/96 with Auto Update Status

								NUM	NUM	RUN OPERATOR PAID FOR						
DATE	SERVICE	DRIVER	RTE	BLK	RUN	BUS		TRIPS	BOARD	RTE	BLK	RUN	RTE	BLK	RUN	
01/08/96	WEEKDAY	11111 Driver, B A	82	381	47	3309		2	89	82	381	46				RUN 2
01/09/96	WEEKDAY	11111 Driver, B A	82	301	46	3309		1	51	82	381	46				RUN 1
01/10/96	WEEKDAY	11111 Driver, B A	82	301	47	3308		2	93	82	381	46				
01/11/96	WEEKDAY	11111 Driver, B A	82	46	381	3307		2	96	82	381	46				
01/12/96	WEEKDAY	11111 Driver, B A	82	381	82	3309		2	84	82	381	46				
01/11/96	WEEKDAY	22222 Dent, Ax C	82	320	02	3125		1	215	320	581	02				
01/11/96	WEEKDAY	33333 Wreck, T	82	204	02	3125		1	215	02	382	04				
				Total For Route				11	843							
01/08/96	WEEKDAY	17330 Archer, J B	228	323	228	1488		2	70	228	323	13				
01/09/96	WEEKDAY	17330 Archer, J B	228	323	228	1488		2	65	228	323	13				
01/10/96	WEEKDAY	17330 Archer, J B	228	323	228	1488		2	60	228	323	13				
				Total For Route				6	195							
01/09/96	WEEKDAY	00000	46	523	25	1488		2	65	246	823	25				
01/10/96	WEEKDAY	00000	46	523	25	1488		2	65	246	823	25				

Source: Houston METRO.

farebox counts by fare category serves as an adjustment factor. The typical level of undercount is from 3 to 7 percent overall, with noncash fare categories (e.g., children who ride free) having far greater levels of undercount than simple cash and pass categories.

Data Systems

Manufacturers of electronic fareboxes supply PC-based data systems. Historically, these systems have been proprietary and are not easily modified. They include standard reports for passenger counts and are used, with satisfaction, by many smaller agencies. However, larger agencies usually desire additional features, such as enhanced screening and editing capability. Agencies also want reports that combine farebox counts with other data sources, for example, to calculate performance ratios. For this reason, the survey (which covered only medium-sized and large systems) found that all but 1 of the 12 agencies that regularly use farebox counts extract ridership data from the manufacturer's data system into another data system. Some agencies report that considerable effort was needed to develop programs for extracting data from the manufacturer's system. The agency that does not extract data, one of the two respondents with Cubic fareboxes, was able to make its own modifications to the manufacturer's software.

Some agencies extract farebox counts into more than one data system, typically a database for general purposes and a spreadsheet for some specific analyses. Allowing for multiple responses, the data systems used for analyzing the farebox counts by the responding agencies that regularly use their farebox counts were as follows (numbers in parentheses indicate the number of agencies using that type of system):

- spreadsheet (7)
- general purpose database (4)
- custom developed database (2)
- general purpose statistical analysis package (2).

Several agencies were in the process of shifting to a new database. Overall, the trend is toward PC-based general purpose databases that can combine data from many sources.

AUTOMATIC PASSENGER COUNTS

APCs use pressure-sensitive mats, active and passive infrared sensors, and optical imaging to detect passenger boardings and alightings. They include a method of determining stop location, ranging from advanced AVL to dead reckoning (relying on odometer readings to ascertain location, based on a reference location and an assumed path). Data are stored on-board and uploaded at the garage.

Because they track vehicle location, APC data are often used for analyzing running time and punctuality as well as passenger activity. Depending on hardware and software characteristics, an APC system can have most or all of the features of a trip time analyzer (discussed later in this chapter).

TABLE 3
FAREBOX COUNT ADJUSTMENT FACTORS FOR UNDERCOUNT AND FOR SAMPLED WEEK REVENUE

MONTHLY ADJUSTMENT FACTORS

RUN OMISSION ADJUSTMENT FACTOR – WEEKDAY – BY MONTH

Route specific by month.

LOCAL & EXPRESS ACCURACY ADJUSTMENT FACTOR – WEEKDAY – BY MONTH

	FY90	FY91	FY92	FY93	FY94	FY95	FY96	AVG
OCT	1.0183	1.0198	1.0164	1.0166	1.0245	1.0448	1.0583	1.0284
NOV	1.0131	1.0225	1.0155	1.0166	1.0291	1.0416	1.0575	1.0280
DEC	1.0169	1.0217	1.0131	1.0166	1.0286	1.0435	1.0587	1.0284
JAN	1.0129	1.0213	1.0137	1.0175	1.0328	1.0492	1.0611	1.0298
FEB	1.0108	1.0252	1.0060	1.0236	1.0347	1.0446		1.0242
MAR	1.0105	1.0222	1.0002	1.0314	1.0375	1.0585		1.0267
APR	1.0130	1.0218	1.0002	1.0317	1.0416	1.0560		1.0274
MAY	1.0167	1.0211	1.0033	1.0309	1.0414	1.0410		1.0257
JUN	1.0177	1.0202	1.0080	1.0289	1.0486	1.0550		1.0297
JUL	1.0203	1.0214	1.0106	1.0249	1.0498	1.0526		1.0299
AUG	1.0215	1.0161	1.0147	1.0245	1.0410	1.0653		1.0305
SEP	1.0221	1.0186	1.0166	1.0242	1.0409	1.0558		1.0297
AVG	1.0162	1.0210	1.0099	1.0240	1.0375	1.0507	1.0589	1.0282
DIFF		0.0048	(0.0111)	0.0141	0.0136	0.0131	0.0082	

REVENUE ADJUSTMENT FACTOR – WEEKDAY – BY MONTH

	FY90	FY91	FY92	FY93	FY94	FY95	FY96	AVG
OCT	0.9786	0.9886	0.9875	0.9890	0.9723	0.9353	1.0057	0.9796
NOV	0.9877	0.9913	1.0017	0.9276	0.9883	0.9454	0.9696	0.9731
DEC	0.9029	0.9205	0.8910	0.9152	0.8955	0.9247	0.8984	0.9069
JAN	1.0015	1.0192	1.0096	0.9942	0.9957	0.9992	1.0271	1.0066
FEB	0.9776	0.9633	1.0088	0.9645	0.9975	1.0036		0.9859
MAR	0.9763	0.9613	1.0019	0.9601	0.9566	1.0073		0.9773
APR	1.0226	0.9484	0.9523	0.9820	0.9954	0.9957		0.9827
MAY	1.0061	0.9967	0.9781	0.9682	0.9656	0.9927		0.9846
JUN	0.9866	0.9814	1.0019	1.0004	0.9787	0.9952		0.9907
JUL	0.9737	0.9820	0.9840	0.9776	0.9820	0.9909		0.9817
AUG	1.0118	1.0261	1.0102	1.0034	1.0067	1.0222		1.0134
SEP	0.9844	0.9775	0.9941	0.9901	0.9890	0.9950		0.9884
AVG	0.9842	0.9797	0.9851	0.9727	0.9769	0.9839	0.9752	0.9809
DIFF		(0.0045)	0.0054	(0.0124)	0.0042	0.0070	(0.0087)	

Source: Houston Metro:

Only three agencies responding to this study's questionnaire have used APCs on more than a short-term basis. Two others are beginning to install APCs. However, there were several other agencies using APCs that responded to the Synthesis 29 questionnaire whose responses were reviewed as part of this study.

Measurement Error

APC data are subject to five kinds of errors: (1) general hardware malfunction, (2) miscounting passengers, (3) failing to identify the correct stop, (4) incorrect data segmentation (start of new trip), and (5) incorrect sign-on (route, driver) information. Because of hardware malfunctions and location problems, responding agencies report discarding 10 to 50 percent of the data, with newer systems having generally better performance. The location accuracy of the newer systems is also better.

In a 1991 study of the APC system of the Tri-County Metropolitan Transportation District (Tri-Met, Portland, Oreg.), it was reported that data from only 26 percent of the APC assignments were recovered *(16).* More than one-half of the loss was due to equipment malfunctions. Stoplevel counting accuracy was found to be quite high, with the overall deviation being statistically insignificant, and relatively small tendencies on individual buses to undercount and overcount.

APC counts are generally claimed to be accurate enough for decision making at the route level. Normally, with passenger counts there is a built-in check that is usually part of the screening process, namely, whether boardings and alightings are equal over each trip; it can also be checked that passenger load never goes below zero. Two responding agencies indicated a systematic undercount of about 5 percent overall, with miscounts rarely exceeding two passengers at a stop. Analysts at agencies with established APC programs generally trust the data for route-level analyses. Nevertheless, no known agency except Tri-Met uses APCs as the primary source for determining system-level ridership.

The trend toward low floor buses, which have entries wide enough for several passengers, no stepwells, minimum clearance underneath, and (often) foldout ramps for wheelchairs poses a serious challenge to APC design. It is impossible to use pressure-sensitive mats on some low floor bus designs; optical methods are not impossible, but more difficult.

Controlling measurement error demands rigorous maintenance of the APC equipment. For example, at Ottawa's OC (Ottawa-Carleton) Transpo, each bus is tested every month, and light beams are realigned if necessary. Seattle Metro also does regular ride checks to verify APC accuracy. One agency stated that APC equipment does not compete well for priority with the vehicle maintenance staff; not coincidentally, this agency also reports the greatest percentage of discarded data.

Screening is critical so that only good data are passed on for further analysis. Manual screening is labor intensive. Some errors can be detected automatically, including hardware malfunction, large discrepancies between boardings and alightings, and location inconsistent with route. Others are less easy to detect automatically. For example, one agency cites a common problem near terminals, when an operator may change the headsign before passengers alight at the final stop. The APC system, which is tied to the headsign, will then allocate those alightings to the wrong trip. At least one agency that now performs daily manual checks of its APC data is developing a new system that will automate a good deal of the screening. Manual screening and editing is still common for dealing with stop matching errors. Data users also learn to watch for stop matching errors.

Sampling by Rotating Equipped Vehicles

At all responding systems with long-term APC use, only a small fraction of the bus fleet, ranging from 5 to 12 percent, is equipped with APCs. The equipped buses are generally rotated around the schedule so that every scheduled trip is covered. Accounting for typical amounts of bad data and a certain amount of sampling inefficiency, this level of fleet coverage will allow each weekday run to be sampled about 5 to 15 times each year. For instance, Seattle Metro estimates that most of its trips are sampled nine times each year (three times each schedule period, with three schedule periods per year). That is generally considered sufficient for ridership analysis, especially if trips are aggregated by period. For running time and schedule adherence this is a small sample size for trip-level analysis, although certainly far better than relying on a single ride check. However, it is an adequate sample size for analysis at the route/direction/period level, a more natural level for many running time and punctuality related decisions.

Getting the equipped buses onto the runs for which data are needed requires cooperation of managers at the garage level, who often have higher priorities for deciding on equipment assignment. One agency notes that as none of the APC equipped buses has a wheelchair lift, they cannot get APC data on trips that are advertised to be lift-equipped. Tri-Met developed a statistical sampling plan for rotating its APCs that accounts for its high percentage of lost data *(16).* It relies on poststratification to ensure that the system-wide estimates are not biased by data recovery rates that vary systematically over different types of routes.

Data Systems

Software for processing raw APC data is always acquired or developed when the hardware is procured. It reduces the raw APC detections to counts in a format similar to ride checks, which are stored in a database for route analysis. Seattle Metro developed their database in-house, using a standard database program, first on a mainframe and later on PCs. OC Transpo and Calgary Transit each had a third party develop a database; both are in the process of converting (using the third party software contractor) to a general database program on a PC with improved screening and reporting capability.

The Seattle system maintains 10 years of data; Calgary maintains 1 year of data; OC Transpo keeps only recent data in active storage, while retaining archived data on CDs.

VEHICLE LOCATION DATA

There are three kinds of automated data collection systems that include the capability of detecting a vehicle's time at locations of interest, making them possible data sources for measuring running time and punctuality. They use a variety of technologies for locating a bus, including lowpower infrared beacons, communication with induction loops, satellite-based global positioning, and dead reckoning. Two types of systems—APCs and trip time analyzers—are based upon on-board computers; whereas the third type, AVLs, is based on a radio communication to a central computer.

Automatic Passenger Counters

In addition to counting passengers, APCs record time of arrival and departure from stops, and thus provide a valuable source of data for running time and punctuality analysis. Measurement errors in location detection are less frequent than errors in passenger counting. However, without careful system design and monitoring, there can still be a good deal of uncertainty in the location-time data. For example, if a bus waits at the start of a route for a few minutes before beginning its trip, the time at which the trip finally begins may not be recorded if the doors don't open just before departure; therefore, the apparent running time will include a layover of undetermined length. Analysts that regularly use APC data learn to watch for that kind of error; however, reliance on human screening of this sort makes further automated analysis difficult.

As mentioned earlier, APCs are usually installed in a small fraction of the fleet and are rotated around the schedule. A typical sample size is one observation of each weekday trip per month.

Trip Time Analyzers

Trip time analyzers, which are common in Europe but not in North America, have on-board computers recording events such as passing a loop or beacon, stopping or starting, and opening and closing doors. Software then reduces the event data to trip time components such as dwell time, delay time (time spent stopped or running very slowly with the doors closed), and in-motion time. By making comparisons with the schedule and with neighboring trips, they also report on schedule and headway deviation. Strictly speaking, the hardware and software for recording events on-board is a separate entity (an event recorder) from the trip time analysis software (the trip time analyzer), although in practice they are often designed as a single system.

APC systems are often designed to include most of the features of trip time analyzers. Because analyzing trip time is their express purpose, trip time analyzers tend to have fewer location measurement problems than do APCs. Moreover, in trip time analyzer applications it is customary to equip the entire fleet, making sampling unnecessary. The enormous sample sizes that result give planners and schedule makers a reliable data source for analyzing running time and punctuality, for example, to determine how performance changes with changes in schedule, operations control measures, or traffic engineering features.

Automatic Vehicle Location Systems

AVLs are usually designed primarily to supply real-time location and schedule deviation information at a control center for operational control and security. The central computer polls each bus in turn, usually at intervals of 60 to 120 sec, whereupon they respond with a message containing location information (e.g., global positioning system coordinates or the number of odometer pulses since the last poll) and other critical information, such as the status of mechanical and security alarms. Because of the need for many buses to share the same radio channel, the polling frequency and message size are quite limited, although capacity improves every year with advances in telecommunication.

AVL systems can include on-board computers that store event data, in which case they can serve as trip time analyzers. Most North American systems, however, do not involve on-board data storage. Any off-line analysis must be done using information received by the central computer, which has far less detail than could be recorded onvehicle. Moreover, data transmission can be systematically unreliable in certain locations, such as downtown canyons caused by tall buildings (a rather critical location), causing critical data gaps.

Ironically, data accuracy required for on-line vehicle monitoring, and obtained by most AVL systems, is far less stringent than the accuracy demanded by trip time analyzers, even though AVL is considered a more "advanced" technology. When AVL systems speak of accuracy, they refer to accuracy at the moment the vehicle is polled. That accuracy may be very good, but without an event recorder location between polls is uncertain. AVL can be characterized as a system that strives to accurately determine location at a given time. However, for running time and schedule adherence analysis, what's needed is time at given locations (timepoints). Under typical center city conditions with a 90-sec polling cycle, the error range for the time at which a given point is passed has been found to be 58 sec, assuming perfect location accuracy at the polling moment *(25)*. Furthermore, detailed trip time analysis requires both location and time at which specific events occur, such as when speed drops below or rises above 5 km/hr. Obviously, if one is relying only on polling data received at a central computer, this kind of detail is unachievable.

The error range in time at a location varies proportionally with the polling cycle. As a survey of British experience with AVL reveals *(26),* no common AVL objective demands polling more frequent than every 60 sec except for giving priority at traffic signals, for which polling is every 20 sec, and more frequently as buses approach an intersection. Giving priority at an intersection is an example in which the time at which the vehicle reaches a certain location, rather than location at a given time, is critical.

The size of the time errors inherent in estimates made from AVL data received at the central computer—usually 2 minutes or less—does not preclude some running time and schedule adherence analysis. At least one example of off-line analysis using AVL data has been reported *(2).* In many AVL systems, however, the central computer is not programmed to store the data for off-line analysis. Indeed, off-line analysis is often not part of AVL system objectives. For example, in a recent study of AVL system designs for Las Vegas, off-line analysis is not mentioned as an objective *(27).*

In addition, the modifications necessary for this capability are not trivial. A 1991 study found that few North American agencies with AVL were using it for planning and management information, and that success in adding a data storage feature to existing AVL systems was limited *(28).* This leads to the ironic situation in several agencies of having the entire fleet equipped with AVL, yet relying on manual checks to measure running time and on-time performance. One responding agency's AVL system produces a monthly report on overall schedule adherence, but it was not designed to store the data in a way that makes it accessible for any other desired analysis.

Of the 20 responding agencies, 8 have AVL on 75 percent or more of their fleet, and 3 have AVL on a small fraction of the fleet (some of these are trial installations). One of these latter agencies is Calgary Transit, whose AVL system is essentially an extension of the APC system, with a full set of location data being stored on-vehicle and limited location data sent by radio to the control center. Apart from Calgary Transit, only three other responding agencies use AVL as a data source for off-line analysis of running time and schedule adherence.

Data Systems

Data systems for APCs have previously been discussed. Data systems for AVL are usually custom built, with vastly different ways (if any) of enabling off-line analysis. Milwaukee Transit Service's AVL system stores only exception data, retaining them for 60 days. Analysts can request a download into an Oracle database, from which standard reports on running time and schedule adherence can be run. At Dallas Area Rapid Transit, data are stored for 6 months.

Trip time analyzers used in Europe generally come with a proprietary data system that screens and reduces the raw data, then stores location-time-event information in a database that is capable of producing a number of useful reports. The trip time analysis software is usually supplied by the vendor of the on-board event-recording computer. However, some new software packages for trip time analysis, described in the next chapter, are independent of the data collection device. Because off-line analysis is the main purpose of their design, their databases are generally designed to keep many years' worth of data.

MANUALLY COLLECTED DATA

Manually collected data includes data from operator trip cards, dedicated traffic checkers, and supervisors. Except for operator trip cards, manually collected data naturally involves small samples and therefore present less of a database management problem. Data processing systems for manual data tend to be more informal and homegrown than those used with APC, AVL, and farebox systems, because there is no associated hardware vendor to supply a data system along with the data collection device. An exception to this rule is hand-held devices, which usually come with a data system. Finally, there is a recent trend for software scheduling packages, which are treated by transit agencies as a major capital expenditure, to include database capability options for manually collected data as a way of enhancing the value of their product.

Operator Trip Cards

Operator trip cards are counts made by bus operators of boarding passengers on each trip. They have been largely phased out as agencies have installed electronic registering fareboxes. Of the responding agencies, two (one without electronic fareboxes and one with outdated electronic fareboxes) have operators make counts on a sample of 24 and 4 days a year, respectively. At these two agencies, the operator counts are the main sources of route-level ridership. Two other responding agencies have one or a small set of routes for which, because of some special funding arrangement, operator trip cards are collected every day.

The accuracy of operator trip cards varies widely among agencies. The main problem, of course, is motivating the operators to take the counting seriously. Calgary Transit, which relies on its sample of 24 days a year, checks operator counts regularly against APC counts and finds them very accurate. Another agency describes their regular operator counts as "not excellent, but helpful." Still another agency expressed the opinion that the operator counts were 85 percent accurate.

The four responding agencies that employ operator trip cards use simple PC-based data systems—two use a commercial database package, one a spreadsheet, and one a statistical package. One system stores historical data without any limit, another keeps data for 3 years, and another keeps data on-line for 9 months and then archives it.

Traffic Checker Data

Data collected by traffic checkers is heavily used for analyzing both ridership and operations. All of the responding agencies except Ottawa's OC Transpo and Seattle Metro rely on manual checks as part of their normal data collection program. The three major data collection activities of traffic checkers are ride checks (an on-board checker records boardings, alightings, and time by stop), point checks (a stationary checker records time, load, and sometimes boardings and alightings for all passing vehicles), and fare checks (an on-board checker records fare category for each boarding passenger by stop). Data collection activities of supervisors, primarily checks on schedule adherence, are also included in this section. Pencil and paper is the most common means of recording; however, hand-held devices are increasing in use.

TCRP Synthesis 29 *(1)* gives an extensive analysis of manual passenger counting procedures, with special attention to the degree to which agencies are substituting automated methods for manual checks. That report found that whereas nearly everyone finds the idea of automating data collection appealing, and some "pioneering" agencies had successfully transitioned to automatic data collection, the costs and risks involved in automated systems are still a major obstacle. The pace of transition, however, appears to be increasing, spurred on by suppliers offering their products for trials at several agencies at little or no cost in hopes of persuading more buyers of their worth. Nevertheless, it appears that manual data collection will remain an important data source for several years to come.

Point Check Measurement Error

Measurement error of data collected by checkers on board is considered minimal. Small counting errors during ride checks often mean that boarding and alighting totals per trip do not exactly match and corrections must be made, but these errors are not usually large enough to materially affect estimation accuracy. Some agencies require their checkers to correct apparent errors. This practice improves quality by giving checkers feedback on their performance; furthermore, the checkers are usually in the best position to discern what the error was. Hand-held devices further reduce ride check error, because they typically calculate load en route, giving the checker an immediate opportunity to review counts between stops and alerting the checker to infeasible loads (i.e., negative or nonzero loads at trip end), and allowing for corrections, if necessary.

In fare surveys, checkers sometimes have difficulty determining a passenger's fare category. However, the level of error is usually small and can be minimized if the operator cooperates with the checker.

With point checks, however, making accurate load measurements from outside a vehicle can be difficult, especially if the bus has tinted windows. Observing the load on a "wrapped" bus—one painted with exterior advertising covering the windows—is simply impossible from the wayside. Nevertheless, all of the responding systems that do point checks conduct them from outside the vehicle, because going inside the vehicle would interfere with operations. Among the 10 responding agencies that use point checks as a source for peak load data, only 3 offered estimates of their measurement accuracy. These three agencies were also the only ones that reported having a regular program of checking and improving the point check accuracy. (Several other agencies reported that supervisors check on the accuracy of load measurements, but did not describe how.) Two of the agencies indicated that the error is normally (85 percent of the time) within 10 percent of the true value; another indicated an error range of 5 percent. One agency indicated a systematic undercount of 1 percent. This range of errors is generally considered acceptable for most scheduling and service monitoring decisions. Considering that decisions must usually be based on a sample of only one or a few days and that the sampling error is probably at least as great as the measurement error, further improvements in measurement accuracy would be of little benefit, unless sample size were increased significantly.

Unpublished statistical studies comparing point checks with ride checks at two agencies showed a mixed picture of accuracy in load estimates from wayside traffic checkers. Both studies found that measurement errors displayed a systematic overcount (bias) as well as random errors. Both studies found diminished accuracy when loads were greater, which, unfortunately, is when the load measurements are most important. The first study determined that when a load was above 35 passengers, the systematic overcount was 9 percent and the random error was 10 percent. This would imply that when the true load is 50 passengers, most observations would range from 49 to 59. The other study found that when loads were over 40 passengers, there was a systematic overcount of 9 passengers, with a further random variation of, on average, 10 passengers. This would imply that when the true load is

50 passengers, most observations would range from 49 to 69. The error range found in the first study doesn't look so bad, but the bias and error range found in the second study is clearly greater than would be tolerated by most analysts in making scheduling or service monitoring decisions.

Clearly, one of the keys to accurate wayside load measurements is giving checkers regular feedback on their accuracy. The Toronto Transit Commission's (TTC) program for maintaining the accuracy of point checks involves tests conducted every 2 years. Passenger load is counted on board before buses leave a busy station, and then checkers estimate the load from the street outside the station. Results are sent to the checkers, and those in the bottom third in accuracy are retrained by senior checkers and retested. Two other agencies regularly perform ride checks simultaneously with point checks as a way of testing and improving point check accuracy.

Sampling Error

Because of the high cost of manual data collection, sample sizes are generally smaller than with automated data collection systems, making estimates vulnerable to sampling error. Sampling error affects both operations data (running time and punctuality) and ridership data. The amount of sampling error depends on inherent variability, sample size, and sampling method.

For route-level analyses of ridership and operations, many agencies rely on a single day's observations. It is usually impossible to evaluate the statistical precision of a load, running time, or schedule adherence measurement based on a single day's observations. One can only report what was observed on a certain day, whereas scheduling and other decisions are based on the analyst's subjective evaluation of average conditions. To help the analyst make that subjective evaluation, traffic checkers are usually instructed to report unusual traffic or weather conditions. Analysts will often compare the day's observations with a previous year's counts and with other corroborating data, such as operator or passenger complaints. Reports that indicate ridership and operations measures together are useful in this regard, because, for example, unusual passenger loads can sometimes be explained by lateness. Of course, unusual lateness can be caused by high passenger loads; separating the cause from the effect is a challenge when data are limited.

For quantities estimated at the system level, manual data collection usually affords the opportunity to determine a large enough sample size to control sampling error. Scientific sampling methods are often used for systemwide ridership and passenger-miles estimation (see chapter 4). One of the responding agencies, Tacoma's Pierce Transit, uses a scientific sampling approach for estimating system-wide on-time performance, as described in chapter 5.

Data Systems

Data systems used for data collected using hand-held devices tend to be more formal and better developed than those for which the manually collected data are keyed in. Software for analyzing data from standard data collection activities (ride check, point check) is usually developed as part of the process of acquiring the hand-held devices. Three responding agencies are using reporting software provided by the vendor of the devices, another agency had a third party develop the software, and two agencies had the software developed by their respective information technology departments. Two agencies are still using mainframe computers for processing their hand-held device data, but both are converting to PCs and commercial database programs. In nearly every case, these systems provide standard reports; some also offer general analysis and query capability, either directly from the database or after downloading to a general purpose database. The number of years for which data are kept in the system was four, two, and one for the three agencies (Greater Cleveland RTA, Dallas Area Rapid Transit, and LYNX of Orlando, respectively) that answered this question. One system is not designed for data storage; the data are processed from floppy disks.

At agencies where traffic checker data are keyed in, data systems tend to be less formal. One responding agency has a customized reporting program on a mainframe. The remaining agencies are using spreadsheets and commercial database software on PCs. Data are kept online for no more than 1 year at most agencies (historical data are archived). Two agencies keep data for 2 years, and one responded "six years, but is it worth it?," reflecting the view that there is little use for outdated ride checks.

At many agencies, the analysis software used with manually collected data is simply a program that analyzes a limited set of data immediately after it is collected. Data management, that is, storage and organization, is done informally using floppy disks and similar devices. At other agencies, software is more developed, with facilities for organizing and managing data and performing user-requested information searches.

CHAPTER FOUR

ESTIMATING SYSTEM-LEVEL RIDERSHIP AND PASSENGER MILES

Every transit agency tracks system ridership. Based on survey results, most U.S. agencies use boardings (unlinked trips) as the primary measure of system ridership, whereas most Canadian systems use revenue passengers (linked trips) as the primary measure.

Accuracy levels of ridership estimates can be mandated from external reporting requirements and from internal management needs. The FTA's NTD (formerly called Section 15) reporting requirements mandate that all agencies receiving formula assistance (this includes nearly all U.S. transit agencies) have a precision of ±10 percent at the 95 percent confidence level in their annual system-level estimates of both boardings and passenger miles. The level of accuracy desired for internal management purposes is normally a good deal more stringent. For example, Los Angeles County Metro estimates its ridership from boardings counts, with a sample size sufficient to ensure a precision for the quarterly system-wide boardings estimate of ±3 percent. This leads to a precision of ±1.5 percent in the annual estimate (the 95 percent confidence level applies in both cases). However, it appears that few agencies formally establish an accuracy target and statistically evaluate their ridership estimates. Only two of the responding agencies reported that their ridership estimation procedure is designed to meet a particular accuracy target, and only one agency cited a specific accuracy target, which is ±5 percent at the 95 percent confidence level.

The FTA requires system-wide estimates of passenger miles from most U.S. systems; however, few agencies use this measure for any other purpose. Of the agencies surveyed, none of them appear to track passenger miles at the system level except for NTD reporting. However, APC and ride check reports in three responding agencies include passenger miles at the route level.

In general, the responding agencies use one of three approaches to estimate system ridership: daily counts, sampling with revenue-based estimation, and sampling with direct expansion. The last two approaches can also be used to estimate passenger miles (daily ridership counts cannot be used to determine passenger miles unless an agency's entire fleet is equipped with APCs). Another approach to determining passenger miles is to estimate average passenger trip length from a sample and expand this figure by the number of annual boardings.

ESTIMATING RIDERSHIP BY DIRECT COUNT

Some transit agencies count every passenger. Most commonly, the count is made using electronic fareboxes, in which the majority of the passengers are registered automatically as they pay their fare, and the remainder are registered manually by the operator. As mentioned earlier, farebox counts are accurate enough at some agencies to be used as a basis for determining ridership. There are also some agencies, usually smaller ones, in which operators count every passenger manually, reporting the result every day on trip cards.

Experience indicates that operator errors in registering passengers, while small, usually have a systematic downward bias. Adjustment methods for undercount have already been discussed. Small adjustments are also needed to account for trips with missing data.

REVENUE-BASED ESTIMATION METHODS

At agencies that do not have daily passenger counts, revenue is the most common basis of ridership estimation. Finance and accounting functions require that revenue be counted precisely throughout the year, making it a valuable source of information on system usage. Of the 20 responding agencies, 7, including all 4 responding Canadian agencies, use revenue as their primary source for tracking system ridership. Because revenue is more closely associated with linked trips ("revenue passengers") than unlinked, most of the agencies making revenuebased estimates use linked trips as their primary measure of ridership.

The main drawback to using revenue as an estimation method is that with differing fares and unlimited use passes the relationship between revenue and passenger trips (linked or unlinked) can be weak, and must be estimated using surveys. The correlation between revenue and passenger miles is weaker still. Another disadvantage is that most agencies are not able to count revenue by route (Winnipeg Transit was the only exception among the responding agencies), so that ridership counts are still needed for route-level ridership estimation. Of course, electronic farebox systems can tally revenue by route as it is received, but because they also count boardings by route, they leave no need to estimate boardings from revenue.

Revenue-based estimation methods can be divided into two approaches: those based only on farebox revenue and those that use both farebox revenue and transit pass sales revenue. Farebox revenue is defined to include tickets at their cash value. Passenger-miles estimates are made using farebox revenue only.

Estimation from Farebox Revenue Only

Estimating boardings from farebox revenue requires a conversion factor equal to the ratio of farebox revenue to boardings, sometimes called average farebox deposit. This factor can be estimated from ride check data, provided the farebox revenue register is read at the beginning and end of each checked trip. Similarly, passenger miles can be estimated from farebox revenue using the ratio of passenger miles to revenue obtained from a ride check sample that includes revenue measurements. FTA Circular 2710.4 *(11)* describes such a sampling procedure.

Boardings (but not passenger miles) can also be estimated from revenue using fare survey data (recording the fare category of each entering passenger). Because the fare survey yields greater detail for revenue planning, it is the more commonly used method.

Some agencies do fare surveys continuously, or at least once a year over a concentrated period, and calculate the conversion factor afresh each year. Others rely on fare surveys done once every few years and after fare changes, assuming that the fare mix (i.e., the share of passengers paying each type of cash fare) remains stable between surveys.

Estimating Pass Boardings

The second approach to revenue-based estimation is to use farebox revenue as a basis for estimating passengers paying by cash, ticket, or token ("cash boardings"), and to use pass sales as a basis for estimating pass ridership. Estimating cash boardings from farebox revenue is essentially the same as estimating total boardings from cash revenue. However, the ratio must be estimated from a fare survey (i.e., a simple ride check is not sufficient), because the data must distinguish between cash and noncash paying passengers.

The most straightforward approach to estimating pass use from pass sales is to estimate the number of trips per day made by passholders from a survey of passholders. However, this surveying process can be expensive. One responding agency that follows this approach surveys pass users every few years and assumes that the usage rate is stable between surveys.

The other responding agency that estimates trips made by pass users separately from cash passengers bases their pass use estimate primarily on farebox revenue, with minor adjustments that account for pass sales data.

DIRECT EXPANSION FROM A SAMPLE

Some agencies that do not have daily passenger counts estimate ridership by direct expansion from a ride check sample. The same method is often used for estimating passenger miles. Three sampling approaches are used: (1) a random sample, (2) a concentrated sample, and (3) the "100 percent ride check."

Random Sampling

With random sampling, the sample of trips is checked over the entire year with random selection and a sample size chosen to meet the statistical accuracy target. FTA Circular 2710.1A *(10)* describes a sampling plan of this type that will satisfy NTD accuracy requirements for both boardings and passenger miles. It requires 549 randomly selected trips if sampling is conducted every other day, and more trips if sampling is conducted with a different frequency. This method is used by a fair number of U.S. transit systems, including 5 of the 16 responding U.S. agencies. However, in every known case, ridership estimates made using this method are used only for NTD reporting—different estimation methods are used for internal management and for reporting to oversight boards. The NTD method is not used for other purposes because its margin of error (±10 percent for the annual estimate) is too wide, and simply increasing the sample size to improve accuracy is too expensive. On the other hand, the ridership estimation methods used for internal management are not used for NTD reporting because they cannot be certified (or at least they have not yet been certified) as satisfying NTD statistical requirements, or because the Circular 2710.1A method had to be used anyway for estimating passenger miles (*10*).

Some agencies, including 6 of the 16 responding U.S. agencies, have developed their own sampling plans to estimate annual boardings and passenger miles. In most cases these plans are designed to meet NTD requirements using more efficient sampling techniques than simple random sampling. These sampling techniques include stratified sampling and cluster sampling, in which a group of trips such as one-half of an operator's daily duty is sampled as a unit *(14, 16).* In some cases, the customized sampling plan is designed to meet internal reporting needs as well, in which case its specified accuracy is usually stricter than the NTD requirements.

Concentrated Sample

Several agencies estimate ridership from daily counts made during a few weeks in a given year. The counts are usually made by operators, who may be paid extra for the effort. Sometimes a single typical period of 1 or 2 weeks is selected; sometimes a typical week in each quarter is checked. The ridership estimate resulting from this method does not purport to be the annual average, because the typical week does not usually include the effects of holidays, summer vacation, or winter weather. By tracking the same typical week each year, however, management can see the trend in ridership.

The "100 Percent Ride Check"

A 100 percent ride check or "100 percent sample" is generally taken to mean a ride check that includes one day's observation of every trip in the daily schedule. Despite its name, the 100 percent ride check is still a sample. Because every scheduled trip is observed, between-trip variation introduces no estimation error; however, between-day variation remains as a source of estimation (sampling) error.

Ride checking the entire schedule once each year is a data collection program followed by a large number of transit agencies, including five of the responding agencies (not counting those with APCs, which effectively do a 100 percent ride check several times each year). The primary purpose of the data is for route-level planning and scheduling rather than system-level monitoring. Because route planners and schedulers want to base decisions on data from a typical day, ride checkers often try to avoid periods with atypical ridership patterns such as the Christmas season, summer, and days with severe weather. This conflicts with the need, for NTD reporting, to know average daily boardings. To make the data useful for NTD boardings estimates, either some adjustment must be made to convert typical results to average results or the data must be combined in some way with data collected (but perhaps not used for route planning) on atypical days.

ESTIMATING PASSENGER MILES USING AVERAGE TRIP LENGTH

For agencies in which system-wide boardings are known from daily counts, or estimated to a high degree of accuracy (say ±5 percent or better), passenger miles can be estimated by first estimating average (passenger) trip length from a sample of ride checks and then expanding this figure by total boardings. An increasing number of agencies use this approach because of the growing ability to count boardings using electronic fareboxes. A variety of sampling techniques have been applied to estimate average trip length, including route stratification (longer routes normally have longer average trip lengths) and cluster sampling *(12, 13).* Most route stratification techniques can only be applied when boardings are known by route, underscoring the importance of correct data segmentation when counting passengers by using electronic fareboxes.

The use of concentrated samples and 100 percent ride checks as a basis for determining average trip lengths, even when the ride checks avoid atypical days, is generally justified for systems knowing annual route-level ridership, because average trip length within a route is very stable.

ESTIMATION ACCURACY

Estimation accuracy is affected by two sources of error: measurement error and sampling error. Sources that provide daily counts on all trips, even if up to 20 percent of the data are missing or discarded because of equipment or other failures, have no significant sampling error. With daily sources such as fareboxes, a vigorous screening program can be employed to discard questionable data, because it is always worth sacrificing sample size in order to control measurement error.

However, when ridership is estimated from revenue or from a sample of counts, and when passenger miles is estimated from a ride check or APC sample, accuracy is affected by sampling error as well as measurement error. Sampling error depends on the sample size and on the underlying variability. For revenue-based ridership estimation, underlying variability is determined principally by the fraction of passengers not paying a standard fare as they board, including pass users (unless pass use is registered). For passenger-miles estimation, underlying variability can be significantly reduced by stratification techniques, separating routes with long average trip length from routes with short average trip length. Stratification by route, if feasible, is a powerful method of reducing sampling error, because variation in average trip length is usually far greater between routes than within routes. If sampling is done by cluster (i.e., several trips back-to-back on the same route), cluster characteristics also influence the accuracy of the estimate. Depending on the application, a sampled cluster of, say, four trips may offer the same benefit as only one or two independently sampled trips, due to homogeneity within the cluster *(14).*

For revenue-based estimation, FTA Circular 2710.4 *(11)* specifies a sample of 208 independently selected trips to achieve a precision of ±10 percent at the 95 percent confidence level for both system-level annual boardings and passenger miles. That would imply that an 832-trip sample would achieve an accuracy of ±5 percent at the same confidence level. This result is based on data collected in the early 1980s. However, with increased pass use and recognition of the great variability between and within transit agencies, the FTA no longer stands behind the sample size of 208; agencies using this approach are required to conduct their own statistical study to determine the sample size needed to achieve a given level of accuracy. Furth and McCollom *(15)* discuss statistical experience with revenue-based sampling.

The accuracy of estimates made using a prior year's conversion factor is impossible to assess objectively. However, by tracking pass sales and other related factors one can subjectively evaluate whether the assumption of a stable fare mix is reasonable.

The accuracy of estimates made using customized sampling plans is usually determined as part of the sampling plan design. Depending on characteristics of the transit system and the availability of route-level boardings counts, customized sampling plans to estimate passenger miles for NTD reporting generally require 50 to 90 percent less sampling effort than the standard Circular 2710.1A method *(10)*. A method for small transit agencies that requires a very small sample size is described elsewhere *(12)*.

DATA SYSTEMS

In practice, spreadsheets and databases are usually used to calculate system-wide ridership and passenger-miles estimates. Often a dedicated spreadsheet or database is used to hold survey data used for NTD estimates. At some agencies with a general ride check database, the ride check system reduces each ride check to summary measures (boardings, passenger miles) needed for NTD estimation, and flags the trips that are part of the NTD sample; only those trips are used for NTD estimates, whereas the full dataset is available for other purposes. Revenue and pass sales data, if needed for expanding the sample, are usually transferred by file or by paper for each estimation period.

The more complicated the analysis, the more that is gained by using a database or statistical analysis package. If either analysts or management has identified desirable standard report formats, such a software package can automate much of the analysis and reporting process. For example, Winnipeg Transit uses SAS for Windows (Statistical Analysis Software, a commercial package) for most of its planning analyses. It is used to analyze quarterly fare survey data, employing weights drawn from point check and ride check summaries (also held in files accessible to SAS), yielding factors used in the monthly ridership estimation process. Daily revenue data and schedule summary data are likewise stored in files accessible to SAS. Ridership estimates and reports are generated with user-programmed SAS routines.

CHAPTER FIVE

OTHER ANALYSIS METHODS

This chapter describes several other types of analyses that fairly reflect the state of practice in the analysis of ridership and performance data. The first six types of analysis methods require only data from individual routes; the other methods use data from more than one route or the entire system. Sample reports are presented to illustrate the analysis methods. Analyses that are primarily financial (e.g., revenue or pass sales analyses) were purposely omitted, as were analyses primarily related to fare categories, as these analyses more often fall in the domain of the finance department than of the planning or scheduling department of a transit agency. Also excluded are analyses of facilities such as inventories and reports related to the management of the data collection program (e.g., sampling schedules).

LOAD PROFILES

Load profiles are a standard analysis tool showing passenger activity (boardings, alightings) and passenger load at each stop along a route in a single direction. They help identify locations and values of peak load, as well as underutilized route segments. Load profiles are derived from either manual ride checks or APCs.

"Load" can be either an arriving or departing load, but it is important for reports to note which definition applies. Overall, the departing load appears to be the more commonly used.

In the analysis, boardings and alightings are given by stop. Beginning with an initial load (either observed or assumed zero), the load at each stop is calculated in order by subtracting alightings and adding boardings. With some data collection methods, load is directly observed at various points, providing a check on calculated load.

One of the first requirements of analysis software is that it identify inconsistent boarding and alighting counts. Unless total boardings match total alightings, the load will not return to zero. [Or, if there is an observed final non-zero load ("left on board"), the calculated final load should match this value.] Inconsistent counts can also lead to negative loads en route. Any corrections should be done as soon as possible by the person who collected the data. As mentioned earlier, programmed hand-held devices usually track the boardings/alightings balance in real time and require immediate correction by the traffic checker. Otherwise, a person responsible for data screening will be alerted to make the (usually minor) correction.

Load profiles with different aggregations of trips serve different purposes. A load profile for a single trip is too detailed for most decision making, but can be helpful for analyzing special cases or for giving insight into trip-level variability. Aggregation over established planning and schedule periods is useful for planning and scheduling decisions. Aggregation over the entire day is helpful for planning involving route changes and for showing stop usage (e.g., in prioritizing stops for shelter installation).

When a load profile is meant to represent a period or a full day, some provision is usually needed for trips with missing data. Analysis software at many agencies will insert period-level averages for missed trips.

When dealing with routes with branches, analysis and reporting methods must recognize the branching route structure and carefully account for flow conservation at junction points.

An example load profile from Pierce Transit (Tacoma, Wash.), displayed in text with a row for each stop, is shown in Table 4. It is based on ride check data, generated with user programmed D-BASE software. It is an aggregation over the entire day, and shows values both for the set of trips observed (17 of 30 operated) and for the estimated daily total. This report includes an unexplained branching discontinuity after stop 400.

A graphical representation of a load profile, displayed alongside a route map from Sacramento Regional Transit, is shown in Figure 1. It is based on ride check data, processed in a custom database on a mainframe, and then downloaded to a Paradox database on a PC to produce the visually appealing report format. The graphical display also includes ons and offs by stop, giving the viewer a clear picture of how the load varies along the route, and of which stops have substantial or little passenger activity. Another load profile format that provides still more visual information is shown in Figure 2. Based on ride check data, it shows the load profile and stop activity graphed onto the urban grid in Winnipeg. This report comes from a software package called MADCADD, which connects transit data to a geographic information system (GIS) and to AutoCad. MADCADD is a module of the experimental

TABLE 4
LOAD PROFILE: DAILY SUMMARY BY ROUTE/DIRECTION

02/02/98 BUS ROUTE SUMMARY Page No. 1
Route 10 Direction 2 Day 1 Daily Trips Operated: 30
Pearl St - OB Trips Surveyed: 17

Stop	Street	Cross Street	Surveyed Trips On	Surveyed Trips Off	Surveyed Trips Load	Estimated Daily On	Estimated Daily Off	Estimated Daily Load	Average Load
1	ON BOARD AT	START	0	0	0	0	0	0	0.0
100	S 19TH ST	TCC TRANSIT CTR	161	0	161	284	0	284	9.5
110	MILDRED ST	LAKESIDE LANDNG	4	0	165	7	0	291	9.7
120	S 12TH ST	MILDRED ST	7	0	172	12	0	304	10.1
130	S 12TH ST	WHITMAN ST	4	2	174	7	4	307	10.2
140	S 12TH ST	5958	0	0	174	0	0	307	10.2
150	PEARL ST	S 12TH ST	3	8	169	5	14	298	9.9
160	PEARL ST	S 10TH ST	0	8	161	0	14	284	9.5
170	PEARL ST	6TH AV	17	0	178	30	0	314	10.5
180	PEARL ST	N 11TH ST	6	8	176	11	14	311	10.4
190	HIGHLANDS PKWY	PEARL ST	2	10	168	4	18	296	9.9
195	HIGHLANDS PKWY	TACOMA LUTHERAN	3	14	157	5	25	277	9.2
200	HIGHLANDS PKWY	NEWTON ST	0	0	157	0	0	277	9.2
210	HIGHLANDS PKWY	AUGUSTA PL	0	2	155	0	4	274	9.1
220	HIGHLANDS PKWY	WESTGATE BL	0	0	155	0	0	274	9.1
230	VASSAULT ST	WESTGATE BL	0	1	154	0	2	272	9.1
240	VASSAULT ST	N 24TH ST	0	5	149	0	9	263	8.8
250	VASSAULT ST	N 26TH ST	1	21	129	2	37	228	7.6
260	N 26TH ST	BRISTOL ST	0	8	121	0	14	214	7.1
270	PEARL ST	N 26TH ST	10	26	105	18	46	185	6.2
280	PEARL ST	N 30TH ST	4	18	91	7	32	161	5.4
290	PEARL ST	N 31ST ST	4	7	88	7	12	155	5.2
300	PEARL ST	N 33RD ST	0	3	85	0	5	150	5.0
310	PEARL ST	N 35TH ST	1	1	85	2	2	150	5.0
320	PEARL ST	N 37TH ST	1	23	63	2	41	111	3.7
330	PEARL ST	N 39TH ST	0	1	62	0	2	109	3.6
340	PEARL ST	N 42ND ST	0	5	57	0	9	101	3.4
350	PEARL ST	N 45TH ST	0	3	54	0	5	95	3.2
360	N 46TH ST	VISSCHER ST	0	7	47	[illegible]	12	83	2.3
370	N 46TH ST	DEFIANCE ST	0	3	44	0	5	78	2.6
380	VASSAULT ST	N 46TH ST	0	4	40	0	7	71	2.4
390	VASSAULT ST	N 49TH ST	1	6	35	2	11	62	2.1
400	VASSAULT ST	N 51ST ST	0	9	26	0	16	46	1.5
405	TOBEY JONES	TOBEY JONES	0	0	13	0	0	23	0.8
410	PARK WY	DEFIANCE ST	2	2	18	4	4	32	1.1
420	PARK WY	PEARL ST	2	5	23	4	9	41	1.4
430	PEARL ST	N 54TH ST	0	0	23	0	0	41	1.4
440	N PEARL ST	PT DEFIANCE	0	15	8	0	26	14	0.5
999	ON BOARD AT	END	0	0	0	0	0	0	0.0
TOTAL			233	225		411	397		

\ Report 2 (trips6b.prg)

Source: Pierce Transit, Takoma, Wash.

transit planning system Maditucuc, developed at Montreal's Ecole Polytechnique, which is being used under a research agreement at the transit agencies of four Canadian cities.

Some agencies construct load profiles by segment, indicating load at segment boundaries (usually timepoints) and on/off activity on each segment. An example from Seattle Metro's APC system is given in Table 5, showing a load profile for individual scheduled trips. Because the APC system allows for multiple observations of each scheduled trip (the example report shows 1 trip with 3 observations and 1 with 10 observations), this report shows average, minimum, and maximum values of ons, offs, and load. The load profiles produced by OC Transpo's APC system (not shown) include two additional statistical measures: median and standard deviation. This contrasts with load profile analyses based on single observations, for which the user simply has to trust that the observations were in some sense typical.

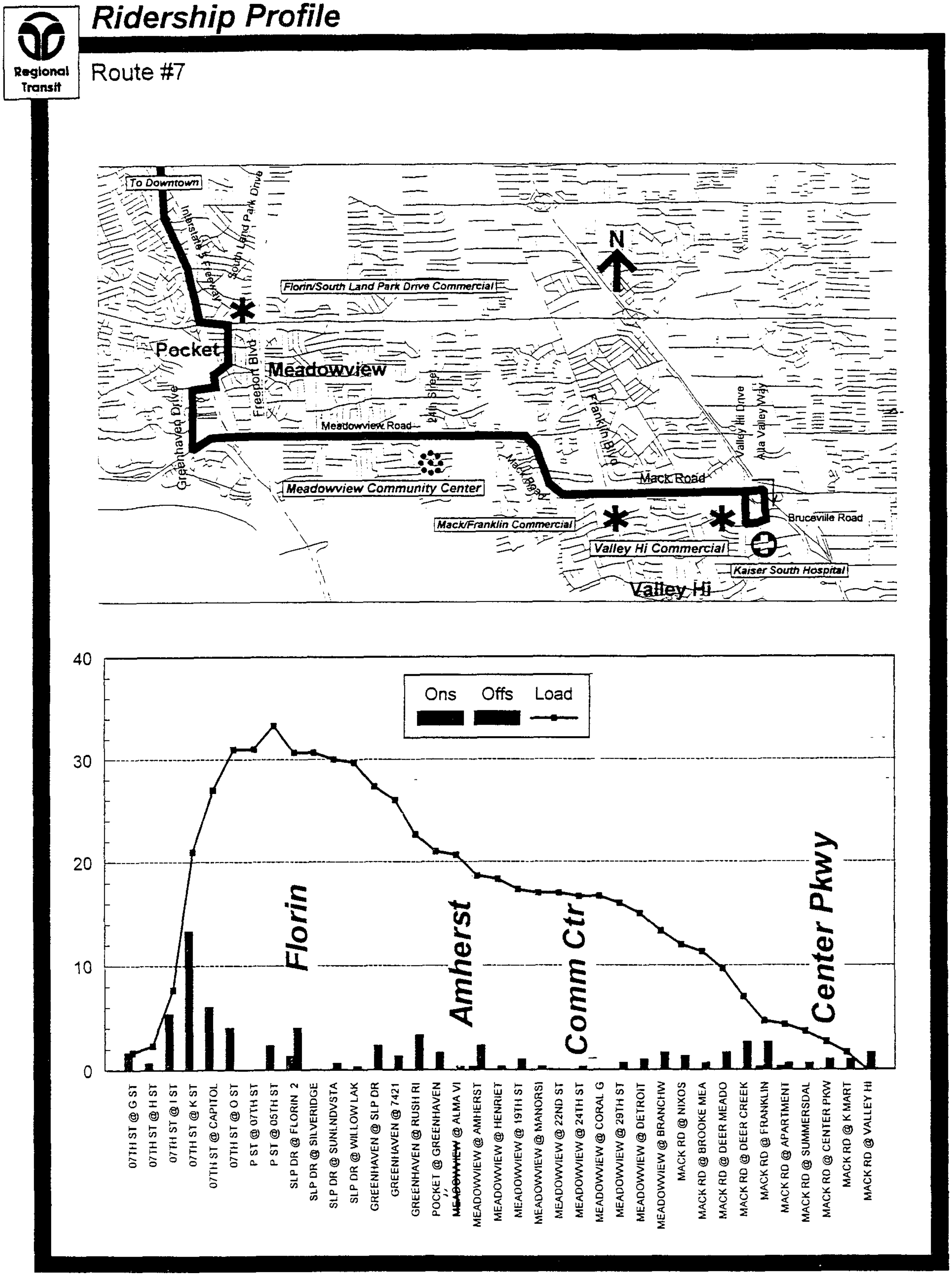


FIGURE 1 Schematic load profile (Sacramento Regional Transit).

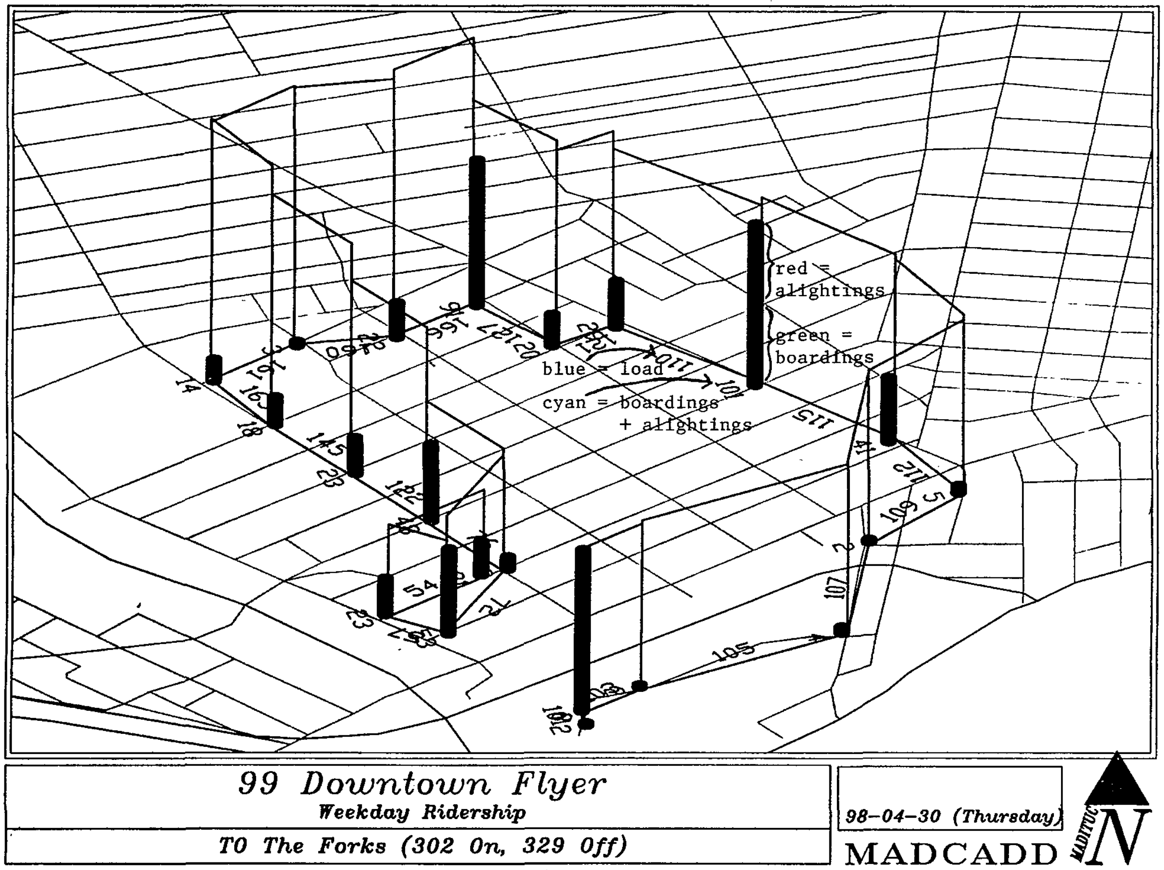


FIGURE 2 Geographic information system-produced load profile (Winnipeg Transit).

TABLE 5

SEGMENT LEVEL LOAD PROFILE: STATISTICAL SUMMARY AT THE TRIP LEVEL

Page 1
Run on 07/15/91 at 11.22.50

TIME POINT LOAD PROFILE 5 WD
BY ROUTE, BY TRIP IN CHRON ORDER
SIGNUP: FALL 90

RTE	DAY	PT	I O	TRIP SEQ#	KEY BLOCK	EX	OBS CNT	TMPT1 SCHED LEAVE	TMPT2 SCHED ARRIV	TMPT1 NAME	TMPT2 NAME	ON AVG PSGRS	ON MAX PSGRS	ON MIN PSGRS	OFF AVG PSGRS	OFF MAX PSGRS	OFF MIN PSGRS	LOAD AVG	LOAD MAX	LOAD MIN
5	WD		I	1040	509	AT	3	6:13A	6:14A	1NW NW90	GRWD87SB	2.0	3	1	.0	0	0	2.0	3	1
					509	AT	3	6:14A	6:25A	GRWD87SB	PHNYN46	24.3	29	21	1.0	2	0	25.3	29	22
					509	AT	3	6:25A	6:30A	PHNYN46	FRMTN38	13.7	14	13	2.3	3	1	36.7	40	33
					509	AT	3	6:30A	6:39A	FRMTN38	5 VIRG	6.7	7	6	7.3	9	6	42.3	45	40
					509	AT	3	6:39A	6:41A	5 VIRG	5 PINE	1.0	2	0	7.3	9	6	36.0	38	33
					509	AT	3	6:41A	6:45A	5 PINE	2 UNON	5.3	6	4	18.7	20	17	29.7	33	26
				1050	510	AT	10	6:24A	6:25A	1NW NW90	GRWD87SB	.7	1	0	.1	1	0	.6	1	0
					510	AT	10	6:25A	6:36A	GRWD87SB	PHNYN46	18.9	25	11	1.9	5	0	18.0	24	12
					510	AT	10	6:36A	6:41A	PHNYN46	FRMTN38	11.4	14	9	3.4	7	1	25.6	32	20
					510	AT	10	6:41A	6:50A	FRMTN38	5 VIRG	3.6	6	1	7.9	12	5	28.9	35	23
					510	AT	10	6:50A	6:52A	5 VIRG	5 PINE	.5	2	0	4.9	8	1	21.3	28	14
					510	AT	10	6:52A	6:56A	5 PINE	2 UNON	2.4	4	2	11.5	15	6	16.9	24	13

Source: Seattle Metro.

TRIP SUMMARIES

For many purposes in scheduling, operations planning, and monitoring, only key ridership summary statistics from a ride check are needed; most often boardings, peak load, and (in some cases) passenger miles. If the summary covers only a part of the route, alightings may also be of interest. If the data sources are point checks, the only ridership information available will be load (and sometimes ons and offs) at the checkpoint. Showing schedule adherence

TABLE 6

TRIP SUMMARIES

Page 1
Run on 07/15/91 at 11.22.50

TRIP RIDERSHIP REPORT
BY ROUTE
SIGNUP: ALL 90 DAY: WD

RTE	PT	I O	EX	TRIP SEQ	KEY BLOCK	OBS	TMPT1 SCHED LEAVE	TMPT2 SCHED ARRIV	TMPT1 NAME	TMPT2 NAME	ON AVE	ON MAX	ON MIN	OFF AVE	OFF MAX	OFF MIN	LOAD AVG	LOAD MAX	LOAD MIN	REV MIN	RIDER PER HR	NUM SEATS	COACH TYPE
5		I	AT	1040	509	3	6:13A	6:39A	1NW NW90	5 VIRG	46	52	43	10	14	8	42	45	40	32	86.3	70	20
			AT	1050	510	10	6:24A	6:50A	1NW NW90	5 VIRG	34	44	25	13	20	8	28	35	23	32	63.8	44	30
			AT	1070	517	9	6:48A	7:15A	1NW NW90	5 VIRG	39	49	27	7	14	4	35	44	25	34	68.8	44	30
			AT	1095	520	5	7:10A	7:37A	1NW NW90	5 VIRG	34	46	24	6	10	5	30	43	20	38	53.7	44	30
			AT	1110	522	4	7:19A	7:46A	1NW NW90	5 VIRG	46	65	33	12	18	10	39	55	29	34	81.2	70	20
			AT	1160	35504	3	7:51A	8:18A	1NW NW90	5 VIRG	70	79	58	14	16	11	63	73	50	38	110.5	70	20
			AT	1195	519	9	8:14A	8:41A	1NW NW90	5 VIRG	31	49	13	7	19	2	28	38	13	34	54.7	44	30
			AT	1230	511	14	8:45A	9:12A	1NW NW90	5 VIRG	34	62	18	10	15	6	30	62	16	33	61.8	44	30
			AT	1250	515	7	9:15A	9:42A	1NW NW90	5 VIRG	36	43	23	8	14	5	30	37	19	33	65.5	70	20
			AT	1270	512	4	9:45A	10:12A	1NW NW90	5 VIRG	31	34	29	11	13	9	25	32	22	33	56.4	70	20
			AT	1290	522	4	10:15A	10:42A	1NW NW90	5 VIRG	27	31	25	11	15	7	19	22	18	33	49.1	70	20
			AT	1310	504	11	10:45A	11:12A	1NW NW90	5 VIRG	23	41	10	9	15	3	18	41	9	33	41.8	44	30
			AT	1330	519	8	11:15A	11:42A	1NW NW90	5 VIRG	23	33	18	10	16	4	17	33	10	33	41.8	44	30
			AT	1350	511	14	11:45A	12:12P	1NW NW90	5 VIRG	20	25	13	8	13	3	15	24	10	33	36.4	44	30
			AT	1370	515	7	12:14P	12:41P	1NW NW90	5 VIRG	21	25	16	8	12	4	16	21	13	33	38.2	70	20
			AT	1390	512	4	12:44P	1:11P	1NW NW90	5 VIRG	22	28	19	6	8	4	19	28	15	33	40.0	70	20
			AT	1410	522	4	1:14P	1:41P	1NW NW90	5 VIRG	23	26	19	8	14	6	15	18	14	33	41.8	70	20
			AT	1430	504	10	1:44P	2:11P	1NW NW90	5 VIRG	20	34	9	10	16	6	17	34	6	33	36.4	44	30
			AT	1450	519	8	2:09P	2:36P	1NW NW90	5 VIRG	16	32	6	6	16	1	12	23	5	33	29.1	44	30
			AT	1470	544	10	2:45P	3:12P	1NW NW90	5 VIRG	24	40	11	11	25	2	15	25	7	33	43.6	70	20
			AT	1490	514	6	3:06P	3:33P	1NW NW90	5 VIRG	15	22	10	8	12	7	10	18	5	34	26.5	70	20
			AT	1510	523	4	3:38P	4:06P	1NW NW90	5 VIRG	23	26	20	11	14	8	17	22	12	35	39.4	70	20
			AT	1530	521	4	4:10P	4:38P	1NW NW90	5 VIRG	22	30	16	13	19	11	17	27	8	35	37.7	70	20
			AT	1550	513	3	4:39P	5:07P	1NW NW90	5 VIRG	14	17	11	7	11	5	11	13	7	35	24.0	70	20
			AT	1570	519	8	5:11P	5:39P	1NW NW90	5 VIRG	16	26	12	12	24	4	11	19	6	35	27.4	44	30
			AT	1590	544	10	5:43P	6:10P	1NW NW90	5 VIRG	10	18	0	5	11	0	9	18	0	33	18.2	70	20
			AT	1610	523	3	6:09P	6:34P	1NW NW90	5 VIRG	19	27	14	10	14	7	14	20	10	31	36.8	70	20

Footnote: Riders per hour based on inbound ons, outbound offs, and revenue hours.

Source: Seattle Metro.

TABLE 7

TRIP SUMMARIES: PERIOD LEVEL AGGREGATION

Page 1
Run on 07/16/91 at 09.20.44

APC DATA EXPANDED TO SYSTEM TOTALS BY TPI
FOR EACH ROUTE AND PERIOD
SIGNUP: SUMMER 55

KEYTPI	DAY	RTE	PT	I O	PERD	TYPE SERV	# OF SCHED TRIPS	#TRIPS WITH APC DATA	% TRIPS WITH APC DATA	START TIME POINT	END TIME POINT	ON AVG PSGRS	ON TOTAL PSGRS	OFF AVG PSGRS	OFF TOTAL PSGRS	MAX LOAD AVG	MAX LOAD TOT
1010403	WD	17		O	AM	L	7	7	100.	1S JAXN	4S WASH	1.4	9.8	2.2	15.4	17.1	119.7
					MID	L	6	6	100.	1S JAXN	4S WASH	1.5	9.0	3.9	23.4	21.3	127.8
					PM	L	9	8	89.	1S JAXN	4S WASH	2.6	23.4	3.3	29.7	14.4	129.6
					XNT	L	8	7	88.	1S JAXN	4S WASH	1.2	9.6	1.3	10.4	7.2	57.6
*TOTAL DAY WD							30	28					201.0		321.0		1800.0
*TOTAL DAYCD							30	28					201.0		321.0		1800.0
	SA	17		O	AM	L	3	1	33.	1S JAXN	4S WASH	.8	2.4	1.4	4.2	4.6	13.8
					MID	L	6	3	50.	1S JAXN	4S WASH	.9	5.4	3.1	18.6	11.8	70.8
					PM	L	3	2	67.	1S JAXN	4S WASH	.7	2.1	1.8	5.4	6.8	20.4
					XNT	L	6	4	67.	1S JAXN	4S WASH	.2	1.2	.8	4.8	3.9	23.4
*TOTAL DAY SA							18	10					46.8		127.8		487.8
*TOTAL DAYCD							18	10					46.8		127.8		487.8
	SU	17		O	AM	L	3	2	67.	1S JAXN	4S WASH	.4	1.2	1.1	3.3	6.3	18.9
					MID	L	6	4	67.	1S JAXN	4S WASH	.5	3.0	2.3	13.8	8.4	50.4
					PM	L	3	3	100.	1S JAXN	4S WASH	2.7	8.1	3.7	11.1	15.3	45.9
					XNT	L	6	4	67.	1S JAXN	4S WASH	.2	1.2	.4	2.4	4.0	24.0
*TOTAL DAY SU							18	13					68.4		135.0		612.0
*TOTAL DAYCD							18	13					68.4		135.0		612.0
*TOTAL KEYTPI	1010403						66	51					864.6		1669.8		7992.6

Source: Seattle Metro.

or running time summaries along with the ridership summaries adds more value to the report, because unusual loads can sometimes be explained by schedule deviation or following a missed trip.

Passenger miles for a trip are usually calculated from the trip's load profile, multiplying load on each segment by segment length, and aggregating over segments. For this purpose, a stop list file with interstop distances must be available for each route in the same data system as the load profile.

A trip summary report from Seattle Metro's APC system is shown in Table 6. It provides one record summarizing multiple observations of each scheduled trip, showing average, minimum, and maximum values of boardings, alightings, and load for the portion of the route between two timepoints (the outer end of the route and the point at which the route enters the downtown). Aggregations to schedule and planning periods are also common to analyze whether a period's headway or running time matches its demand and traffic environment (Table 7). Fixed period definitions are used showing average boardings, alightings, and peak load per trip for each period, along with period and day totals. The system accounts for unobserved trips by simply factoring the observed trips accordingly. More flexible systems allow the user to specify any period.

Two definitions may be given to "peak load": (1) the greatest load occurring on a trip regardless of where it occurs and (2) the load at the "peak point," that is, the point with the greatest passenger volume occurring over a planning period. The peak point may be determined afresh with each new dataset or it may be semipermanently fixed based on historical data. The first point is valuable as a measure of passenger service quality (crowding), the second as a measure of peak demand against which offered capacity may be compared. Most agencies appear to choose one definition or the other, although some report both.

Ride check or APC data covering every scheduled trip can produce the same kind of reports as point or screenline checks, but with the advantage that the user can select any checkpoint. TTC's *Report 10*, shown in Table 8, is an analysis of loads at a chosen point for a given route, direction, and period. For the entire period, it shows the average load and the percentage of trips exceeding the loading standard. It also determines the peak 15-, 30-, and 60-minute period within the period of analysis, and reports average load and the percentage of trips exceeding the loading standard within those subperiods. This is clearly an analysis tied to a service standard for crowding. All of the TTC reports shown in this chapter, unless otherwise noted, are based on ride checks and processed in a custombuilt PC database with final reporting on a mainframe computer (although TTC has begun the process of migrating report generation to a PC platform).

PUBLISHED ROUTE SUMMARIES

Some agencies produce summaries of route ridership statistics that are published for community information. An example (Figure 3; from TTC, although not currently produced), shows all day ridership and peak hour load statistics for a single observed day in each of the last 3 years.

TABLE 8

SUMMARY OF TRIP LOADS AT A TIMEPOINT

REPORT 10 - RIDING COUNT WEEKDAY RECAP. (ROUTE SUMMARY) - RCWKRECR PAGE: 1

ROUTE: 95 YORK MILLS COUNT: 1014 MON FEB 02 98 (FROM 04:00 TO 31:00)
BRANCH: ALL

SC: 17 STOPS: 75 TO 75 REPORT PRODUCED: 13.46.33 ON: DEC 22 98
DIR: WEST LOCATION: STOP 75 YORK MILLS RD AT DON MILLS

BRANCHES SERVING THIS STOP:

FROM	TO
01 VICTORIA PARK AT PARKWOODS	YORK MILLS AT SUBWAY STATION

		TOT	IR	ARRIVE			DEPART		...STD BUS		TRIPS...	
		TRIPS	TRIPS	LOAD	ONS	OFFS	LOAD	AVE	OVER	65	UNDR	55 **
TIME PERIOD	TO 0859	45	7	1933	262	195	2000	44.4 D	20	44 %	14	31 %
	0900 - 1459	52	0	1326	196	333	1189	25.5 A	1	2 %	45	87 %
	1500 - 1859	58	10	802	192	210	784	13.8 A		%	58	100 %
	1900 - 2159	22	0	286	54	68	272	13.0 A		%	22	100 %
	2200 - END	20	0	162	38	48	152	8.1 A		%	20	100 %
	ALL DAY TOTAL	197	17	4509	742	854	4397	22.9 A	21	11 %	159	81 %

** SEE REPORT 12 FOR TRIP-STOPS OUTSIDE LOAD STANDARDS

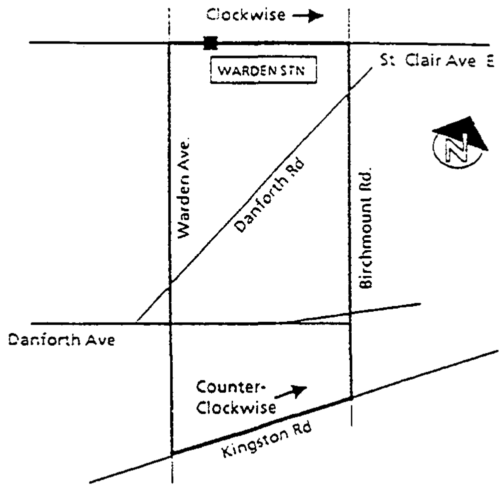
		TOT TRIPS	IR TRIPS	ARRIVE LOAD	ONS	OFFS	DEPART LOAD	AVE	OVER	65	UNDR	55
TIME PERIOD	TO 0859											
PEAK 60 MIN FROM	07:31 TO 08:30	21	2	1048	135	116	1067	50.8 D	13	62 %	3	14 %
PEAK 30 MIN FROM	07:50 TO 08:19	11	1	582	78	58	602	54.7 D	8	73 %		%
PEAK 15 MIN FROM	08:17 TO 08:30	8	0	382	54	47	389	48.6 D	5	63 %	2	25 %
TIME PERIOD	0900 - 1459											
PEAK 60 MIN FROM	09:02 TO 09:58	16	0	363	65	78	350	22.7 A	1	6 %	14	88 %
PEAK 30 MIN FROM	09:06 TO 09:35	10	0	234	48	46	236	23.6 D	1	10 %	8	80 %
PEAK 15 MIN FROM	09:06 TO 09:19	5	0	164	44	33	175	35.0 D	1	20 %	3	60 %
TIME PERIOD	1500 - 1859											
PEAK 60 MIN FROM	17:19 TO 18:18	17	1	265	63	53	275	16.2 D		%	17	100 %
PEAK 30 MIN FROM	17:17 TO 17:46	9	0	144	44	27	161	17.9 D		%	9	100 %
PEAK 15 MIN FROM	16:00 TO 16:14	6	2	108	32	22	118	19.7 D		%	6	100 %
TIME PERIOD	1900 - 2159											
PEAK 60 MIN FROM	19:37 TO 20:36	7	0	128	23	33	118	18.3 A		%	7	100 %
PEAK 30 MIN FROM	20:34 TO 20:57	4	0	76	15	14	77	19.3 D		%	4	100 %
	21:45 TO 22:13	4	0	67	22	12	77	19.3 D		%	4	100 %
PEAK 15 MIN FROM	20:34 TO 20:44	3	0	54	14	13	55	18.3 D		%	3	100 %

Source: Toronto Transit Commission..

ROUTE PROFILE FOR

WARDEN SOUTH (69) BUS ROUTE

ROUTING:



SERVICE:

All Day, 7 days per week

NOTE: Service is available both clockwise and counter-clockwise from Warden Stn all day on weekdays and Saturday daytime; counter-clockwise only on Saturday evenings and Sunday (all day).

RIDERSHIP:

	ALL DAY (BOTH WAYS)				
	AM Rush	Day Normal	PM Rush	Evening	Total
Tuesday, October 17, 1989	1014	1565	1180	663	4422
Tuesday, October 2, 1990	1288	1996	1581	795	5660
Wednesday, September 25, 1991*	1176	1644	1201	656	4677*
% Change from Previous Count	(8.7)	(17.6)	(24.0)	(17.5)	(17.4)

	MAXIMUM HOUR (HEAVY WAY ONLY)			
	AM	Avg Veh. Load	PM	Avg Veh Load
Tuesday, October 17, 1989	195 (SB)	49	267 (SB)	67
Tuesday, October 2, 1990	392 (SB)	44	308 (SB)	77
Wednesday, September 25, 1991*	374 (SB)	31	313 (SB)	39

Note: SB = southbound onto Warden Avenue (counter-clockwise)
*The 1991 count was taken shortly after the Sept 12-19 TTC strike

FIGURE 3 Public route ridership summary (Toronto Transit Commission).

ROUTE-LEVEL SCHEDULE ADHERENCE AND HEADWAY REGULARITY

A majority of the responding agencies report schedule adherence. Of the 20 responding agencies, 10 analyze schedule adherence at the route level, whereas another 5 analyze it at the system level only. Definitions of "on time" vary from agency to agency; among the responding agencies, acceptably early varies from 0 to 1 minute, and acceptably late from 2 to 10 minutes. In their reporting,

TABLE 9

SCHEDULE ADHERENCE REPORT BY ROUTE/DIRECTION/PERIOD

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY
METROBUS
SCHEDULE ADHERENCE INDICATORS REPORT

LINE NAME BETHESDA-SIL SPR J1 J2 J3 LINE NUM 16 SERV WEEKDAY RUN DATE 12/23/1997

DIRECTION: WESTBOUND

START TIME (HHMMC)	300A	530A	930A	300P	700P	
END TIME (HHMMC)	530A	930A	300P	700P	300X	TOTAL
SCHEDULED REVENUE TRIPS	2	39	17	22	13	93
AVERAGE TRIP TIME (MIN)	34	43	43	44	34	42
AT CONTROL PT. NO TRIPS: ON TIME	1	30	11	18	11	71
2-5 MINUTES LATE	0	9	4	4	0	17
>5 MINUTES LATE	1	0	2	0	1	4
>1 MINUTE EARLY	0	0	0	0	0	0
AVERAGE DEVIATION (MIN)	7.00	2.67	5.00	3.25	8.00	3.90
AT CONTROL PT. PC TRIPS: ON TIME	0.50	0.77	0.65	0.82	0.85	0.76
2-5 MINUTES LATE	0.00	0.23	0.24	0.18	0.00	0.18
>5 MINUTES LATE	0.50	0.00	0.12	0.00	0.08	0.04
>1 MINUTE EARLY	0.00	0.00	0.00	0.00	0.00	0.00
AT ALL POINTS NO TRIPS: ON TIME	6	111	33	90	47	287
2-5 MINUTES LATE	2	127	59	50	23	261
> 5 MINUTES LATE	6	35	32	19	12	104
>1 MINUTE EARLY	2	17	10	10	14	14
AVERAGE DEVIATION (MIN)	5.70	4.27	5.13	4.23	4.47	4.53
AT ALL POINTS PC TRIPS: ON TIME	0.38	0.38	0.25	0.53	0.49	0.41
2-5 MINUTES LATE	0.13	0.44	0.44	0.30	0.24	0.37
>5 MINUTES LATE	0.38	0.12	0.24	0.11	0.13	0.15
> 1 MINUTE EARLY	0.13	0.05	0.07	0.06	0.15	0.08

DIRECTION: EASTBOUND

START TIME (HHMMC)	300A	530A	930A	300P	700P	
END TIME (HHMMC)	530A	930A	300P	700P	300X	TOTAL
SCHEDULED REVENUE TRIPS	0	16	16	34	17	83
AVERAGE TRIP TIME (MIN)	0	34	39	45	37	40
AT CONTROL PT. NO TRIPS: ON TIME	0	9	5	11	6	31
2-5 MINUTES LATE	0	4	6	8	6	24
>5 MINUTES LATE	0	2	2	7	4	15
>1 MINUTE EARLY	0	1	3	7	1	12
AVERAGE DEVIATION (MIN)	0.00	7.86	8.00	5.36	4.64	6.25
AT CONTROL PT. PC TRIPS: ON TIME	0.00	0.56	0.31	0.32	0.35	0.37
2-5 MINUTES LATE	0.00	0.25	0.38	0.24	0.35	0.29
>5 MINUTES LATE	0.00	0.13	0.13	0.21	0.24	0.18
>1 MINUTE EARLY	0.00	0.06	0.19	0.21	0.06	0.14
AT ALL POINTS NO TRIPS: ON TIME	6	154	83	198	97	538
2-5 MINUTES LATE	2	183	110	141	84	520
> 5 MINUTES LATE	6	43	51	44	29	173
>1 MINUTE EARLY	2	23	14	41	22	22
AVERAGE DEVIATION (MIN)	5.70	4.04	5.06	3.97	4.14	4.29
AT ALL POINTS PC TRIPS: ON TIME	0.38	0.38	0.32	0.47	0.42	0.40
2-5 MINUTES LATE	0.13	0.45	0.43	0.33	0.36	0.39
>5 MINUTES LATE	0.38	0.11	0.20	0.10	0.13	0.13
> 1 MINUTE EARLY	0.13	0.06	0.05	0.10	0.09	0.08

NB: ALL DATA CLASSIFIED ON THE BASIS OF SCHEDULED TIME AT THE CONTROL POINT

Source: Washington Metropolitan Area Transit Authority.

some agencies distinguish between degrees of lateness, for example, 2 to 5 minutes late versus more than 5 minutes late.

A typical route-level schedule adherence analysis is shown in Table 9, a report from the Washington (D.C.) Metropolitan Area Transportation Authority (WMATA) that shows a frequency distribution of trips by degree of lateness. It is based on a ride check covering every scheduled trip once and processed using a SMART database on a PC. One pair of tables is based on a preselected control point for the route; the other is based on observations at every control point. The trips are aggregated by planning period, and the number and fraction of trips falling into different categories of punctuality are shown. "Average deviation" is based only on the trips that were two or more minutes late. Clearly, there is a strong difference between measures based at a single point versus multiple points; it is more difficult to be on time at (say) four points than at one.

One of the TTC's schedule adherence reports (not shown) gives a frequency distribution of lateness and "earliness" by minute (i.e., number of trips that were 1 minute late, 2 minutes late, etc.). This format allows the analyst to apply any desired definition of "early," "on time," and "late," which may vary according to the purpose of the analysis.

Data sources with multiple day observations permit further statistical analysis. OC Transpo's route-level schedule adherence report, based on point checks on a few days, simply lists the results of each day separately, leaving further inference to the analyst. Reports from automated systems making daily observations are described later in the section *Trip Time Analyzers.*

On routes having a high enough frequency that passengers don't consult a schedule, waiting time and load imbalances are more affected by headway variability than by schedule deviation. Assuming that passengers are always able to board the first bus that appears, average passenger waiting time is one-half the average headway, plus a component that grows with the square of the headway coefficient of variation (CV, which equals the standard deviation of the headway divided by average headway). Passenger load is affected similarly. For example, if the headway's standard deviation is one-half as great as its mean (CV = 0.5), average wait time will be 25 percent greater than it would be if headways had no variation. Loads will also be heavily imbalanced, with some trips overloaded and others underloaded, and with most of the passengers on trips that are overloaded.

As with schedule deviation, headway variability measures for a route can be based at a single control point or on data from several points. TTC's *Report 8,* shown in Table 10, includes the mean headway, the CV, and the minimum and maximum observed headway at timepoints along a route for a specified period (up to 8:59 a.m. for the example shown).

Two other measures of headway variability that have been used are the fraction of headways more than 50 percent greater than the scheduled headway (a measure more readily understood by management than headway CV) and the expected fraction of passengers that have to wait more than one scheduled headway. This latter figure is calculated as the fraction of a period in which the time since the most recent departure was more than one scheduled headway *(29).*

At timed transfer points, a critical measure of operational performance is whether or not scheduled connections were made. An example report, based on point checks on Norfolk's Tidewater Transportation District Commission, is shown in Table 11.

RUNNING TIME

Running time and running time variability are primary inputs to scheduling, helping to determine scheduled running times and necessary layovers. Running times can vary considerably between trips and between days, and schedules are purposely built to account not only for average running time, but also to provide a sufficient buffer so that most delays can be absorbed without the vehicle's next trip beginning late. That buffer can be built into the running time, into the layover at the end of the trip, or can be a combination of the two. Reports that analyze variability in running time are therefore more valuable than those that report only averages.

Whether scheduled running times are based on average running times, ideal running times (i.e., running time under favorable traffic conditions), or something like 85 percentile running times (i.e., running time under unfavorable conditions) is a matter of agency policy. Using ideal running times helps to guard against trips being early en route, which is far more annoying to waiting passengers than trips being late. With this policy, trips will tend to run late, and will therefore need greater scheduled layovers. Using the 85 percentile value running times helps prevent trips from being late, which can be important on long routes or routes involving heavy transfer volumes. It also means less layover time is needed in the schedule. However, this practice leads to longer journey times and increases the likelihood that trips will be early en route, unless strict controls against "running hot" are observed. The average running time policy is a compromise between those extremes. Yet even under this policy, while average running time is sufficient to determine scheduled running

TABLE 10

HEADWAY VARIABILITY REPORT

REPORT 8 - RIDING COUNT HEADWAY VARIABILITY REPORT - RCHDWYVA PAGE: 6
FOR PERIOD: TO 0859 WESTBOUND
ROUTE: 95 YORK MILLS COUNT: 1014 MON FEB 02 98 (FROM 04:00 TO 31:00)
BRANCH: ALL
MINOR DELAYS.

SC: 17 REPORT PRODUCED: 11.55.31 ON: DEC 22 98

TIMEPOINTS: DESTINATION CODES:

1	LOOP (GO STN) AT LAWRENCE AVE E		2			5	
12	LAWSON AT MEADOWVALE		2			5	
20	LOOP (CUL DE SAC) AT ELLESMERE RD			3			6
22	ELLESMERE RD AT MEADOWVALE			3			6
33	ELLESMERE RD AT MILITARY TRAIL EAST		2	3		5	6
36	ELLESMERE RD AT NEILSON		2	3		5	6
40	ELLESMERE RD AT MARKHAM		2	3		5	6
44	ELLESMERE RD AT MCCOWAN		2	3		5	6
54	ELLESMERE RD AT KENNEDY RD		2	3		5	6
57	ELLESMERE RD AT BIRCHMOUNT		2	3		5	6
65	ELLESMERE RD AT VICTORIA PARK		2	3		5	6
66	VICTORIA PARK AT PARKWOODS	1					
70	YORK MILLS RD AT FENSIDE	1	2	3		5	6
78	YORK MILLS RD AT LESLIE	1	2	3		5	6
83	YORK MILLS RD AT BAYVIEW	1	2	3			6
91	YORK MILLS AT SUBWAY STATION	1	2	3		5	6

TIMEPOINTS	1	12	20	22	33	36	40	44	54	57	65	66	70	78	83	91
HEADWAY STATISTICS																
OBSERVATIONS	13	13	14	14	29	29	33	35	35	35	35	8	44	44	32	44
AVERAGE (MM-SS)	12-28	12-41	12-43	12-43	06-14	06-17	05-37	05-16	05-22	05-22	05-28	09-38	04-22	04-22	06-04	04-25
STD DEV'N	6.9	7.2	6.7	6.6	4.4	4.5	4.4	3.7	3.8	4.0	3.8	3.1	3.4	3.5	3.8	3.8
COEFF.VAR'N (%)	56	57	53	52	71	71	79	71	71	75	69	33	78	81	62	86
MAXIMUM (MM-SS)	32-00	32-00	34-00	33-00	18-00	17-00	19-00	17-00	18-00	19-00	16-00	15-00	12-00	14-00	15-00	14-00
MINIMUM (MM-SS)	05-00	06-00	03-00	02-00	00-00	00-00	00-00	01-00	00-00	00-00	00-00	04-00	00-00	00-00	00-00	00-00

IMPROVISED ROUTING TRIPS INCLUDED

Source: Toronto Transit Commission.

time, scheduled layovers should be related to running time variability.

One major input on running time is feedback from operators and patrons. Operators will usually complain if there is not enough running time built into the schedule, and patrons will often complain if passed by an overcrowded vehicle or if vehicles depart early; consequently, informal checks by supervisors often follow. This led one data collection manager to comment that their APC system "mostly tells us what we know already." Passengers and operators, however, tend to focus more on the exceptions than on the average performance. Operators will often say nothing if the scheduled running time is too generous (although patrons sometimes complain if they see an operator obviously killing time). Formal means of data collection are therefore important.

WMATA's ride check program rotates over the routes, analyzing each trip in the daily schedule for one route before proceeding on to the next. After a route has been checked, a route running time analysis is performed. Depending on checking resources, each route's weekday schedule is checked every 12 to 18 months. The ride check summary (Table 12) combines in one report information on running time, schedule adherence, and ridership. On the left is shown, by trip and timepoint, the scheduled versus actual arrival time, the ons and offs since the previous timepoint, and the peak load within the segment since the previous timepoint. On the right is shown, by trip and by segment as well as for the entire route, the scheduled versus actual running time. The summary at the bottom of the page incorporates the trips listed on the page. Analysts can examine these results to decide whether the scheduled running time should be modified. Displaying load and schedule adherence alongside running time helps the analyst decide whether an abnormal value of running time might have been related to an abnormal passenger load. Not shown on the report, but often added manually, are the boundaries between "running time periods," that is, periods with

TABLE 11

TRANSFER CONNECTIONS REPORT

TIDEWATER REGIONAL TRANSIT

CONNECTIONS AT DIRECT TRANSFER CENTERS
OCTOBER 1997

CHESAPEAKE

20th & Seaboard
Routes #6, #13, Maxi

Date	Scheduled Meets	Observed Trips	Total Passenger	Transferring Passengers	Trips Connecting	% Connecting Trips
01-05-93	24	87	2,234	90	83	95%
06-28-94	24	87	2,299	84	84	97%
06-26-95	24	86	2,437	114	85	99%
07-08-96	24	86	4,011	105	85	99%
06-09-97	24	87	6,000	142	87	100%

Chesapeake Square
Routes #44, #61

Date	Scheduled Meets	Observed Trips	Total Passenger	Transferring Passengers	Trips Connecting	% Connecting Trips
10-02-97	10	23	880	13	21	91%

NORFOLK

Elm Street Direct Transfer Center
Routes #3, #8, #9, #15, #61

Date	Scheduled Meets	Observed Trips	Total Passenger	Transferring Passengers	Trips Connecting	% Connecting Trips
04-28-93	24	165	5,286	455	161	98%
06-09-94	24	168	5,630	673	159	95%
06-15-95	24	174	6,279	665	163	94%
07-02-96	24	174	7,742	655	170	98%
06-11-97	24	189	7,897	514	189	100%

Source: Tidewater Transportation District Commission.

constant scheduled running time. Schedule makers can modify scheduled running times in three ways: (1) by modifying the running times for a given period, (2) by changing the boundary between running time periods, or (3) by splitting a running time period into two or more running time periods.

Other helpful analysis features included in the reports of various agencies were summaries of observed running time by schedule period including mean, standard deviation, minimum, and maximum values both by segment and overall. Standard deviation is a helpful measure for determining 85 percentile running times (the 85^{th} percentile can be approximated by the mean plus one standard deviation), which may be used for determining necessary layover or, at an agency with strict schedule adherence control, scheduled running time.

Because they use APC data and therefore have many days of observations, the running time analysis done by OC Transpo shows a distribution of observed running times. An example in which trips are aggregated by the hour of the day is shown in Table 13. In addition to the distribution, summary statistics include mean, median,

TABLE 12

RUNNING TIME AND PASSENGER ACTIVITY REPORT: BY TRIP

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY
METROBUS PASSENGER AND TIME REPORT

PAGE 2 LINE NAME BETHESDA-SIL SPR J1 J2 J3 LINE NUM 16
DIR WESTBOUND

SERV WEEKDAY RUN DATE 12/23/1997
DATES 11JUN97 TO 08DEC97

ROUTE BLOCK	R T	CP SILV STAT	E-W& GRUB	E-W& CONN	JNBR CONN	BETH STAT	MEDI STAT	CENT WEST	DEMO OGTN	MONT MALL	-	-	CP SILV STAT	E-W& GRUB	E-W& CONN	JNBR CONN	BETH STAT	MEDI STAT	CENT WEST	DEMO OGTN	MONT MALL	R/T S/A	TOTBD AML
J2	N	603A	609A	613A	-	619A	627A	630A	635A	638A				6	4		6	8	3	5	3	35	
MJ-07		604A	610A	613A		621A	628A	631A	640A	644A				6	3		8	7	3	9	4	40	
28JUL97			20 0	0 1		0 7	4 8	1 0	0 1	0 8													25
			20	20		19	12	9	9	8													20
J3	N	613A	619A	623A	-	629A	637A	640A	645A	650A				6	4		6	8	3	5	5	37	
MJ-01		613A	618A	622A		627A	638A	640A	649A	651A				5	4		5	11	2	9	2	38	
22JUL97			31 0	1 0		3 17	0 5	0 0	1 12	0 2													36
			31	32		35	18	13	14	2													35
J1	N	620A	626A	-	632A	-	638A	641A	646A	651A				6		6		6	3	5	5	31	
MJ-09		621A	628A		635A		641A	644A	649A	655A				7		7		6	3	5	6	34	
4AUG97			30 0		2 7		0 15	6 5	0 3	0 8													38
			30		32		25	16	11	8													32
J2	N	622A	628A	632A	-	638A	646A	649A	654A	657A				6	4		6	8	3	5	3	35	
WN-61		624A	632A	635A		640A	648A	651A	657A	701A				8	3		5	8	3	6	4	37	
2JUL97			24 0	0 1		0 6	2 8	0 5	0 1	0 5													26
			24	24		23	18	11	6	5													24
J3	N	630A	636A	640A	-	646A	654A	657A	702A	707A				6	4		6	8	3	5	5	37	
MJ-08		633A	640A	645A		651A	658A	701A	707A	714A				7	5		6	7	3	6	7	41	
22JUL97			35 0	3 4		0 13	3 9	8 6	1 3	0 15													50
			35	38		34	24	23	17	15													38
J2	N	638A	644A	648A	-	654A	702A	705A	710A	713A				6	4		6	8	3	5	3	35	
MJ-10		639A	646A	649A		656A	703A	705A	716A	718A				7	3		7	7	2	11	2	39	
22JUL97			29 1	0 2		1 16	1 6	4 1	0 5	0 4													35
			29	28		27	11	10	9	4													29

TOTAL SCHEDULED MINUTES 210
AVER. SCHEDULED MINUTES 35
SUM OF AMLS 178

TOTAL ACTUAL MINUTES 229
AVER. ACTUAL MINUTES 38 DIFF. + 3
AVER. OF AMLS 30

Source: Washington Metropolitan Area Transit Authority.

TABLE 13

RUNNING TIME VARIABILITY REPORT

```
PROCESSED·   98-06-01 12 33 37                    AUTOMATIC PASSENGER COUNTING SYSTEM                                  PAGE   3
REFERENCE    422172                              DISTRIBUTION OF RUNNING TIMES BY SECTION
ROUTE.       1 SOUTH KEYS-DOWNTOWN/CENTREVILLE             WEEKDAY SERVICE                            PERIOD· 97-09-02 TO 97-12-20
DIRECTION·   SOUTHBOUND    Pattern  4                                                                DAY OF WEEK  MON - FRI
TERMINALS.   NICHOLAS RIDEAU to GREENBORO STOP                                                   RECOMMENDED TIME     0%
```

TIME PERIOD	SCHED TIME	MEAN	MED.	STD DEV	REC TIME	MAX BENEF TIME	NO OBS	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59
								RUNNING TIMES (MINUTES)																		
06 01 - 07·00	44 2	36 5	36 5	1 6	36 5	34 8	11						1	3	5	2										
07 01 - 08·00	46 0	40 6	40 4	2 3	40 6	39 8	20							1	1	4	9	4	1							
08 01 - 09 00	46 0	40.8	40 0	3 6	40 8	38 8	25							1	2	8	9	2	1	1			1			
09·01 - 10 00	44 4	39 6	39 4	3 0	39 6	38 3	22							1	6	6	8					1				
10 01 - 11·00	44 0	40 7	40 1	2 6	40 7	40 0	23								4	7	5	4	2	1						
11:01 - 12 00	44 0	42 3	42 0	2 4	42 3	41 0	21								1	1	8	9		1	1					
12 01 - 13:00	44.0	43 6	43 1	3 7	43 6	42 0	24									4	5	6	5	1	1	1		1		
13 01 - 14·00	44 0	43 0	42 6	2 8	43 0	40 7	20								1	2	5	6	3	2	1					
14.01 - 15 00	45 1	45 0	44 1	2 2	45 0	43 3	19											8	5	4	1	1				
15·01 - 16 00	49 0	46 7	46 3	3 6	46 7	45 5	20									1	1	1	5	6	1	3	2			
16 01 - 17 00	50 0	49 5	49 5	3 1	49 5	47 9	17												2	3	7	3	1			1
17 01 - 18·00	50 0	48 2	48 3	5 4	48 2	40 5	18										3	2	1	3	2	2	3	1		1
18 01 - 19·00	46 4	49 9	48 5	3 4	49 9	46 1	5													1	2		1	1		
19.01 - 20 00	41 0	42 9	42 2	4 4	42 9	37 6	6								1	1	1		1	1	1					
20 01 - 21 00	41 0	40 0	40 0	0 8	40 0	38 8	5									2	3									
21:01 - 22 00	40 2	36 8	37 3	2 0	36 8	34 9	5						1		3	1										
22 01 - 23·00	38 7	37 4	37 3	3 3	37 4	35 8	9						1	3	2	1	1	1								
23:01 - 00 00	37 0	32.6	31 7	3 7	32 6	28 5	11				4	2	1	2	1		1									
00·01 - 01·00	33 0	30 3	29 1	3 2	30 3	29 5	10		1		5	1	1	2												

Source: Ottawa-Carleton Regional Transit Commission.

TABLE 14

OBSERVED LAYOVER REPORT

REPORT 7 - RIDING COUNT TIME LAYOVER - TRIP DETAIL - RCTMELO PAGE: 1
ROUTE: 95 YORK MILLS COUNT: 1014 MON FEB 02 98 (FROM 04:00 TO 31:00)
BRANCH: ALL
1 VICTORIA PARK AT PARKWOODS YORK MILLS AT SUBWAY STATION
2 LOOP (GO STN) AT LAWRENCE AVE E YORK MILLS AT SUBWAY STATION
3 LOOP (CUL DE SAC) AT ELLESMERE RD YORK MILLS AT SUBWAY STATION
5 LOOP (GO STN) AT LAWRENCE AVE E YORK MILLS AT SUBWAY STATION
6 LOOP (CUL DE SAC) AT ELLESMERE RD YORK MILLS AT SUBWAY STATION
MINOR DELAYS.

SC: 17 REPORT PRODUCED: 13.03.44 ON: DEC 22 98

RUN	DS CD	CONT TIME	DR	START TIME	END TIME	EAST END		WEST END	I R
1	2	04:41	E	04:41	04:57	:12	*		1
		05:56	W	05:09	05:56			:09	
		06:05	E	06:05	06:57	:12	*		
1	5	08:04	W	07:09	08:04			:04	
		08:08	E	08:08	09:06	:12	*		
1	2	10:19	W	09:18	10:19			:04	
		10:23	E	10:23	11:14	:06			
		12:14	W	11:20	12:14			:03	
		12:17	E	12:17	13:14	:03			
		14:12	W	13:17	14:12			:04	
		14:16	E	14:16	15:14	:02			
		16:14	W	15:16	16:14			:02	
1	1	16:16	E	16:16	16:46	:01			
		17:03	W	16:47	17:03			:02	
		17:05	E	17:05	17:26	:01			
		17:46	W	17:27	17:46			:03	
		17:49	E	17:49	18:11	:01			
		18:34	W	18:12	18:34			:03	
		18:37	E	18:37	18:59	:02			
		19:23	W	19:01	19:23			:03	
1	2	19:26	E	19:26	20:05				1
2	6	04:44	E	04:44	04:53	:07			1
		05:44	W	05:00	05:44			:08	
2	2	05:52	E	05:52	06:45	:10			
2	5	07:52	W	06:55	07:52			:05	
		07:57	E	07:57	08:57	:05			
2	2	09:58	W	09:02	09:58			:05	
		10:03	E	10:03	10:55	:06			
		11:57	W	11:01	11:57			:06	
		12:03	E	12:03	13:01	:02			
		14:01	W	13:03	14:01			:04	

* LAYOVER 10 - 60 MINUTES
LAYOVER GREATER THAN 60 MIN IGNORED

Source: Toronto Transit Commission.

and standard deviation of running time, which can be compared with the scheduled time (averaged, if need be, over the scheduled trips in the hour).

The TTC does an analysis of layover (Table 14). This report is a simple listing of the layovers observed in a day's ride check. Layovers of 10 minutes or greater are flagged.

With three-quarters of the responding systems relying exclusively on traffic checkers to measure running time, the cost of getting an adequate sample for statistical analysis is prohibitive for most agencies. Running time and layover decisions are instead based on a very limited sample, relying on feedback from operators, patrons, and schedule adherence checks to indicate when the scheduled running time might need adjustment. One respondent said that although his agency's ideal is to use 85 percentile running times, they often have too little data to do more than "eyeball" what that value might be. Reliable estimation of running time variability requires a sample size of at least 30 observations, preferably more, spread over many days. The ability to collect this type of information is one of the advantages of automatic data collection equipment such as APCs, AVL, and trip time analyzers, discussed in the following section.

TRIP TIME ANALYSIS

Trip time analyzers record events such as starting, stopping, and opening doors to determine trip time components,

TABLE 15

TRIP TIME ANALYSIS REPORT

PROCESSED: 98-06-01 12:36:30
REFERENCE: 422133

AUTOMATIC PASSENGER COUNTING SYSTEM
REVENUE TIME UTILIZATION

PAGE 1

From Stop: CF630 - BANK HOLMWOOD FS
To Stop: CA100 - BANK SLATER NS
Route: 1 SOUTH KEYS-DOWNTOWN/CENTREVILLE

Period: 97-09-02 to 97-12-20
Day Type: WEEKDAY
Time: 06:31:00 - 09:30:00

	Average Time per Trip Minutes	Std Dev	% of Time
Moving between stops	4 79		53 80
Stop and go time	0 46	0 9	5 16
Idle time	0 08	0 2	0 93
Dwell time	1 21	0 7	13 56
Excess time	2 37	0 9	26 55
TOTAL	8 91	1 6	100%

Layover time	0 00
Average sched time per trip	13 17
Total distance (KM)	2 38
Average Moving Speed (KM/HR)	29 79
Average Total Speed (KM/HR)	16 02
Total Trips Captured	69

Source: Ottawa-Carleton Regional Transit Commission.

such as time in motion and time delayed in traffic. Although ride checkers often note some information about general or special traffic conditions, trip time analyzers give far greater detail. The extra detail and larger sample size can help pinpoint where schedule adjustments and traffic engineering improvements are needed. Trip time analyzers are especially valuable in giving an agency feedback as to whether schedule adjustments or traffic engineering improvements were successful. Although trip time analyzers can be based on manual observation (e.g., the Volvo Traffic Analyzer, popular in the late 1970s and early 1980s, relied on a hand-held device), automatic event recording equipment is preferable because it affords a much larger sample size.

One drawback to basing scheduled running time simply on observed running time is that operators, conscious of being observed, may be trying to keep to the existing schedule. This introduces some bias during manual data collection. Furthermore, even with automated data collection, operators may be killing time to prevent running early and, therefore, some of the observed running time may not be needed. Unless these intentional delays can be identified, it becomes hard to recognize when a route's scheduled running time is too great.

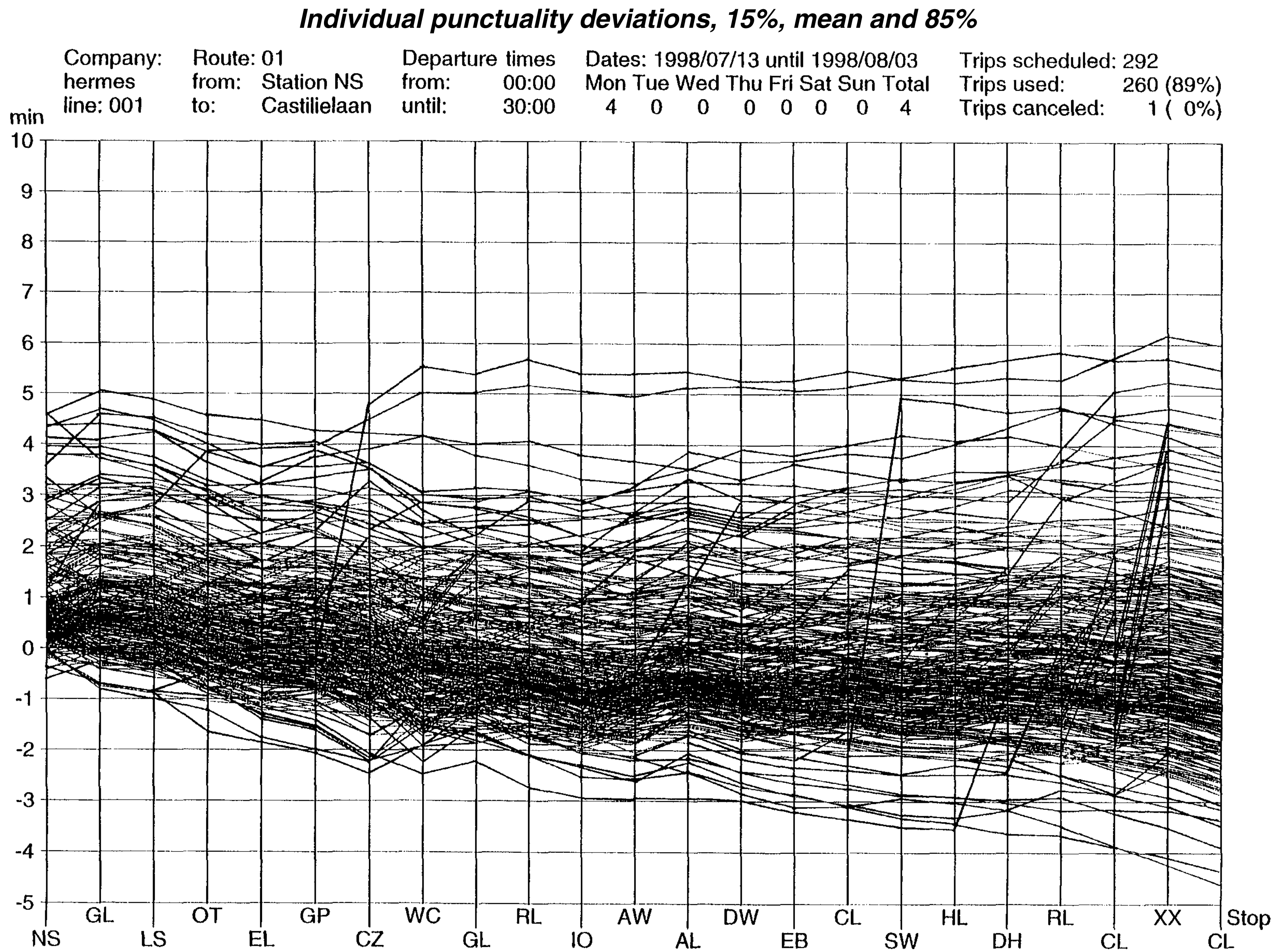
OC Transpo's APC system features trip time analysis. Data from observed trips are stored in a database, allowing users to do analyses for any specified route segments aggregated over selected dates and periods of the day. An example report (Table 15) shows that trip time is divided into five components. Two measures of speed, one of which counts only the time in which the bus is moving, are also calculated.

The trip time analysis program used by the Hermes Bus Company in Eindhoven, The Netherlands, is called Tritapt (Trip Time Analysis for Public Transport) and was developed at the Delft University of Technology *(30)*. It analyzes event records made by on-board computers supplied by Peek Traffic, reducing them to five trip time components that are stored in a database. The user can perform an analysis on any set of trips and days.

One of Tritapt's trip time components is "control time," defined as time spent at stops beyond the necessary dwell time. This is assumed to be extra time spent at a stop to prevent the bus from departing ahead of schedule. In its reports, "net traject time" is trip time excluding control time, meant to reflect the time actually needed to perform a trip.

Tritapt's schedule adherence report (Figure 4) shows schedule deviation along a route/direction by stop. (In Europe, it is customary for every stop to be a scheduled timepoint.) The user selects the period of the day and dates to be included in the analysis. Stops, with abbreviated names such as NS and GL, are shown on the horizontal axis, and schedule deviation in minutes appears on the vertical axis. Positive values indicate late departures, negative values early departures. The format in Figure 4(*a*) has a broken line for each selected trip; in the present example, 260 trips were selected. As the number of selected trips increases, the broken lines become too cluttered, and a different format [Figure 4(*b*)], presents summary statistics: mean, minimum, maximum, and 15- and 85-percentile schedule deviations at each stop.

The schedule adherence report is useful for measuring the quality of the schedule and of the service. When the


Individual punctuality deviations, 15%, mean and 85%
Company: hermes line: 001
Route: 01 from: Station NS to: Castilielaan
Departure times from: 00:00 until: 30:00
Dates: 1998/07/13 until 1998/08/03
Mon Tue Wed Thu Fri Sat Sun Total
4 0 0 0 0 0 0 4
Trips scheduled: 292
Trips used: 260 (89%)
Trips canceled: 1 (0%)
min
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
NS GL LS OT EL GP CZ WC GL RL IO AW AL DW EB CL SW HL DH RL CL XX CL
Stop

(a)

(b)

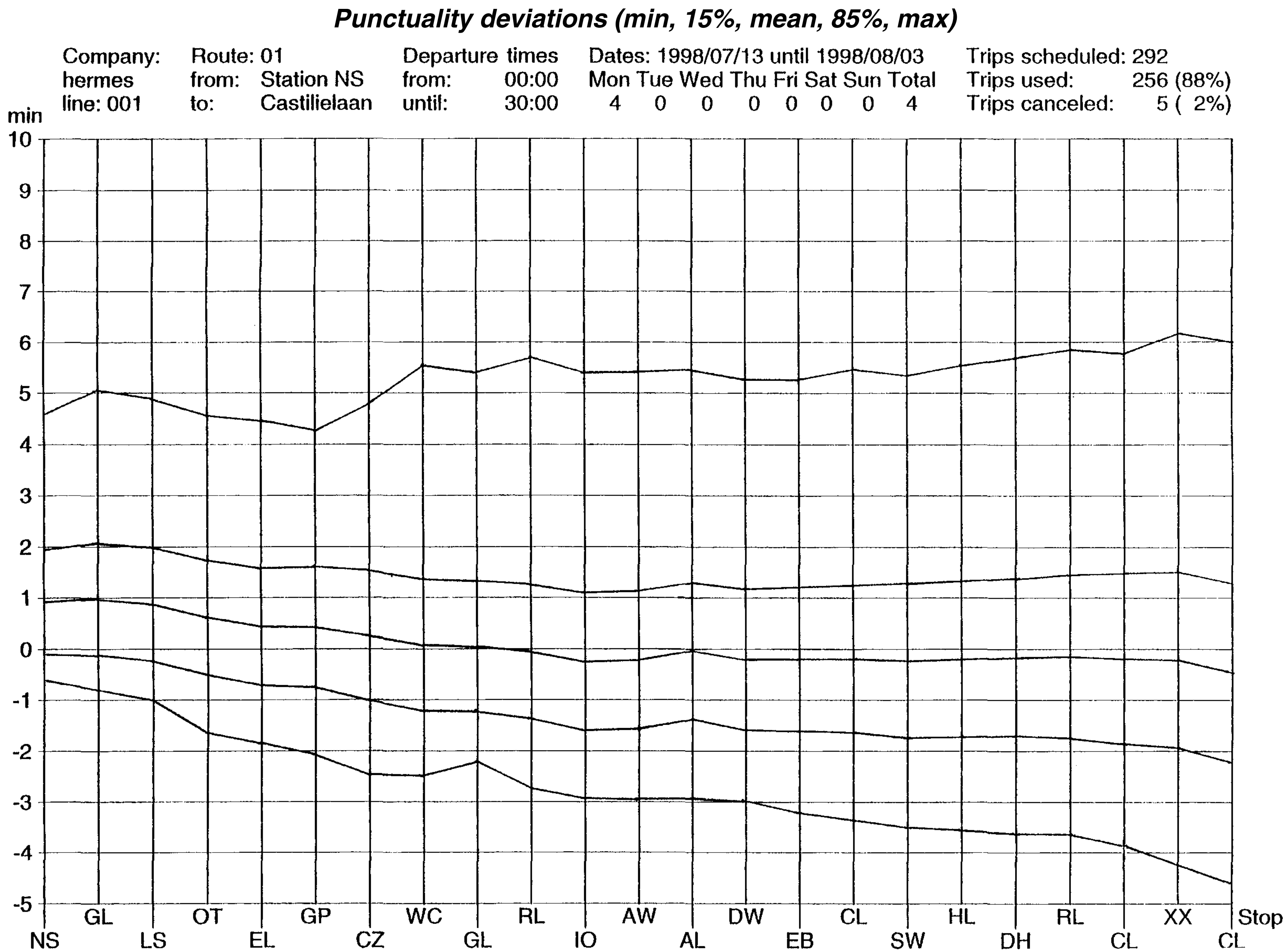


FIGURE 4 Schedule adherence report for a route/direction (Hermes, Eindhoven) (*Copyright* Theo Muller, TU Delft). *(a)* Trip level detail. *(b)* Statistical summary.

mean schedule adherence at a single stop is far from zero, that indicates a need to adjust the scheduled departure time from that stop. Large variations in schedule adherence can indicate the need for better control (e.g., not allowing early departures) and for traffic priority measures. If the mean schedule deviation increases as one reads from the start of the route to the end, that indicates that the schedule does not allow enough running time; a gradually decreasing schedule deviation indicates that the allowed time is too generous, and the operators may be compensating by beginning their trips late. The transit agency can use such a report to see whether schedule adjustments, changes in control, and traffic engineering improvements have brought schedule deviations into the desired range, say, 0 minutes early to 2 minutes late.

The need for traffic engineering attention is shown by an analysis of delays between stops (Figure 5). The graphical representation shows a hairline for each observation, as well as mean and 85 percentile values by stop. Tritapt defines delay as time spent stopped or at a speed of less than 5 km/hr, excluding time at a bus stop.

Other Tritapt analyses suggest changes in scheduled running times. The report shown in Figure 6 projects mean, 85 percentile, and maximum observed net traject time for each scheduled trip over a user-defined set of days. Because agency policy is to use 85 percentile running times for scheduling, an algorithm groups the trips into periods of the day in which the 85 percentile net traject time is relatively constant and suggests this time as the scheduled running time for that period of the day. Another analysis (Figure 7) shows, for a given period of the day, what the scheduled segment running times should be to satisfy a feasibility criterion—that the time allowed from a stop to the end of the line should be enough to complete the trip on time 85 percent of the time, based on a procedure described by Muller *(31)*.

Some of the large scheduling software packages, including Hastus and Trapeze, have recently introduced trip time analysis modules based on event data from APC systems or timepoint data from ride checkers. Because they integrate performance data with schedule data, these modules easily do schedule adherence analysis and running

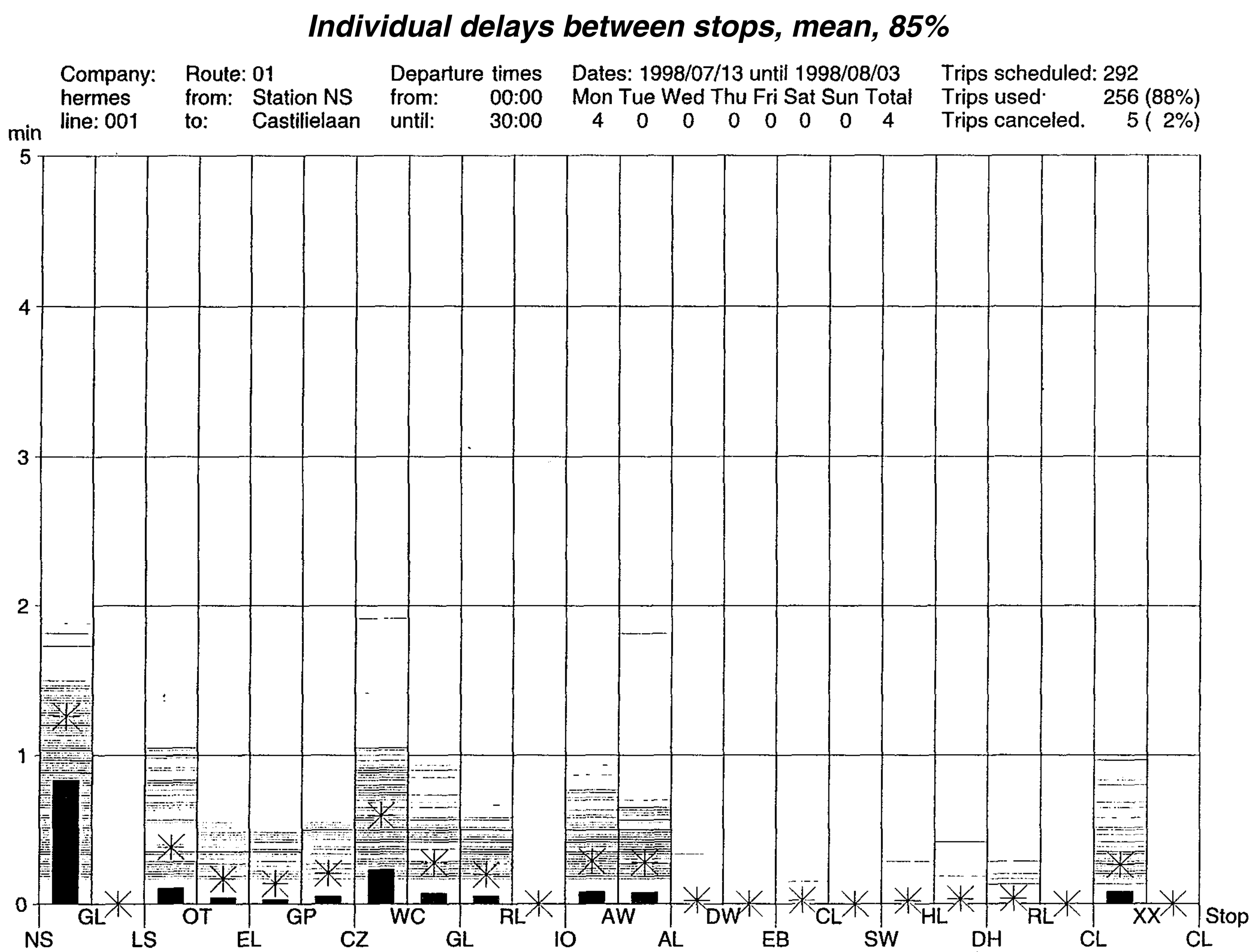


FIGURE 5 Delays between stops report (Hermes, Eindhoven) (*Copyright* Theo Muller, TU Delft).

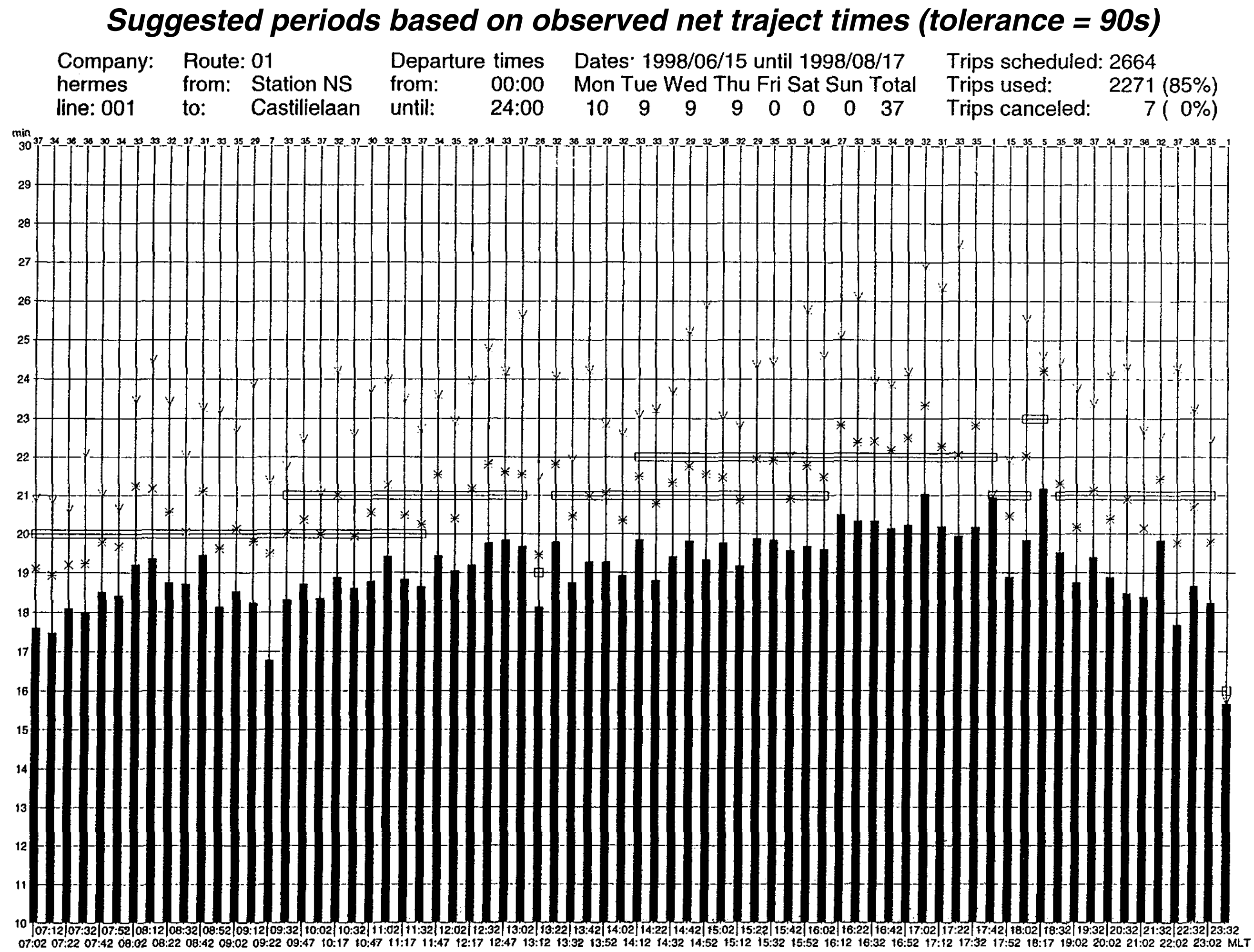


FIGURE 6 Identification of periods of homogeneous net trip time (Hermes, Eindhoven) (*Copyright* Theo Muller, TU Delft).

time analysis. They allow results from running time analyses to be fed easily back to the scheduling system if the analyst wishes to change the scheduled running time.

In North America, only agencies with APCs have been doing any significant trip time analysis. Recent generation AVL systems, which include event recorders and methods for determining location between polls, may begin to follow suit. The availability of trip time analysis software may encourage agencies without APCs to invest in trip time analysis hardware, either as part of an AVL system or standing alone for off-line analysis only.

ROUTE ECONOMIC PERFORMANCE COMPARISON

Most transit agencies calculate economic performance indicators for each route. Most performance indicators are productivity or cost recovery ratios, comparing a measure of output to a measure of input, or comparing revenue to cost. Of 19 responding agencies, 7 report route productivity each month, 5 report each quarter, 1 reports twice a year, and 6 report once a year.

Many of the inputs for these analyses, such as vehicle-hours per route, come from the scheduling system. The chief input from the agency's data collection program is route-level ridership. Route-level revenue appears in many reports as well. In some cases it is simply determined from ridership using an average fare factor; in other cases a more detailed estimation is made based on route-level ridership by fare category. Other inputs taken from the data collection program at various agencies include passenger miles and peak loads.

The data system used to calculate performance indicators thus draws input from both the scheduling system and the data collection program. Recently installed scheduling systems are almost all PC-based, although some agencies are still using systems on mainframe computers. In either case, most scheduling systems are capable of producing reports that list the desired inputs (e.g., vehicle miles) by

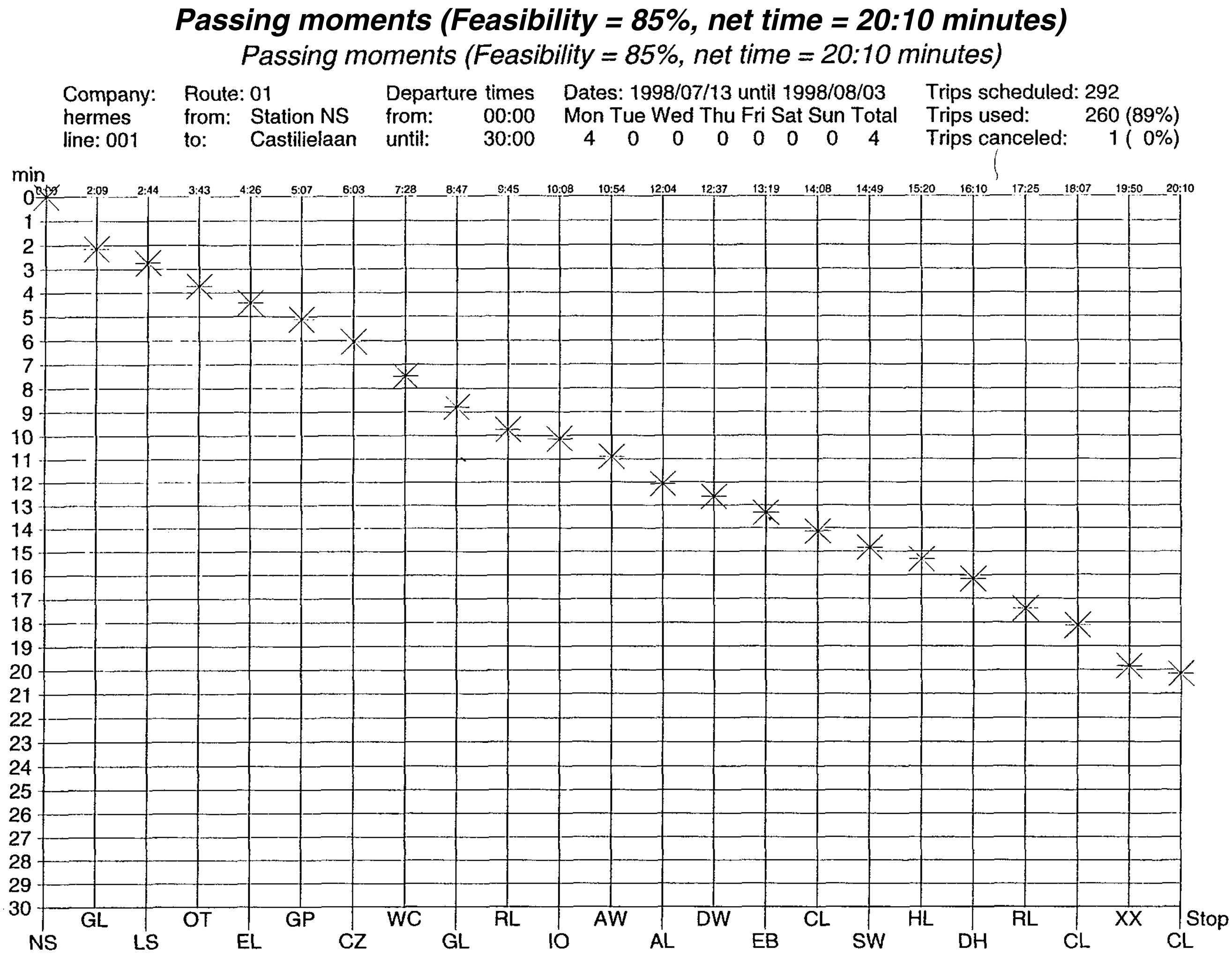


FIGURE 7 Suggested stop to stop scheduled running times (Hermes, Eindhoven) (*Copyright* Theo Muller, TU Delft).

route in a standard format that can then be downloaded into the database used to calculate the performance indicators. The data system used to calculate route performance indicators is sometimes separate from that used for ridership and other collected data. A spreadsheet or simple database program is sufficient for calculating and reporting performance indicators. Its inputs come from reports generated by both the ridership database and the scheduling system. This transfer is often partially automated, that is, the performance indicator database can read an input file produced by the ridership or scheduling database. However, at many transit agencies, inputs are still keyed in manually from printed reports.

More often, the performance indicators are calculated using the data system that holds route-level ridership data, making data transfer from the ridership database unnecessary. The desire to calculate performance indicators is one of the motivations for transferring farebox data—often the main source of route-level ridership and revenue—from its proprietary database to a more flexible, open database.

Although many route-level economic performance indicators have been proposed and used, there is no uniform agreement across agencies for any particular set of indicators. In addition, although a review of all the various indicators that have been used or proposed is beyond the scope of this report, some example reports will be presented that illustrate this kind of analysis.

An example performance indicators report is shown in Table 16. This example, from the Kansas City Area Transportation Authority and developed on a spreadsheet, uses inputs keyed in manually from farebox system reports (boardings counts by route and by fare category), the scheduling system (pay hours and vehicle miles), and pass sales. It determines average revenue per passenger for each route by allocating cash revenue over the routes in proportion to registered cash fares, and by allocating pass sales revenue in proportion to registered pass use. Simple formulas are used to calculate direct cost (called variable cost at some other agencies) for each route. Three perfo-rmance indicators are calculated for each route: direct cost

TABLE 16

ROUTE ECONOMIC PERFORMANCE COMPARISON REPORT

Mar-98

ROUTE LEVEL	SYSTEM MONITORING		WEEKDAY SCHEDULE		RATES	LB HOURS $24 84 SB HOURS $15 70	LB MILES $0.27 SB MILES $0 19	FLEX HRS FLEX MILES	$13 60 $0 09
ROUTES	EQUIV PAY HOURS	PASSENGERS PER HOUR	DAILY MILES	PASSENGERS PER MILE	ROUTE DIRECT COST	DIRECT COST PER PASSENGER	REVENUE PER PASSENGER	DIRECT OPER. COST RATIO	SUBSIDY PER PASGR
#1/4 MINN-ARG.	75	14 1	803	1.3	$1,331.12	$1 26	$0 60	47 4%	$0 66
#102 CENTRAL	8	7.2	72	0.8	$145.29	$2.41	$0 56	23.2%	$1 85
#6 QUINDARO	34	26 7	555	1.6	$636.38	$0 70	$0 48	68 0%	$0 23
#5/7 SEV-PARA.	15	14 4	214	1.0	$311.89	$1.47	$0 68	46 0%	$0 79
#8 INDIANA	53	20 5	599	1 8	$1,487.37	$1.36	$0 52	38.5%	$0 84
#109 NINTH ST/SB	24	16 8	267	1.5	$434.33	$1 06	$0 52	49 0%	$0 54
#110 WOOD-BRKLN	16	12.5	182	1.1	$285.78	$1.43	$0 56	39 3%	$0 87
#12 TWELFTH ST	75	28.2	700	3 0	$2,059.87	$0.97	$0 50	51 9%	$0 47
#121 CLEVELAND	19	8.3	260	0 6	$350 06	$2.19	$0 54	24 4%	$1 66
#123 TWENTY-THIRD	10	10 7	136	0.8	$184 93	$1 71	$0 54	31 7%	$1 17
#24 INDEPENDENCE	125	24 7	1,356	2.3	$3,398.72	$1.10	$0 55	49 6%	$0 56
#25 TROOST	224	31 7	2,709	2.6	$6,304 71	$0 89	$0 48	53 8%	$0 41
#126 EAST 5TH	17	9 8	157	1.0	$293.86	$1 79	$0 38	21 3%	$1 41
#27 TWENTY-SEV	88	26 1	845	2.7	$2,422.34	$1.05	$0 50	47.2%	$0 55
#28 BLUE RIDGE	138	14 5	2,463	0.8	$4,092.11	$2 04	$0 60	29 5%	$1 44
#29 K.C.I	39	9 3	755	0 5	$1,163 00	$3.24	$0 59	18 1%	$2 65
#30 NORTHEAST	47	20.2	459	2 1	$1,281.90	$1.36	$0 55	40 7%	$0 81
#31 THIRTY-FIRST	66	34 5	593	3 9	$1,806.18	$0 79	$0 44	55.1%	$0 35
#32 GRACEMOR	9	7 8	103	0 7	$158.52	$2.30	$0 63	27.2%	$1 68
#33 VIV-ANTIOCH	34	8.2	442	0 6	$650.62	$2 32	$0 50	21.5%	$1.82
#35 LIBERTY	8	7 4	118	0.5	$150 11	$2.48	$0 62	24 9%	$1 86
#37 GLADSTONE	21	9 4	364	0 5	$620.34	$3.14	$0 62	19 7%	$2 52
#38 MEADOWBROOK	31	14.5	420	1 1	$885.50	$1.97	$0 56	28 5%	$1 41
#39 THIRTY-NINTH	111	29 1	975	3.3	$3,027 52	$0 93	$0 45	48 2%	$0 48
#47 ROANOKE	70	15.5	847	1.3	$1,958.80	$1.82	$0 52	28.8%	$1.29
#51 WARD PRKWY	88	17 6	961	1.6	$2,432.97	$1.58	$0.55	34 5%	$1 03
#53/54 ARM-PASEO	113	22.0	1,350	1.8	$3,174.33	$1.28	$0 56	43 6%	$0 72
#55 ROCKHILL	29	14 0	417	1.0	$827 98	$2.06	$0 57	27 5%	$1 49
#56/57 COUNTRY CL	197	22.1	2,234	2.0	$5,504 93	$1.26	$0 53	41 7%	$0 74
#63 SIXTY-THIRD	47	10 8	577	0.9	$849 10	$1.67	$0 42	24 9%	$1 26
#69 LIBERTY XX	8	11.4	138	0 7	$193 90	$2.12	$0 73	34 3%	$1 39
#71 PROSPECT	173	32.8	2,136	2.7	$4,885 64	$0 86	$0 47	54 8%	$0 39
#73 CASINO CRUISE	24	7 7	385	0 5	$446 03	$2.43	$0 53	21 9%	$1 89
#175 SEVENTY-FIFT	26	12.1	365	0 9	$481.99	$1 52	$0 48	31 4%	$1 04
#191 YELLOW IND	16	10.1	211	0.8	$291.29	$1 80	$0 52	29.2%	$1.27
#193 RED INDEP	16	11.5	217	0.8	$292.43	$1.59	$0 44	27 8%	$1 15
#155 FIFTY FIFTH	26	8 6	271	0 8	$457 07	$2 05	$0 59	28 7%	$1 46
#296 METRO-FLEX	14	6.2	252	0.3	$210.78	$2.45	$0 46	19 0%	$1 98
#298 SKC WORNALL	13	4.1	214	0.3	$196 10	$3 65	$0 50	13 6%	$3 16
#234 TIFFANY SPRI	8	0.9	155	0 0	$127 74	$16.93	$0 64	3 8%	$16 28
#283 IND. GREEN	16	4.0	140	0 5	$230.20	$3 56	$0 62	17 3%	$2 94
#284 IND. PURPLE	16	2.2	126	0.3	$228 94	$6 57	$0 48	7 3%	$6 09
#285 IND BLUE	16	3 0	163	0.3	$232.27	$4 88	$0 52	10 6%	$4 36
#236 NORTHLAND LI	12	1.3	205	0 1	$176.21	$11.37	$0 60	5 3%	$10 77
#246 JOBLINK	9	1.4	234	0 1	$140 74	$11.14	$0 38	3 4%	$10 76
TOTAL	2,225	20.9	27,145	1 7	$56,821.87	$1.22	$0 51	41 6%	$0 72

Source: Kansas City Area Transportation Authority.

TABLE 17

ROUTE ECONOMIC PERFORMANCE COMPARISON REPORT: COMPOSITE RANKING

LYNX
Route Performance

April 1998 ***Overall***

Link #	$ Subsidy/ Passenger	Passengers/ Trip		Passengers/ Revenue Hour		Passengers/ Revenue Mile		% Farebox Return		Composite Rank
08	0.58	50.87	2	41 47	4	3 03	5	46.59	1	1
04	0 67	52 22	1	36 07	5	2 50	12	44.38	3	2
48	0 55	30 99	11	41 88	2	2 79	9	44 96	2	3
49	0.58	30.26	13	41.49	3	3 19	4	42 72	4	4
20	0 75	36.58	7	35 16	7	2.84	7	37 34	6	5
25	0.74	35.93	8	35 99	6	2.68	11	36 70	7	6
28	0.77	24.79	19	33.85	9	2.82	8	37.99	5	7
22	0 83	20.92	27	34 00	8	3 52	2	33.19	11	8
07	0.89	24 74	20	32.18	11	2.93	6	33 13	12	9
41	1.09	50 20	3	26.74	17	1.77	21	34 11	10	10
19	0.92	18.46	30	31.09	12	3.44	3	31 10	14	11

Source: LYNX, Orlando, Fla.

TABLE 18

WATCH LIST: ROUTE WITH SUBSTANDARD ECONOMIC PERFORMANCE

EXHIBIT I BUS ROUTE WATCH LIST MARCH, 1996

ROUTES TARGETED FOR REVIEW BY DAY TYPE

Routes with stars have appeared on the weekday watch list for at least 7 of the previous 8 performance reports

		WEEKDAY		SATURDAY		SUNDAY	
ROUTE	NAME	Bottom 20%	< 52% VCR	Bottom 20%	< 52% VCR	Bottom 20%	< 52% VCR
7	HARRISON			X		X	X
8A	SOUTH HALSTED						X
10	MUSEUM OF SCIENCE & INDUSTRY				X		X
11	LINCOLN	X					
15	★ SHOPPERS LOOP	X	X				
16	★ LAKE STREET	X	X	X	X	X	X
17	WESTCHESTER		X				
18	★ 16TH/18TH	X		X	X	X	X
23	WASHINGTON EXPRESS						X
24	★ WENTWORTH			X	X	X	X
25	WEST CERMAK	X	X		X		
27	SOUTH DEERING						X
30	★ SOUTH CHICAGO	X		X	X	X	X
31	★ 31ST	X	X	X	X		
32	★ WEST 31ST	X	X				

Source: Chicago Transit Authority.

per passenger, subsidy per passenger, and cost recovery (revenue divided by direct cost).

With routes ranking differently according to different performance indicators, some agencies have developed a formal method of combining results from different indicators. An example, taken from Orlando's LYNX (the Central Florida Regional Transit Agency) and shown in Table 17, shows each route's rank with respect to four indicators, from which a composite ranking is determined. Routes are listed by composite rank, with the bottom quartile noted. This report is generated from a custom-programmed Foxpro database on a PC, which combines farebox data extracted electronically from the GFI farebox system, traffic checker data uploaded from hand-held devices, and data extracted from the scheduling system.

Looking at historical rankings provides an additional dimension for analysis. A monthly report from the CTA (Table 18) is the "watch list"—routes whose cost recovery

TABLE 19

ROUTE SCHEDULE ADHERENCE COMPARISON

To: All Concerned

From: Don Larson, Traffic & Schedules Office Manager

Subject: ON-TIME PERFORMANCE

Date: 1/22/98

Listing below are the on-time performance figures by line which were checked in th month of **April, 1997**.

DIV. No.	LINE No.		Counted	No. Trips Sharp	Late	No. Trips On Time	Percent On Time
2	7	Solano & The Alameda	61	5	22	34	55.7%
2	12	Piedmont & Linda	75	11	12	52	69.3%
2	43	First Ave. & E14th St.	84	1	28	55	65 5%
2	43	Solano & The Alameda	106	5	30	71	67.0%
4	40	First Ave & E.14th St.	104	1	34	69	66.3%
4	57	Fruitvale & MacArthur	112	5	24	83	74 1%
4	58	Fruitvale & MacArthur	103	13	20	70	68.0%
2	59	Piedmont & Linda	68	13	7	48	70.6%
3	72	BART/Del Norte	151	17	50	84	84.4%
3	73	BART/Del Norte	56	5	19	32	57.1%
4	124	Fruitvale & MacArthur	72	4	12	56	77.8%
		SYSTEM TOTAL	992	80	258	654	65.9%
		PERCENTAGE	100%	8.1%	26.0%	65.9%	

Source: AC Transit, Oakland, Calif.

is either below a standard or ranks in the bottom 20 percent for their route type. A special mark indicates routes that have appeared on the watch list in at least seven of the last eight performance reports. This report is produced on a mainframe using software developed in-house, using data extracted electronically from the GFI farebox system and from the scheduling system.

In recent years there has also been a trend toward monitoring operational performance or service quality measures such as on-time performance, crowding, or operational speed at the route level. Our survey did not uncover any examples in which such measures are being reported alongside economic performance measures. Single indicator reports were common, for example, a comparison of routes in schedule adherence. A monthly report shown in Table 19 from Oakland's AC Transit shows schedule adherence for the routes checked that month. This report is prepared manually, based on point checks, by extracting summary data from the EZdata database, which processes checks made with hand-held devices.

SYSTEM-LEVEL SCHEDULE ADHERENCE

Many transit agencies monitor operations and service quality by measuring schedule adherence at the system level. Of course, knowing route-level schedule adherence is more valuable because it can better indicate where improvements are needed and can always be aggregated to yield a system-level estimate. However, the number of observations needed to reliably estimate schedule adherence for every route—at least 100 per route—is prohibitive for agencies without automatic data collection. Recording several hundred observations across the entire system is, by contrast, much more achievable, even with manual observation.

TABLE 20

SYSTEM-LEVEL SCHEDULE ADHERENCE REPORT

PIERCE TRANSIT

On-Time Performance

Performance Summary for January, 1998

Wednesday, February 25, 1998 — Page 1

System-Wide On-Time Performance

	Early			On-Time			Late		
	3+	2	1	0-1	2-3	4	5	6	7+
All Trips	0	0	2	154	46	.12	3	4	4
Percent		0.89%			94.22%			4.89%	

On-Time Performance By Area

	Early	Late	On-Time	%Early	%Late	%On-Time
Central	1	4	93	1.02%	4.08%	94.90%
Commerce	0	1	13	0.00%	7.14%	92.86%
East	0	1	14	0.00%	6.67%	93.33%
North	0	2	48	0.00%	4.00%	96.00%
Northwest	1	0	5	16.67%	0.00%	83.33%
Olympia	0	0	0			
Seattle	0	0	0			
Southwest	0	3	39	0.00%	7.14%	92.86%
	2	11	212	0.89%	4.89%	94.22%

On-Time Performance Time of Day

	Early	Late	On-Time	%Early	%Late	%On-Time
Morning	0	0	1	0.00%	0.00%	100.00%
AM_Peak	1	2	26	3.45%	6.90%	89.66%
Mid_Day	0	1	89	0.00%	1.11%	98.89%
PM_Peak	0	6	56	0.00%	9.68%	90.32%
Evening	1	2	40	2.33%	4.65%	93.02%
	0	0	0			
	2	11	212	0.89%	4.89%	94.22%

Source: Pierce Transit, Tacoma, Wash.

Some transit agencies assume an informal approach, taking schedule adherence observations as they come, so to speak. For example, street supervisors may make schedule adherence checks when they have free time or schedule adherence observations may be part of data collection activities undertaken for another primary purpose. These observations are all collected to determine the percentage of trips that were on time. It is impossible to assign a level of accuracy to such an estimate, for while the sample size may be great, the selection is certainly not random, and there tend to be numerous biases in such an estimate.

A few agencies take a more deliberate approach to scientifically estimating schedule adherence. Tacoma's Pierce Transit (Table 20) randomly selects 220 trips per month for schedule adherence checks. Street supervisors build their work schedules around these checks. If the level of punctuality is such that 90 percent or more of the trips are normally on time (as is the case at Pierce Transit), this size sample provides a margin of error of ±4 percent at the 95 percent confidence level in the estimated fraction of trips that are on time, early, or late. A breakdown is also given for different parts of the service area and for different times of day. This report is produced on a PC using a Paradox database. The street supervisor data are keyed in.

Other agencies take an intermediate approach, doing dedicated schedule adherence checks, but sampling in such a way that it is difficult to determine the accuracy of the estimate. For example, it is natural to concentrate the checks, having a stationary observer observe all the trips passing a point for 1 or 2 hours. Of course, they are not independent observations and the effect of the cluster sample on accuracy is not usually assessed.

GEOGRAPHIC ANALYSES

Some scheduling and planning applications call for analyses by location based on data from all the routes serving that location. These analyses require data from all routes, coded and structured in a way that reflects, at least to some degree, the underlying geography.

The simplest data structure is for every physical bus stop to have a unique identity and for each route's stop list to point to the physical stops. This kind of data structure allows for analyses to be focused on a single physical stop or a group of stops. Several responding agencies do this type of analysis. For example, Table 21, taken from Seattle Metro's APC system, is a stop activity or screenline report showing passenger and vehicle activity (ons, offs, passenger volumes, vehicle passage) at a given stop, including all routes serving that stop. Table 22, from OC Transpo's APC system, shows a report of passenger activity in an "area," meaning a user-defined group of stops. The "area" can be defined to correspond to a traffic analysis zone used in metropolitan transportation planning analyses, enabling the agency to estimate transit's share of trips from the zone. Similar reports are also used at agencies that rely on manually collected data.

Truly geographic data structures and analyses are just beginning to see application in monitoring and operations planning at transit agencies. (The use of GISs for long-range planning is common, but these applications do not usually use service-monitoring data, such as passenger counts, and are usually functionally separate from service monitoring and operations planning.) In a truly geographic data structure, not only are routes linked to physical stops, but the physical stops are linked to geographic coordinates. This data structure permits integration with other databases using the same geographic coordinates, such as street maps, census files, land-use maps, and transportation planning files.

Five of the 20 responding agencies have some connection between their service monitoring data and a GIS, and a sixth is expecting to be using a GIS soon. One advantage of the GIS is that it can enhance standard reports by showing a geographical dimension. An example is the route load profile superimposed on a street map shown in Figure 2.

More importantly, the GIS facilitates analyses that involve a geographic dimension that would be far more difficult to do without geographically based data. Some of these analyses have traditionally been part long-range planning, even though they have applications to shor-trange service changes as well. An example is the calculation of an accessibility index, such as the fraction of the population living within 0.5 mile of a transit stop, which can be affected by a route extension or other route change. Another example is calculating the population living within 0.5 mile of a proposed new route. These examples do not make use of ridership data, and many transit agencies have institutional arrangements in which such GIS analyses can be performed by the regional planning agency.

GIS databases that incorporate traditional ridership data are still in the early stages of development. One such system, mentioned earlier, is the experimental MADCADD system, used in four Canadian cities. The Trapeze and Hastus scheduling systems have recently introduced geographically based modules for analyzing ridership data. Examples of geographically based analysis using ridership data include summarizing boardings in an area of interest, calculating passenger and bus volumes across a screenline, and calculating boardings per thousand residents within 0.25 mile of a stop or a line. Although the GIS capabilities of these modules are limited, that they can be included as part of a scheduling package procurement or upgrade makes it easier for many transit agencies to acquire a geographic ridership analysis system.

Tracking passenger trips beyond the route level—to estimate an origin/destination (OD) matrix or transfer volumes—is important in long-range planning, but still lies outside the realm of routine passenger data collection. (An exception is the transactional farebox, which may be able to track route-to-route transfers and individual travelers' trip patterns over varying lengths of time.) This type of

TABLE 21

BUS STOP ACTIVITY REPORT

Page 1
Run on 07/15/91 at 11.22.50

BUS STOP ACTIVITY
DATA FOR ALL STOPS - WEEKDAYS ONLY
SIGNUP: FALL 90

SEATTLE METRO APC SYSTEM
RPT5

KEYZONE	ON STREET	INT	CROSS STREET	DIR	PERIOD	I O	RTE	TYPE SER	# OF UNIQUE TRIPS SEEN	# OF TOTAL TRIPS SEEN	# OF TIMES BUS STOPPED	ON AVG PSGRS	TOTAL ONS	OFF AVG PSGRS	TOTAL OFFS	LOAD APPR AVG	AVG NUM SEAT
60	1 AV	FS	UNION ST	S	AM	I	5	E	5	31	6	.25	1.3	.16	.8	7.5	70
								L	2	8	6	.60	1.2	1.23	2.5	7.9	57
							11	L	4	73	58	.40	1.6	.54	2.1	5.3	50
							15	E	5	22	19	.72	3.6	7.37	36.8	35.9	70
								L	4	14	14	.60	2.4	4.72	18.9	17.1	57
							16	L	2	23	17	.77	1.5	1.05	2.1	14.4	58
							18	E	4	16	15	1.80	7.2	7.22	28.9	28.2	70
								L	2	13	13	.90	1.8	3.73	7.5	13.7	57
							28	E	7	75	33	.61	4.3	.23	1.6	8.9	51
								L	2	8	6	1.03	2.1	.10	.2	10.1	57
							305	E	2	7	0	.00	.0	.00	.0	4.2	44
						O	12	L	17	165	155	7.22	122.8	1.60	27.2	11.7	45
							20	L	7	88	80	1.66	11.7	.72	5.0	9.7	47
							21	L	6	41	33	1.84	11.0	.74	4.5	15.1	66
							22	L	5	32	31	2.40	12.0	4.16	20.8	23.3	54
							23	L	6	26	23	2.69	16.1	2.65	15.9	18.6	57
							54	L	7	58	46	1.49	10.4	.61	4.3	8.4	51
							55	L	6	30	20	.97	5.8	.30	1.8	12.0	70
							56	L	8	75	59	2.01	16.1	.32	2.6	10.4	53
					MID	:	0	L	1	76	8	.25	.3	.05	.1	1.2	55
						I	16	L	1	6	6	.00	.0	1.67	1.7	13.2	47
							28	L	13	45	42	1.81	23.6	.67	8.7	11.0	58
							302	E	6	53	11	.16	.9	.15	.9	3.1	49
							305	E	5	33	7	.07	.4	.09	.5	2.3	45
						O	12	L	39	334	325	4.03	157.0	1.70	66.4	13.5	45
							20	L	12	100	98	2.26	27.1	.95	11.4	13.5	44
							21	L	12	85	76	4.26	51.1	.89	10.7	24.5	50
							22	L	14	62	59	2.11	29.5	2.95	41.2	21.2	62
							23	L	13	56	51	2.60	33.8	2.30	29.9	21.7	62
							54	L	13	105	101	2.76	35.9	.54	7.0	17.4	58
							55	L	13	63	60	1.88	24.5	.42	5.5	19.2	70
							56	L	12	68	63	2.06	24.7	.70	8.4	11.6	57
							91	L	25	198	142	1.07	26.7	.10	2.5	6.0	45

Source: Seattle Metro.

TABLE 22

AREA PASSENGER ACTIVITY REPORT

PROCESSED· 98-06-01 12:07·25
REFERENCE: 422226

AUTOMATIC PASSENGER COUNTING SYSTEM
PASSENGER ACTIVITY BY AREA BY TIME PERIOD
WEEKDAY SERVICE

PAGE 1

AREA: GA31 CF700-CF620 (Made up of a collection of bus stops)

PERIOD: 97-09-02 TO 97-12-20
DAY OF WEEK: MON - FRI

ROUTE	STATISTIC	EARLY 03:01-06·30 ONS	OFFS	AM PEAK 06:31-09:30 ONS	OFFS	MIDDAY 09:31-15:30 ONS	OFFS	PM PEAK 15.31-18:30 ONS	OFFS	EVENING 18.31-03.00 ONS	OFFS	TOTAL ONS	OFFS
1	MINIMUM	1	0	1	1	2	0	0	0	0	3	0	0
	MAXIMUM	2	2	10	4	11	12	13	23	10	14	15	23
	MEDIAN	1	1	3	2	4	4	6	9	3	6	4	5
	AVERAGE	1 1	0.8	3 3	2 3	4 8	5 0	5.6	9 2	3 4	7 0	4 4	6 0
	STD DEV	0 5	0.5	2.5	1.0	2.3	3 4	2.8	4.9	2 8	3 2	2.8	4 4
	OBSERVED	4	4	11	11	25	25	21	21	13	13	73	73
	% SAMPLED	100	100	100	100	100	100	100	100	100	100	100	100
7	MINIMUM	0	0	0	0	0	0	3	4	0	1	0	0
	MAXIMUM	0	0	9	9	9	15	11	39	7	16	11	39
	MEDIAN	0	0	1	3	3	6	5	13	1	4	3	5
	AVERAGE	0 0	0.0	1.8	3.4	3.5	5.9	6 1	14.1	1.9	4.9	3 1	6 2
	STD DEV	0 0	0.0	1 9	2 1	2.4	3 9	2 5	9.1	2.2	3 8	2.7	5 7
	OBSERVED	0	0	24	24	31	31	12	12	16	16	82	82
	% SAMPLED	0	0	100	100	91	91	100	100	100	100	96	96
11	MINIMUM	0	0	0	0	0	0	0	0	0	0	0	0
	MAXIMUM	0	0	10	6	0	0	0	0	0	0	10	6
	MEDIAN	0	0	3	3	0	0	0	0	0	0	3	3
	AVERAGE	0 0	0.0	4 1	2.7	0.0	0.0	0.0	0.0	0 0	0 0	4 1	2.7
	STD DEV	0.0	0.0	3.2	1.9	0.0	0.0	0.0	0 0	0.0	0.0	3 2	1.9
	OBSERVED	0	0	10	10	0	0	0	0	0	0	10	10
	% SAMPLED	0	0	100	100	0	0	0	0	0	0	100	100
TOTAL	MINIMUM	1	0	0	0	0	0	0	0	0	1	0	0
	MAXIMUM	2	2	10	9	11	15	13	39	10	16	15	39
	MEDIAN	1	1	2	3	4	5	6	10	2	5	4	5
	AVERAGE	1 1	0 8	2 6	3.0	4 1	5 5	5 8	11.0	2 6	5 8	3 7	5 9
	STD DEV	0 5	0 5	2 5	1.9	2.4	3.6	2 6	7.0	2.6	3 6	2 8	5 0
	OBSERVED	4	4	45	45	56	56	33	33	29	29	165	165
	% SAMPLED	100	100	100	100	95	95	100	100	100	100	98	98

Source: Ottawa-Carlton Regional Transit Commission.

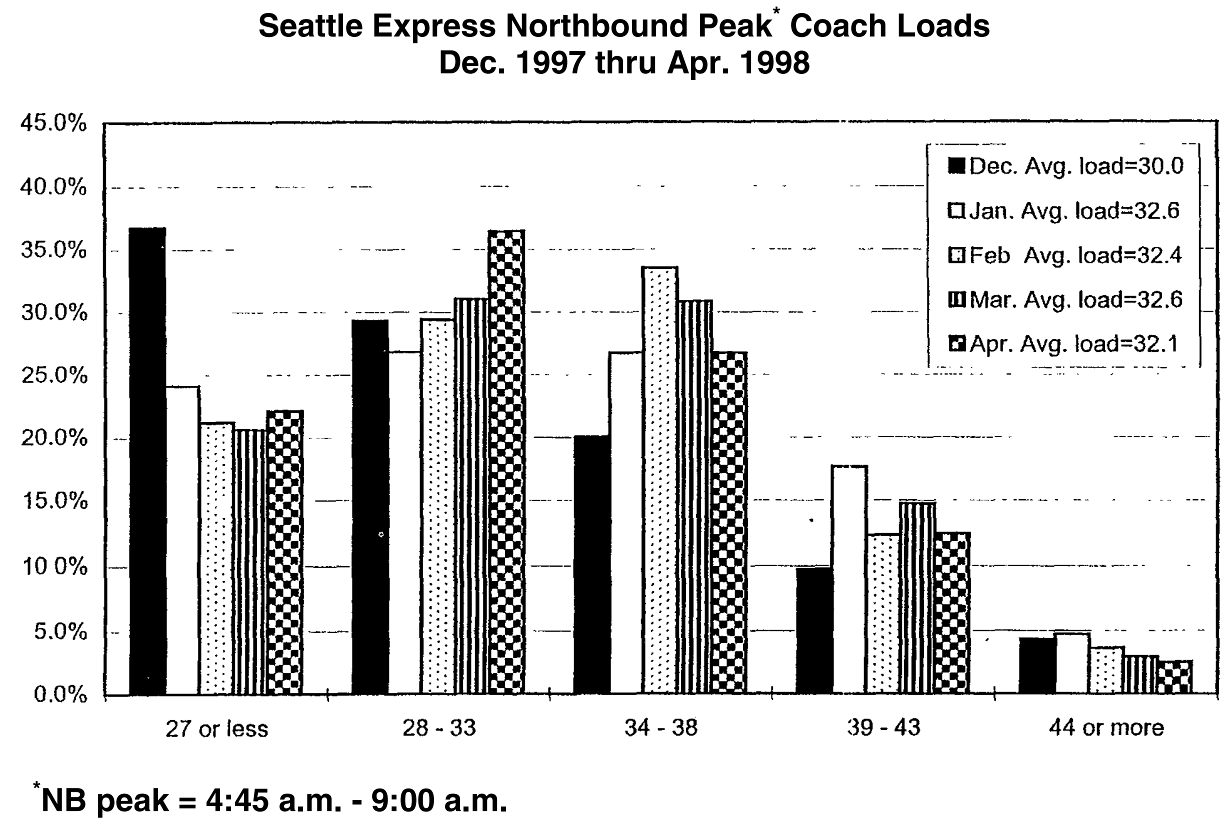


FIGURE 8 Ridership trends report: route level (Pierce Transit, Tacoma, Wash.).

data is particularly valuable for geographic analyses that transcend the route level and may be in greater demand as the GIS becomes a more common tool in planning and service monitoring. Example analyses might include determining the impact on transferring passengers of schedule changes, estimating the number of passengers that might be diverted to a new route, or analyzing the impact of a fare policy change involving transfer charges or distance-based fares. Some of these analyses, such as using routine passenger counts to update a transit OD matrix, will require the development of new estimation methods.

HISTORICAL ANALYSES

Analyses showing historical trends in system or route patronage or performance are useful for many reasons. To do a historical analysis, a database must either keep data over a long period of time or make and store relevant data summaries before old data are removed. Standard business software (spreadsheets, databases) can be used to prepare this type of report in a variety of formats.

Historical ridership reports at both the system and the route level are common. Figure 8 is an example of a graphical report from Tacoma's Pierce Transit of ridership on the Seattle express route showing the load distribution over 5 months. This report is produced from an RBASE database using data extracted from the GFI farebox system.

Tracking ridership changes on routes with service changes is a particularly critical analysis. A report for Norfolk's Tidewater Transit (Table 23) is an ad hoc report from a PC database summarizing ridership changes in meaningful ways—for example, by community, route type, and by routes affected by a road construction project. The database takes information from ride checks recorded using hand-held devices, the scheduling system, and the GFI farebox system. Tidewater Transit is now developing a more integrated Oracle database that will more easily combine data sources. This example underscores the value of a flexible database that allows users to query and develop reports responding to nonroutine as well as routine situations.

Changes to a route's layout or schedule can complicate some historical analyses, such as historical trends in running time or in trip-level ridership. The simple solution is to allow such analyses only as far back in time as the routing and/or schedule is unchanged. More complex solutions require some modeling assumptions. However, even the simple solution requires some intelligence on the part of the database to recognize when routing and schedule changes occurred and to know for which analyses data from changed routes may or may not be admitted.

TABLE 23

RIDERSHIP CHANGES ON ROUTES WITH SERVICE CHANGES

Fiscal Years 94-95 & 95-96 Performance Analysis

City/Route	Hours 1995	1996	Change	Passengers 1995	1996	Change	Passengers/Hour 1995	1996	Change	Passenger Revenue 1995	1996	Change	Average Fare 1995	1996	Change
#61 Crossroads															
Chesapeake	0	1,296		0	1,410			1.1		0	1,771				
Norfolk	4,048	835		11,622	17,320		2.9	20.7	622.47%	16,612	15,602	-6.08%	1.429	0.901	-36.98%
Portsmouth	0	49		0	2,320			47.3		0	1,442				
Va Beach	0	3,368		0	2,455			0.7		0	1,917				
Subtotal	4,048	5,548	37.06%	11,622	23,505	102.25%	2.9	4.2		16,612	20,732	24.80%	1.429	0.882 ,	-38.29%
Norfolk															
Church St Restructuring															
#4 Church St.	13,973	14,975	7.17%	229909	182433		16.5	12.2	-25.96%	154487	147258	-4.68%	0.672	0.807	20.13%
#10 Ghent/Park Place	0	1,824		0	5192			2.8		0	5398			1.040	
Subtotal	13,973	16,799	20.22%	229909	187625	-18.39%	16.5	11.2	-32.12%	154487	152656	-1.19%	0.672	0.814	21.08%
Norfolk CBD Parking															
#16 P&R Lot 39	0	2,905		0	164395			56.6		0	0				
#40 P&R	2,540	3,105	22.24%	100834	31110		39.7	10.0	-74.76%	0	0				
Subtotal	2,540	6,010	136.61%	100834	195505	93.89%	39.7	32.5	-18.06%	0	0				
Portsmouth															
#44 Midcity	2,505	8,779	250.46%	92,881	109,434	17.82%	37.1	12.5	-66.38%	58,870	69,786	18.54%	0.634	0.638	0.61%
#48 Shuttle	0	662		0	3,666			5.5		0	0				
Va Beach															
#24 Laskin Rd	1,595	1,829	14.67%	43,521	45,773	5.17%	27.3	25.0	-8.28%	40,352	38,540	-4.49%	0.927	0.842	-9.19%
#27 Northampton Blvd.	2,836	3,150	11.07%	22,020	40,166	82.41%	7.8	12.8	64.22%	13,023	24,222	85.99%	0.591	0.603	1.97%
Park & Ride Express															
#19 Timberlake NB	3,774	3,183	-15.66%	39,471	46,476	17.75%	10.5	14.6	39.61%	52,269	68,475	31.00%	1.324	1.473	11.26%
#22 Indian River NB	3,058	3,320	8.57%	37,439	48,486	29.51%	12.2	14.6	19.29%	49,147	65,818	33.92%	1.313	1.357	3.41%
#28 Indian River CBD	951	100	-89.48%	4,172	295	-92.93%	4.4	3.0	-32.76%	4,441	247	-94.44%	1.064	0.837	-21.34%
#35 Pembroke NB	1,752	167	-90.47%	13,892	1,107	-92.03%	7.9	6.6	-16.40%	18,793	1,162	-93.82%	1.353	1.050	-22.41%
Subtotal	9,535	6,770	-29.00%	94974	96364	1.46%	10.0	14.2	42.90%	124650	135702	8.87%	1.312	1.408	7.30%
Total Changed Routes	37,032	49,547	33.80%	595,761	702,038	17.84%	16.1	14.2	-11.93%	407,994	441,638	8.25%	0.685	0.629	-8.14%
Share of All Routes			3.85%			1.57%						0.58%			
Total All Routes	374,032	386,800	3.41%	7,241,175	7,508,249	3.69%	19.4	19.4	0.27%	5,898,830	6,167,889	4.56%	0.815	0.821	0.84%
Net All Other Routes	337,000	337,253	0.08%	6,645,414	6,806,211	2.42%	19.7	20.2	2.34%	5,490,836	5,726,251	4.29%	0.826	0.841	1.82%
Share of All Routes			0.07%			2.21%						3.99%			

#61 Crossroads is a new route linking to Pentran. Note that the changes are essentially a redistibution among cities.
#44 Midcity was extended significantly on both ends.
#35 Pembroke Ex was discontinued.
#24 Laskin Rd. is a beefed up reverse commute express.

Source: Tidewater Transportation District Commission.

CHAPTER SIX

CONCLUSIONS

A wide variety of types of analyses are being done in transit agencies in support of operations planning, scheduling, and service-monitoring functions. This synthesis documents common analyses performed at the system level and at greater levels of geographic and time detail.

In addition to documenting typical analysis methods and reports, specific conclusions of this synthesis are as follows:

- *With proper attention, measurement error can be controlled.* Although some data sources present greater challenges to the recording of accurate measurements than others, measurement error can be reduced to acceptably small levels with the appropriate effort. Errors stemming from operator failure—primarily a problem with electronic farebox counts—can be controlled if data are regularly screened, feedback is given promptly within the standard channels of discipline and retraining, and with the cooperation of managers in the transportation and maintenance departments. Errors stemming from equipment malfunction—primarily a problem with APCs, but with other devices as well—can be controlled with automated screening of data and responsive hardware and software maintenance. Errors in observing loads in point checks can be controlled by regular testing with feedback and retraining.

- *Automated data collection holds the key to doing statistically valid analyses of running time and route-level schedule adherence.* Agencies without automated data collection rely on very small samples to estimate necessary running time and to monitor schedule adherence. They compensate by relying on subjective inputs such as operator and passenger complaints and comments made by traffic checkers. Agencies with automatic collection of running time and punctuality data are able to perform objective analyses of performance. These analyses give objective guidance for needed improvements in scheduling, operations control, and traffic engineering, and provide feedback on the effect of such improvements.

- *By failing to capture location data for off-line analysis, many automatic vehicle location systems miss an opportunity to support off-line analysis of operations data.* Although off-line analysis of running time and schedule adherence is less glamorous than real-time displays of vehicle location, its importance for scheduling and operations monitoring should not be overlooked. Unfortunately, many existing AVL systems were not designed to capture data for off-line analysis, and adding this capability to existing systems is often impractical. Part of the problem is that off-line trip time analysis demands a different kind of location accuracy than does real-time monitoring. Agencies desiring to use AVL as a data source for analyzing operations data must ensure that this capability is an essential component of the system design. APC systems and trip time analyzers, which are customarily designed exclusively for off-line data analysis, usually provide more useful operations data than AVL systems.

- *Statistical treatment of estimates has not spread far beyond federal mandates for NTD reporting.* Based on our survey of industry practice, the statistical precision of most ridership and operations measures is unknown, and statistical sampling is not the norm except for estimating system-wide annual boardings and passenger miles for NTD reporting. Furthermore, sample sizes with manually collected data are often too small for estimates to have a reasonable statistical precision, except for system-level measures. Conversely, there are numerous examples of statistically valid sampling plans with manually collected data for such varied uses as system-wide schedule adherence, adjustment factors for farebox undercount, and average trip length. Furthermore, where automated data collection systems measure data from every trip daily, statistical estimation is unnecessary. Where automated data collection systems are used for sampling—such as when APC-equipped vehicles are rotated over the vehicle duties in the schedule—larger samples and better statistical precision are obtained than with manual data collection.

- *Industry practice is not yet mature enough in its development of data systems for planning and service-monitoring data.* There are still a large number of small, informal data systems such as spreadsheets in use that require a good deal of manual data input and intervention. Report formats that give the information in the most useful, readable manner seem to be more the exception than the rule. Many of the report formats still look like outputs from 1960s mainframe programs, suffering from tiny print, clutter, vast empty spaces, cryptic titles and legends, and absence of graphics. Data transfers between data systems at transit agencies—for example, farebox, schedule, and ridership data systems—often entail a good deal of manual work, with output from one system sometimes keyed into a second system. Some agencies are still using old, inflexible data systems, sometimes on old mainframe computers. Many agencies are in the process of developing new data systems based on commercial database software running on PCs, programmed by users or consultants to produce desired reports. These new data systems are designed to integrate data from several sources. Several agencies have invested heavily in the software needed to get data into a standard format so that an interface can be made with another system. It is worth noting that, with all of the software development being done by and for agencies, no examples have been observed of one agency's software being shared with another agency.

- *The industry is migrating to general purpose database packages for data analysis.* Software packages used by agencies to analyze transit ridership and performance data can be divided into three groups: (1) general purpose database and spreadsheet software, (2) custom software, and (3) software supplied to support a particular data collection device. Custom software appears to be only a remnant of the mainframe era and is being replaced. Software packages that support devices have limited capability, because many analyses require integrating data from different sources. For example, all of the agencies with fareboxes responding to this study export farebox data to their own databases because their analysis and reporting needs are beyond the capabilities of the farebox data system. Almost all of the recent developments in data analysis software have involved the use of general purpose, commercially available database packages on PCs (sometimes networked). Agencies are converting from both custom software on mainframes and from less powerful software on PCs. General purpose database packages have low cost, give the agency a wealth of modern tools, and are readily updated as software tools advance. These databases are flexible, allowing the agency to tailor its database structure to its data types and its report formats to its reporting and analysis needs. However, adapting general purpose database software for receiving and analyzing transit data requires expertise that is not available at many transit agencies.

- *Although route-level analyses of ridership are well developed, network-level and geographic analysis methods are still in their infancy.* Useful ridership reports are common at the route and subroute level with differing levels of time detail. In contrast, network analyses and analysis methods based on geographic areas are only beginning to appear. This difference stems from factors related to both data collection and database structuring. Route-level data collection is easily conducted by following the vehicles serving a route, although passenger travel patterns beyond individual routes (e.g., transfer patterns and origin-destination information) are not captured by typical data collection practices. Also, storing and analyzing data by route requires a much simpler data structure than that required by network analysis. In addition, geographic analyses require that data be coded with geographic coordinates with a common reference system. Although geographic data systems for long-range planning are well developed, geographic data systems that accept routine ridership data (e.g., ride checks and APC counts) as input are still in the experimental stages of development.

- *Commercially available data systems for transit ridership and operations data analysis may play a role in advancing industry practice in data analysis.* Historically, the only commercially available software specifically for transit data analysis has been software tied to a specific data collection device. However, new products that are not tied to particular data collection devices are being developed by suppliers of scheduling software and by university research centers. These new products have strong database capabilities, and some have geographic databases that permit higher levels of data integration and analysis. For agencies that lack the expertise to develop their own modern data system based on a general purpose database, a commercially available product structured for transit data may meet the need for improved analysis capability. Even at agencies with a modern database system, a commercially available product with geographic capability may be preferred to the custom modification of a GIS. Whether these and other similar new products will prove successful is yet to be determined and will depend on their quality, flexibility, ease of use, price, and adaptability to the needs of different transit agencies.

Based on the findings of this study, the following issues seem promising for further research:

- *Research into standard data definitions and interfaces may simplify efforts to integrate data from different sources.* Closed and inconsistent data structures in proprietary data collection systems makes integrating data from different sources more difficult. The current movement toward standard definitions and interfaces in transit data, which is focused primarily on real-time data analysis, should be expanded to encompass data used off-line. Research into data definitions and data structures being used and/or needed on both sides of the interface may lead to some recommended standards that will ease the flow of data between systems, and may lead to a more competitive market for data analysis products. Particular attention should be focused on data structures that will support the kinds of geographic and network analyses desired by transit planners. If industry concurs with the results of such research, it could follow a course of officially defining standards and requiring compliance with standards in future procurements of data collection systems and software.

- *Detailed case studies of a few advanced data systems could serve as a model for transit agencies developing their own databases.* It would be useful to profile in detail a few recently developed data systems that integrate several data sources using commercial database software. These profiles might help guide similar development efforts at other transit agencies. Important facets of the study would be data structures, algorithms used to automate the transfer of data from other databases, algorithms used to screen and edit data, and report formats. Likewise, it would be useful to closely examine a few recently developed geographic databases using transit monitoring and planning data.

- *Research is needed to clarify the costs and benefits of trip time analyzers.* There is an enormous gap between agencies that have very little operations data and those with trip time analyzers that collect and analyze information on every operated trip. Based on the experience of European systems with event recorders on every bus and North American systems with APCs on a fraction of the fleet, the uses and benefits of a large sample of trip time data should be further explored and compared with the costs of such a system. Because many of the benefits of the additional data are related to their role in improving service quality, the needed research must try to account for both the direct effect of data on service quality and the indirect effect of improved service quality on ridership and on operating efficiency.

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APPENDIX A

Questionnaire and Response Summary

Note: For some questions, agencies gave multiple responses, in which case the number of responses is greater than the number of responding agencies. When no answer is given, it is because answers were sparse and not suitable for summarization.

1. Approximate size of active bus and trolleybus fleet:

150 to 250	5
500 to 900	9
1,000 to 1,300	4
1,500 to 2,000	2

2. Scheduling software supplier:

G/Sched	4
Hastus	6
Minisched, RUCUS	2
Trapeze	6

Computer platform:

Mainframe	2
PC	14
Workstation	2

3. Does your passenger count or running time data interact with a Geographic Information System either in your agency or a cooperating agency (city, metropolitan planning agency)?

Yes	7

4. Farebox vendor and year of latest software upgrade?

Cubic	2
Duncan	1
GFI	13

Did you have the farebox software customized to enhance ridership data collection or reporting? If so, please explain.

Yes	5

What is the finest level at which you routinely segment your farebox data?

Trip	9
Hour	1
Route	5
Vehicle assignment	1

Because ridership data from fareboxes depends heavily on operator compliance, ridership data quality depends on the commitment of the organization. Which statement best describes the attention your organization pays to ensuring quality of ridership data from fareboxes?

0	Fareboxes are used for revenue collection; passenger counting is essentially ignored.
3	Ridership data are collected, but little attention is given to enforcing data quality, so that the ridership data can hardly be used by data analysts.
5	Some attention is given to data quality, but the data cannot be used without detailed checking by the end user, making use of this data source burdensome on the analyst.
6	The organization is committed to providing data analysts with good quality ridership data from the farebox; end users can use the data, but must still be wary because bad data occurs frequently.
2	The organizational commitment is very strong; the data quality seen by the end users is as reliable as data from traffic checkers.

If you choose either of the last two statements, please describe the key aspects of the process by which good ridership data from the fareboxes is assured.

Do you extract data electronically from the vendor's software system so that you can process it in a separate data system?

Yes	10

If your answer was yes, what data system do you then use for analysis and reporting farebox ridership data?

Commercial database	3
Own database	2
Spreadsheet	6
Statistical package	1

How many years of data is it designed to store?

Is this data system linked to your scheduling system (e.g., in order to know the current trip list)?

Yes	2

5. How often do operators collect ridership data that is entered into a computer database?

4 days/year, every route	1
24 days/year, every route	1
Every day, special routes only	2

What data system is used, and on what computer platform?

Commercial database, PC	1
Spreadsheet, PC	2
Statistical package, PC	1

Is the data system linked to the scheduling system (e.g., for knowing scheduled times)?

Yes	2

How many years of data is it designed to store?

6. Number or percentage of buses equipped with both AVL and APC? with AVL only?

Manufacturer?

For buses with AVL only: can the AVL system analyze data off-line (e.g., over the last month, X% of the trips on route Y were on time)?

Yes	6
No	3

Who supplied the data system for data storage and reporting?

Our agency	2 for APC, 3 for AVL
Hardware vendor or 3rd party	2 for APC, 4 for AVL

Is this data system based on a commercially available database system?

Yes	7
No	2

If so, which one, and on which computer platform?

Is this data system linked to the scheduling system (e.g., for knowing route descriptions and scheduled times)?

Yes	6
No	4

How many years of data is it designed to store?

2 to 6 months	2
1 year	3
10 or more years	3

Who programs (or programmed) this data system to produce reports?

Data users	6
MIS department	1
3rd party	3

7. *Traffic checker riding checks (with or without handheld-devices).*

The regular sampling program, excluding special projects and requests, includes:

Dedicated Section 15 (NTD) sample of:	(13 responses, from 205 to 550 trips/year)
Weekday trips are checked:	(4 "as needed"; 9 between 0.33 and 2 times a year)
Weekend trips are checked:	(4 "as needed"; 4 between 0.33 and 1 times a year)

Is the data routinely entered into a computer?

No	2
Via hand-held devices	7
Keyed in	8

What kind of database is used for riding checks?

Commercial database	5
Custom/specialized database	4
Spreadsheet	5
Statistical package	1

Is this data system/database linked to scheduling system (e.g., for generating stop lists and knowing scheduled times)?

Yes	8
Partially/working on it	3
No	4

How many years of data is it designed to store?

1 to 2	5
4 to 10	3
No limit	4

Who programs (or programmed) this data system to produce reports?

Data users	6
MIS or other department	5
Vendor or 3rd party	5

8. *Point checks made by traffic checkers or supervisors* (answer this section only if you have a regular program of point checks, with or without hand-held devices. A "point check" is data collection done at a fixed point by observing passing vehicles.)

What is the approximate number of regularly checked points in the data collection program?

13 to 40	5
50 to 100	3
101 to 300	3

How often are points normally checked?

Weekday peak periods	3 to 15 times/year (average = 6.1)
Weekday midday	0 to 12 times/year (average = 3.6)
Weekend:	0 to 5 times/year (average = 1.2)

For what purposes is point check data used?

Schedule adherence	100%
Passenger load	77%
Running time (multiple points)	46%
Transfer meets	8%

If you measure load, do you do it from outside or inside the vehicle?

100% from outside.

Is the data entered into a computer?

No	4
Via hand-held devices	5
Keyed in	5

What kind of database is used for point check data?

Commercial database	3
Custom/specialized database	3
Spreadsheet	4
Statistical package	1

Is the data system linked to the scheduling system (e.g., for knowing scheduled times)?

Yes 3

How many years of data is it designed to store?

Four responses: 2, 4, and 5 years, and no limit

Who programs (or programmed) this data system to produce reports?

Data users	4
MIS or other department	1
Vendor or 3rd party	2

9. *Estimating annual unlinked trips and passenger miles for the National Transit Database (Section 15)* (for U.S. systems only).

Do you use a method published by the FTA, or a customized method?

Customized method	7
FTA Circular 2710.1A (direct expansion)	5
FTA Circular 2710.4 (revenue based)	4

10. How frequently is system ridership reported to a public body (such as a Board of Directors)?

Weekly	1
Monthly (or 4 week period)	15
Quarterly	1
Annually	2

Do you report linked or unlinked trips?

Both	4
Linked	3
Unlinked	13

What estimation method do you use?

Estimate is based primarily on:	
Farebox counts	12
Revenue	7
Operator trip cards	1

Do you specify statistically the level of accuracy of your primary system-wide ridership estimates? If yes, what is it?

Two agencies responded "Yes." The only complete response was ±5% at 95% confidence level for annual linked trips.

11. Measurement error can be a concern for any data source, but particularly for point checks (for passenger load measurements), fareboxes (ridership data), operator trip cards, and APC. Please answer the following questions for any applicable data source.

Please describe efforts made to verify and improve measurement accuracy.

Do you find there to be a systematic undercount or overcount? If yes, how great?

Data source	*Undercount exists*	*Doesn't*	*Average undercount*
Farebox	5	1	8%
APC	3	0	6%
Point checks (load)	1	3	2%
Trip cards	1	0	7%

To give an idea of the level of error in individual measurements, please fill in the blank: 85% of the time the error is no more than ____%.

12. What is the primary data source for determining passenger loads on routes and in periods in which the scheduled headway depends on passenger volume?

Point checks	10
Ride checks	7
APC	3
Farebox counts	2
Operator trip cards	1

Other than farebox data, what is the typical annual sample size (even if schedule changes are based only on the last few months of data)? Every trip for the routeperiod is observed about:

Once per year	5
3 to 4 times per year	5
6 times per year	3
10 to 15 times per year	3

When contemplating a headway change on a route is the routinely available data usually adequate or do you often have to request special counts?

Routine data usually adequate	9
Often must request special	8

13. How many times per year does your transit agency produce regular reports of:

	1-2	*3-4*	*12*
Route-level ridership	5	4	11
Route-level economic evaluation	7	5	7

What is the primary data source for determining route-level ridership?

Farebox counts	10
Revenue	1
Ride checks	5
Point checks	2
APC	3
Operator trip cards	2

14. What is the primary data source for determining schedule adherence (underline appropriate)?

Supervisor point check	9
Other point check	9
AVL	4
Ride check	3
APC	2

For what scope do you report schedule adherence? How frequently?

	Annually	*Quarterly*	*Monthly*	*Unknown*
System-wide only		4	3	
Route or trip level, too	2	2	3	2

In reporting schedule adherence, a trip is considered "on time" if it is no more than ____ minutes early, and no more than _____ minutes late.

	Minutes						
	0	*1*	*2*	*3*	*4*	*5*	*10*
Early tolerance	9	7					
Late tolerance			1	3	2	9	1

On routes with small headways, headway regularity is sometimes a greater concern than schedule adherence. Does your agency report a measure related to headway (ir)regularity?

Percent of headways within 1.5 scheduled headways	1
Mean, standard deviation, etc., of headway	1

Is your data collection program designed to meet a standard level of statistical accuracy for the percent of trips that are on time?

Yes	3

15. Does your agency's program of monitoring running time on existing routes include (check all that apply):

Periodic monitoring and reporting for all routes	8
Monitoring and reporting on routes when prompted by a problem indicator such as poor on-time performance, customer complaints, or operator comments	19

What is the primary data source for determining running time?

Ride check	16
Multiple point check	8
AVL	3
APC	2

If there are periodic reports for each route, how frequent are they?

Average	2.4 times per year (7 responses)

Does the running time analysis use statistical guidelines, such as using 85-percentile running times, or the 3rd worst measured running time, or average running time plus one standard deviation?

Yes	2
No	10

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