Using Automatically Collected Data to Improve the Bus Service Planning Process

by
Jared Arthur Fijalkowski
Bachelor of Arts, Geography
Clark University, 2004

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Signature of Author...
Department of Civil and Environmental Engineering
May 21, 2010

Certified by...
Nigel H. M. Wilson
Professor of Civil and Environmental Engineering
Thesis Supervisor

Certified by...
John P. Attanucci
Research Associate of Civil and Environmental Engineering
Thesis Supervisor

Accepted by...
Daniele Veneziano
Chairman, Departmental Committee for Graduate Students

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Abstract

Most large transit agencies have shifted from collecting transit performance data manually to using automated data systems to measure performance. These systems, which include Automatic Vehicle Location (AVL), Automatic Passenger Counters (APC), and Automated Fare Collection (AFC), enable transit agencies to (1) collect larger and more detailed sets of performance data, (2) measure transit performance more from the perspective of customers, and (3) conduct more systematic service evaluation processes. While many transit agencies have adopted these data collection technologies, many have not modified their service planning processes to reflect the full advantages of automated data systems.

This thesis evaluates the current performance metrics used by the Chicago Transit Authority (CTA) and the Massachusetts Bay Transportation Authority (MBTA) in their respective service planning processes. A set of recommended performance metrics are proposed in the categories of bus loading, service reliability, passenger demand, and cost effectiveness that take advantage of the benefits of automatically collected data. Next, a service planning process is proposed by which transit agencies can use automatically collected data to systematically evaluate bus transit performance at the route, corridor, and system levels. In addition to making general recommendations applicable to all large transit agencies, this thesis makes specific recommendations for the CTA and the MBTA to improve their respective service planning processes to make full use of the capabilities of automated data systems.

This thesis finds that performance metrics which take advantage of the large and detailed data sets that automated data systems provide can more accurately and acutely identify performance problems, leading planners to develop better solutions. Also, the efficiencies in automated data collection compared with manual data collection allow transit agencies to perform a more comprehensive and systematic process by which the performance of all transit service is evaluated on a regular basis. Finally, while automated data systems provide a high level of detail about bus transit performance, contextual information about route operations remains critical to accurately identifying and resolving performance problems.

Thesis Supervisor: Nigel H. M. Wilson
Title: Professor of Civil and Environmental Engineering

Thesis Supervisor: John P. Attanucci
Title: Research Associate of Civil and Environmental Engineering

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Contents

List of Figures

List of Tables

1 Introduction

Throughout the last decade, many transit agencies have begun to use various technologies which enable them to automatically collect large amounts of data about system performance. These data are changing many functions in the transit agency, including the service planning process, on which this thesis focuses. Compared to the manual data collection methods on which transit agencies previously relied, automated data collection is more cost-effective and generates larger amounts of more precise data. This data provides opportunities for agencies to expand upon traditional approaches to performance measurement by using more accurate and more customer-centric performance metrics. Additionally, automated data systems allow transit agencies to conduct the service planning review process more systematically and in greater depth. However, many transit agencies using automated data systems have yet to realize the full benefits that these technologies provide because they continue to measure performance and evaluate service in the same ways as they did when data was collected manually. Although these agencies currently benefit from greater efficiency in data collection, their continued use of performance metrics and service planning processes that are geared toward manual data collection, with its inherent limitations, prohibit them from realizing some of the greatest advantages of automated data systems.

As this thesis will discuss, many transit agencies continue to use the performance metrics that were available under the manual data collection paradigm. These metrics tend to be more operator-oriented – focused on the provision of service by agencies – as opposed to customer-centric – focused on service as perceived by customers. Additionally, many current metrics use average values to measure performance, which dilute the impacts that instances of particularly poor service (e.g. very large gaps between buses) have on performance. Since performance metrics are a major component of an agency's service planning process, transit agencies exclusively using operator-oriented metrics fail to realize the full breadth of opportunities that automated data systems provide for service planning. Customer-centric metrics that consider the full distribution of performance values can now be accurately calculated due to the availability of larger quantities of higher quality data. Since transit agencies strive to provide safe and reliable transit to the greatest number of customers possible, it is critical that the decisions agencies make about service reflect the customer experience of service.

This thesis argues that transit agencies should develop systematic, ongoing service planning processes that use all of the benefits of automatically collected data. First, this thesis will identify performance metrics that best measure transit performance from the customer perspective, allowing planners to consider the full distribution of performance values rather than simple averages. Then, the thesis will propose a framework for the systematic evaluation of bus service that includes these metrics, allowing agencies to identify potential causes of and solutions to poor service quality. These general recommendations will be followed by specific recommendations for the two agencies used in this thesis as case studies: the Chicago Transit Authority (CTA) and the Massachusetts Bay Transportation Authority (MBTA), which have different levels of resources and face different constraints.

1.1 Major Themes

This thesis addresses three major themes which make it possible for transit agencies to evolve out of the manual collection paradigm into a more modern approach to performance measurement and service planning that fully recognizes all of the benefits of automated data collection. These themes include the transformation of transit agencies from being data-poor to data-rich, the shift from operator-oriented to customer-centric performance metrics, and the development of data-driven service planning processes that systematically identify and address performance problems. These themes are briefly introduced below.

Data-Poor to Data-Rich

Manual data collection is time consuming and labor intensive, as many staff members are required to collect data and entering the results into a database. Because of the high cost of manual data collection compared to the amount of data collected, the volume of data and frequency of data collection is necessarily low. These relatively small data samples are less precise and limit transit agencies to focusing primarily on the estimation of average values of performance, generally capturing the operating agency's perspective. As a result of these inherent limitations of manual data collection, agencies that collect data manually are data poor.

In the last decade, the proliferation of automated data systems such as Automatic Vehicle Location (AVL), Automatic Passenger Counters (APC), and Automated Fare Collection (AFC) has begun to transform transit agencies from being data-poor to being data-rich. Automated data systems, when expanded to a large proportion of an agency's bus fleet, produce vast quantities of data, enabling agencies to analyze route and system performance in great detail. While the initial purchase and system integration costs of the technologies are substantial, automatic data systems eliminate the need for costly manual data collection.

Operator-Oriented to Customer-Centric Metrics

In the era of manual data collection, system performance was generally measured from the operator's perspective. Although this perspective is useful in allocating resources and meeting budgets, it provides little insight into the customer experience. Technologies that generate data automatically and in great volume have the capability of measuring the variability of transit performance in the ways that customers experience on a day-to-day basis. Measuring the customer perspective of performance is important because customers ultimately choose whether or not to use specific transit services based on their experiences with those services. Customer-centric performance metrics quantify the burdens that are placed on customers by poor transit performance and enable transit agencies to focus their efforts and resources to minimize these impacts.

In addition to route-level analyses that consider the customer perspective on service quality, researchers have demonstrated that AFC data, in conjunction with AVL and APC technologies, can measure performance for customers' entire journeys (consisting of linked trips on multiple routes) throughout the transit system (Zhao 2004, Cui 2006, Gordillo 2006, Chan 2007, Uniman 2009). However, since many transit agencies continue to use performance metrics that were developed based on the limitations of manually collected data, which are at best a partial accounting for a potential customer's decision to use public transit, agencies' service planning processes do not harness this ability of automatically collected data.

Systematic Performance Evaluations

Once equipped with automated data systems, transit agencies should fully integrate performance metrics into a systematic service planning process. A systematic service planning process is one in which the performance of all routes, corridors, and the system as a whole is regularly monitored to identify problems and overall service quality trends at each level of analysis using the full set of available data and information. Agencies can develop analytical tools to automatically process data to enable planners to easily review performance at each level of analysis. Planners then use a multi-step process to identify problems and develop appropriate solutions. Additionally, planners review the impacts of past service changes to determine whether they were successful at resolving the problems they were intended to address. Though implementing this systematic service planning process requires investment in information technology and staff resources, this process allows agencies to realize the benefits of their existing automated data systems to improve system performance, and is therefore an efficient use of agency resources.

1.2 Research Objectives

This thesis will explore the use of automatically collected data to measure bus system performance more systematically and from the perspective of customers. It will culminate with a recommended process by which transit agencies can systematically review bus route, corridor, and system performance to identify problems, their potential causes, and effective solutions.

To frame the discussion, the following questions will be addressed:

- What advantages do automated data systems provide over manual data collection methods?
- How can automatically collected data be used to measure performance from the perspective of customers?
- What types of problems should a service evaluation process identify, and what measures should be used to identify them?
- What opportunities does automatically collected data provide to improve the service planning process?
- What methods and procedures should be implemented to ensure comprehensive and systematic reviews of performance?

In order to answer these questions, this thesis will achieve the following objectives:

1. Review the methods of data collection and analysis used under the manual data collection paradigm to understand the limitations of manually collected data.
2. Examine current industry and academic examples of data processing procedures, performance metrics, and service planning processes to identify ways that automatically collected data could further improve the identification, diagnosis, and resolution of transit performance deficiencies.
3. Identify the performance metrics which most clearly identify service quality problems and potential solutions using automatically collected data.
4. Develop the processes by which service planners utilize the full benefits of automatically collected data in reviewing bus performance, identifying problems and their potential causes, and developing strategies to improve service quality.

1.3 Research Approach

The goal of this research is to develop a framework for the systematic evaluation of bus route, corridor, and system performance which identifies problems, their potential causes, and appropriate strategies to solve them using automatically collected data. This thesis will first review the short range transit planning process proposed by Bauer (1981), which was developed under the manual data collection paradigm. It will then review the current service planning processes at the CTA and the MBTA, including the service standards used to measure service performance as well as the processes by which the agencies review route and system performance.

Following these reviews of past and current practices, performance metrics – representing passenger crowding, reliability, and passenger demand – will be proposed which measure performance at a high level of detail using automatically collected data. Appropriate threshold values that directly show whether routes are meeting performance goals will be considered, though they may not be appropriate for every metric. The CTA and MBTA both have established threshold values for some metrics in their service standards; these will be critically reviewed for their applicability in an improved service evaluation process.

Once the preferred performance metrics have been selected, the proposed process for evaluating a set of bus routes will be presented. The description of the process will include a proposed timeframe for service evaluation, a process for identifying problems and potential solutions, and the procedures for developing strategies that improve service quality. The recommended service evaluation process is designed to be generally applicable to all large transit agencies. It aims to guide agencies in making service planning decisions and is intended to be flexible enough to be applicable if the budget allows for additional operating resources or requires service reductions. Specific recommendations will be made for the CTA and the MBTA to improve their respective service planning processes, given the agencies' current and potential resources, capabilities, and constraints. The thesis will conclude with a summary of the analyses and recommendations and a discussion of future research opportunities.

1.4 Thesis Outline

The remainder of this thesis is divided into five chapters that culminate in a recommended process for systematically using automatically collected data in the service planning process. The chapters are arranged as follows:

- Chapter Two provides an overview of manual and automatic data collection, including the types of data collected, the performance metrics used to evaluate performance, and the benefits and limitations of each data collection method. This chapter also provides a summary of Bauer's

(1981) recommended short range transit planning process, which is based on manual data collection methods.

- Chapter Three includes overviews of the data availability and performance metrics employed by the CTA and the MBTA, as well as the agencies' service planning processes, which are based on a combination of manually and automatically collected data. The chapter highlights the limitations of these processes and argues that the benefits of automatically collected data should be incorporated in an improved service planning process.
- Chapter Four includes critical assessments of the CTA and the MBTA performance metrics in the categories of bus loading, service reliability, and passenger demand. It also describes and provides examples of recommended performance metrics which utilize the advantages of automatically collected data, including the ability to consider the distribution of values to measure performance from the perspective of customers. The recommended metrics are included in the recommended service planning process.
- Chapter Five presents the recommended service planning process, including a summary of the data and information that drive the process, the analyses that identify problems and their causes, the processes to implement changes in service, and the evaluation of past service changes to inform future decision making. General recommendations are made first, followed by specific recommendations for the CTA and the MBTA.
- Chapter Six summarizes the findings and recommendations of the thesis, presents conclusions, and discusses areas for future research.

2 Data Collection, Performance Metrics, and Service Planning Processes

This chapter presents an overview of both manual and automatic data collection, including (1) the data collection methods, processes, and technologies used under each approach, (2) the types of data collected, and (3) the performance metrics commonly used or otherwise available. The data collection elements of the Bus Transit Monitoring Study developed by Multisystems, Inc. (1985) and the short range transit planning process, recommended by Bauer (1981) and developed for use with a manual data collection program, is summarized. Additionally, this chapter highlights the limitations of manual data collection methods with regard to performance measurement and argues that automatic data collection methods allow transit agencies to correct, or at least improve upon, these limitations.

2.1 Manual Data Collection

Prior to the deployment of automated data systems, transit agencies collected performance data manually, relying on staff to count passengers, measure schedule adherence, and distribute passenger surveys. Other information about route performance, such as operator input and passenger complaints, also played a critical role in evaluating bus transit performance. This section describes (1) the data collection methods and processes that agencies employed to collect data manually, (2) the types of data collected, (3) the performance metrics used to estimate bus route performance and identify performance problems, and (4) the limitations of manually collected data to fully and accurately capture service performance.

2.1.1 Data Collection Methods and Types of Data

Manual data collection methods require staff to observe bus transit operation on the street. Some agencies employ dedicated staff to collect data, while others rely on bus operators, managers, planners, and contracted labor to gather data. As shown in Table 2-1, agencies that collect data manually use some or all of six data collection methods: point checks, ride checks, driver checks, farebox readings, revenue counts, and passenger surveys. During point checks, data tabulators collect bus loading and schedule adherence data while stationed at specified locations along a route, typically at the peak load point, route endpoint, major transfer points, or other important locations along a route. Data collectors performing ride checks observe passenger boardings and alightings and schedule adherence while riding a bus. Driver checks and farebox readings are methods by which drivers report passenger demand, schedule adherence, and revenue data in addition to performing their primary bus operation duties.

Transit agencies perform revenue counts at cash handling facilities, providing revenue data and information. Finally, transit agencies distribute passenger surveys to gather data and information about passengers and their journeys, including demographic, origin-destination, fare type, and other information. Passenger surveys are typically conducted in person or via a mail-in survey form (Multisystems Inc., 1985). These methods are generally time consuming, labor intensive, and often require bus operators to participate in data collection in addition to their operating duties.

Table 2-1: Manual Data Collection Methods and Types of Data

Method	Data Collected	Information Provided	Notes
Point checks (data tabulator collects data at peak load point, endpoints, or important activity centers)	Bus passing times, boarding counts, loading counts	Bus loads, schedule adherence	Both directions can be checked. Can be conducted all day or during peak periods.
Ride checks (data tabulator collects data while riding bus)	Numbers of boarding and alighting passengers along route, bus start and finish times. Sometimes includes intermediate times, transfer data.	Loading patterns, peak load points, schedule adherence	Relatively expensive to collect (uses one data tabulator-hour for every vehicle-hour of service checked).
Driver checks	Passenger boardings, bus start and finish times. Sometimes includes fare payment method.	Total daily ridership, ridership by time period	Can be collected on every trip. Requires no additional staff time but data reliability is a concern.
Farebox readings	Total revenue, bus start and finish times	Revenue per trip/run	Done at the beginning or end of each trip, run, or day.
Revenue counts	Cash revenue in farebox at end of run or day	Revenue by day, route	Cannot supply route data if bus operates on more than one route each day
Passenger surveys	Passenger origins and destinations, fare classification, socio-economic, trip purpose, customer opinions of service	Origin-destination, average trip length, transfer rate	Usually a printed form, sometimes phone surveys. Usually a special effort for a particular purpose.

Source: Multisystems, Inc, (1985)

The agency staff who gather data also supply observational and anecdotal information about route performance to provide the context during service evaluation. Observational and anecdotal performance information is descriptive and is critical in situations where quantitative data is difficult or too expensive to collect (Bauer, 1981). Examples of anecdotal information include the identification of major transfer points and locations of major origins and destinations. Information about route characteristics or performance can also come from external sources, including passengers, elected officials, or other transportation agencies. Additionally, some agencies deploy temporary staff specifically to collect anecdotal information as "secret shoppers." Secret shoppers observe qualitative aspects of performance from the perspective of customers, including driver behavior and cleanliness (Kittelson and Associates, 2003). Even when hard data is available, anecdotal information is a critical supplement providing a more complete picture of route performance.

Under the manual data collection paradigm, planners used data and anecdotal information gathered through the six methods described above to identify performance problems at the route, corridor, and system levels. The process by which manually collected data is collected and analyzed to identify and resolve problems is described later in Section 2.2.

2.1.2 Performance Metrics

Once collected, performance data and contextual information must be organized and summarized to be useful in the service planning process. Staff enter data and information into a computer database for it to be aggregated by route, corridor, or the entire system (Bauer, 1981). Agencies measure performance in the categories of passenger demand, bus loads, passenger behavior, revenue, and service reliability. Table 2-2 lists some of the metrics used to measure performance using manually collected data and the corresponding manual data collection techniques used.

2.1.3 Limitations

There are several drawbacks to relying solely on manually collected data to measure performance, including the tradeoff between data accuracy and cost, the focus on the agency perspective on performance, and issues with data reliability.

Tradeoff between Data Accuracy and Cost

Manual data collection methods require significant investments in human capital in order to ensure accurate results and are therefore expensive to execute. For example, these methods require staff to ride buses or be stationed along a bus route for a significant portion of the day in order to ensure that minimum sample sizes are obtained. In some cases, agencies must hire a separate staff dedicated solely to collecting and tabulating data. In other cases, time is diverted from primary staff functions to collect data. Additionally, manually collected data requires significant amounts of staff time to transfer data from paper to computer databases, and the costs of data processing increase as the volume of data increases. Therefore, there is a tradeoff between data accuracy and cost (Bauer, 1981). Agencies using manual data collection methods face significant challenges striking a balance between the cost of data collection and the level of accuracy that the data provides.

Table 2-2: Performance Measures Using Manual Data Collection Methods

Performance Category	Performance Measure	Point Checks	Ride Checks	Driver Checks	Farebox Readings	Revenue Counts	Passenger Surveys
Passenger Demand	Ridership		X	X	X	X	
	Passengers/mile		X	X	X	X	
	Passengers/hour		X	X	X	X	
	Passengers/trip		X	X	X	X	
Bus Loads	Average bus load	X	X				
	Maximum bus load	X	X				
	Peak bus load	X	X				
Passenger Behavior	Average passenger trip length		X				X
	Percent of transfers		X	X	X	X	
Revenue	Total Revenue		X	X	X	X	
	Revenue/mile		X	X	X	X	
	Revenue/hour		X	X	X	X	
	Revenue per passenger		X	X			X
Service Reliability	Percent of buses on-time	X	X	X	X		
	Scheduled run time-actual run time	X	X	X	X		

Source: Bauer (1981), Multisystems, Inc. (1985)

More specifically, the tradeoff between data accuracy and cost varies among manual data collection techniques. For example, driver checks have little to no marginal cost to implement, as drivers collect data while performing their other operating duties. However, the data may be less accurate, as drivers must first attend to their primary operating functions. On the other hand, ride checks are a relatively expensive data collection method; one hour of a ride checker's time is spent collecting one hour of data on a single bus. While the data collected is relatively accurate, since the ride checker has no other duty than to collect data, the high cost of this data collection method restricts some transit agencies from performing ride checks regularly for each route. To deal with this tradeoff, transit agencies can use conversion factors (ratios of the averages of two related measures) in order to infer data that is costly to collect from related data that is inexpensive to collect. For example, peak loads are relatively inexpensive to collect (using point checks), whereas passenger boardings (which require ride checks) are inexpensive to implement. Transit agencies can measure the relationship between these two data sets on a particular route and develop a conversion factor to be able to infer passenger boardings from peak load data. While this method provides a cost savings, the resulting passenger boarding data is less accurate than if it were collected using ride checks. Therefore, the tradeoff between accuracy and cost still exists (Multisystems Inc., 1985).

Because of the tradeoff between accuracy and cost, agencies tended to manually collect data rather infrequently and in relatively small quantities. In order to collect data throughout the entire bus network, a single bus route may not have data collected for months or years. Under the manual data collection paradigm, it was common to use a single day's sample of bus performance data to represent an average day for a long time period. While a single day of data collection might in some cases accurately represent an average day, manual data collection made it very difficult to understand daily and seasonal trends in ridership, schedule adherence, and other aspects of performance. Such analysis would require supplementary data collection efforts beyond the standard data collection program.

Performance Metrics Represent Agency Perspective Based on Average Values

The small volumes of data and the low frequency of manual data collection on a particular route restricted transit agencies to using metrics that are based on average values, which do not reflect the distribution of values. In addition, one or two "outlier" values may disproportionately impact the value of a small sample mean. Given that manual data collection results in relatively infrequent samples of passenger demand data, performance metrics developed for use with manually collected data focus on how well the agency meets its goals in providing service, as opposed to how customers experience service. The metrics described in Section 2.1.2 are aimed at measuring how well the *agency* is meeting its operating plan to provide service in terms of ridership, revenue, and schedule adherence, not, for example, how *customers* are experiencing crowding or bus arrival predictability. Performance measurement from the perspective of customers requires larger, more detailed, and more complete data sets than typical manual data collection efforts provide.

Data Reliability

Another disadvantage of manual data collection lies in the inherent fallibility of manual methods: human error. Data collectors can make mistakes in estimates or tabulations, some of which go unnoticed during data processing, resulting in imperfect data. Additionally, some data is inherently difficult to collect manually due to insurmountable physical limitations. For example, counting all passengers as they board and alight a crowded bus at each stop is a challenging, sometimes impossible task for data collectors. In these ways, manual data collection methods are prone to collection error (Bauer, 1981).

Moreover, some inaccuracies in data collection result from the unreliability of data collectors. For example, bus operators are often sources of schedule adherence and passenger demand data, particularly in small transit agencies. Since data collection is a driver's secondary duty (after operating the vehicle safely according to the operating plan), drivers may understandably become distracted from their data collection responsibilities (Multisystems Inc., 1985). Also, if operators are disciplined for not adhering to the schedule, and they themselves are the source of the data that would determine whether or not they are on schedule, there is an incentive to report inaccurate data in order to avoid sanctions. Additionally, staff whose sole task is to collect data can also be unreliable. For example, if data collectors become distracted, or otherwise misses something, they might fill in their forms with their best guess of the data that they missed rather than submitting tabulations with gaps. This is not meant to imply that transit agency staff members are wholly unreliable; this discussion merely highlights some reasons why data that is collected manually may not be completely accurate.

2.2 Service Planning Processes Using Manually Collected Data

Manual data collection methods were driven by a service planning process by which transit agencies monitor performance, identify deficiencies in service, and make modifications to the operating plan to improve performance. This section reviews two processes that were developed for use with manually collected data. The first is a three-step process for agencies to regularly collect transit performance data for use in an agency's service planning process. Next, a short range transit planning process, consisting of a ten-step process to identify and resolve performance problems, is reviewed. Finally, the applicability of these processes within the context of automatically collected data is discussed.

2.2.1 Bus Transit Monitoring Study

The data collection program presented in the Bus Transit Monitoring Study by Multisystems, Inc. (1985) uses various manual data collection methods to measure and identify changes in performance. This program is meant to provide the data sets and analyses necessary for transit agencies to apply their service planning processes in order to monitor performance and make improvements to service. There are three phases to the data collection program: baseline, monitoring, and follow-up.

Baseline Phase

During the baseline phase, transit agencies perform a comprehensive data collection process using the data collection techniques presented in Table 2-1. Transit agencies then apply the performance metrics outlined in Table 2-2 to provide a "snapshot" of the performance of all routes at one point in time. In some cases, transit agencies may subsequently use conversion factors to infer some measures from others in order to reduce monitoring data collection costs. These conversion factors are estimated from the baseline data. The data collection effort within the baseline phase serves as the basis for later analyses in which changes in performance are calculated (Multisystems Inc., 1985).

Monitoring Phase

During the monitoring phase, transit agencies collect data to be able to apply specific performance measures that are likely to change or which need to be regularly updated to meet scheduling, evaluation, or reporting requirements. Table 2-3 lists the data that are typically collected during the monitoring phase, including the level of detail at which each type of data is measured.

Table 2-3 Data Collected During Monitoring Phase

Type of Data	Level of Detail	Purpose
Bus load at peak load point	Route, direction, and time period	Frequency determination, service planning
Revenue	Route, direction, and time period	Financial analysis
Boardings	Route, direction, time period, and fare category	Federal reporting, service planning
Passenger miles	Route and time period	Federal reporting
Schedule adherence	Route, direction, and time period	Service planning
Running time	Route, direction, and time period	Schedule evaluation, service planning

Source: Multisystems, Inc. (1985)

In addition to these metrics, transit agencies also measure key data items ("change indicators") to indicate whether other related categories of performance may have also changed. Multisystems, Inc. (1985) recommends two categories of change indicators: passenger activity and running time. Transit agencies can use peak load or revenue as change indicators for other aspects of passenger activity, including passenger attitudes toward transit, passenger origin-destination patterns, and transfer activity. Likewise, agencies can use schedule adherence as a change indicator for running time. After the testing of conversion factors estimated in the baseline phase, transit agencies can use established conversion factors to infer some measurements from others. If this is the case, the types of data that are collected during the monitoring phase may be different from those listed in Table 2-3.

The frequency of data collection within the monitoring phase varies based on the specific needs of the agency regarding each measured data item. For example, transit agencies may wish to measure schedule adherence quarterly but may only need to measure passenger miles annually. Transit agencies should develop a standard monitoring period during which each type of data listed in Table 2-3 and the change indicators are measured. This time frame should be based on the smallest reporting period required. For example, if the data item with the shortest reporting period must be collected quarterly, the entire monitoring phase should be conducted quarterly. Data items that only require annual monitoring can be collected over the course of four monitoring periods to gather the required sample size (Multisystems Inc., 1985).

Follow-up Phase

During the follow-up phase, agencies determine if conditions have changed and if modifications to the operating plan are needed to improve performance. Changes can be indicated within an agency's performance monitoring process based on measured changes in the indicators. Multisystems, Inc. (1985) recommends that agencies redo the baseline phase if the passenger activity change indicator changes by 25 percent or more between the baseline measurement and subsequent measurements. Similarly, agencies should redo the baseline phase if the running time change indicator (proportion of early or late trips) changes by more than 0.15. Service changes (e.g. major route restructuring, fare policy change, etc.) that are implemented would require agencies to redo the baseline phase.

2.2.2 Bauer's Short Range Transit Planning Process

Bauer (1981) proposed a short range transit planning process to be implemented under the manual data collection paradigm. This section provides an overview of this process, including a discussion of how manually collected data is used to identify and resolve performance problems. Elements of Bauer's process are applicable to today with the advancements of automated data collection. Therefore, this process serves as a basis for the recommended improvements to the service planning process to take full advantage of the benefits of automated data collection, which will be discussed in Chapter Five.

The service planning process consists of an evaluation of performance and the resolution of identified problems. Bauer presents a suggested short range transit planning process to show, based on industry practice and planning theory, how the this process can and should work. Bauer describes three distinct levels of analysis – route, corridor, and system – and how they fit into a two stage planning process consisting of problem identification and problem resolution.

Bauer recommends ten steps in her short range transit planning process, which consist of both tasks that transit agencies should complete and decisions they should make. These are:

1. Collect or obtain information and/or data,
2. Decide if the information or data indicates that there is a problem,
3. Decide whether or not the available data or information is sufficient to base a decision on,
4. Decide if the problem is serious enough to take action,
5. Clarify the problem so that it is understood,
6. Formalize ideas on what actions are considered appropriate to take,
7. Sketch feasible solutions,
8. Eliminate infeasible options, and choose the best solution,
9. Develop the suggested change in service so that it is ready to be implemented, and
10. Gain official approval for the change (Bauer, 1981).

Steps one through four comprise the problem identification stage which enables planners to identify problems and consider whether or not to pursue them. Steps five through ten comprise the problem resolution stage and enable planners to identify an effective solution, such as a service change or other intervention, to address the problem identified in the first stage of the process. The following sections describe the three levels of analysis and the problem identification and problem resolution stages of Bauer's process.

Levels of Analysis

Bauer's short range transit planning process differentiates between three levels of analysis: route, corridor, and system. Each level of analysis identifies distinct problems or constraints and has different strategies to alleviate them. Route-level analysis is used to evaluate individual route performance using performance metrics that address ridership, passenger crowding, service reliability, and cost effectiveness. Transit agencies can identify problems and implement solutions at the route level independent of the performance of other routes. For example, transit agencies can increase the running time and frequency on a single route without affecting any other routes. Corridor-level analysis is used to evaluate both route and area level performance, including routing changes. This level of analysis allows agencies to consider how problems and potential solutions affect a group of routes in a particular area. For example, if a transit agency implements a routing change on one bus route, it can affect the ridership on connecting bus routes. System-level analysis is used to evaluate agency-wide performance and the provision of service as a whole. Analysis at this higher level can result in changes that affect a number of routes and large groups of customers. System-level analysis considers performance aggregated over all routes and is particularly useful when resources are temporarily or permanently reduced due to budget constraints (Bauer, 1981). For example, a reduction in overall service levels necessitated by the budget can affect some or all routes in a system. The connections between these levels of analysis and the proposed short range transit planning process are discussed in the following sections.

Problem Identification Process

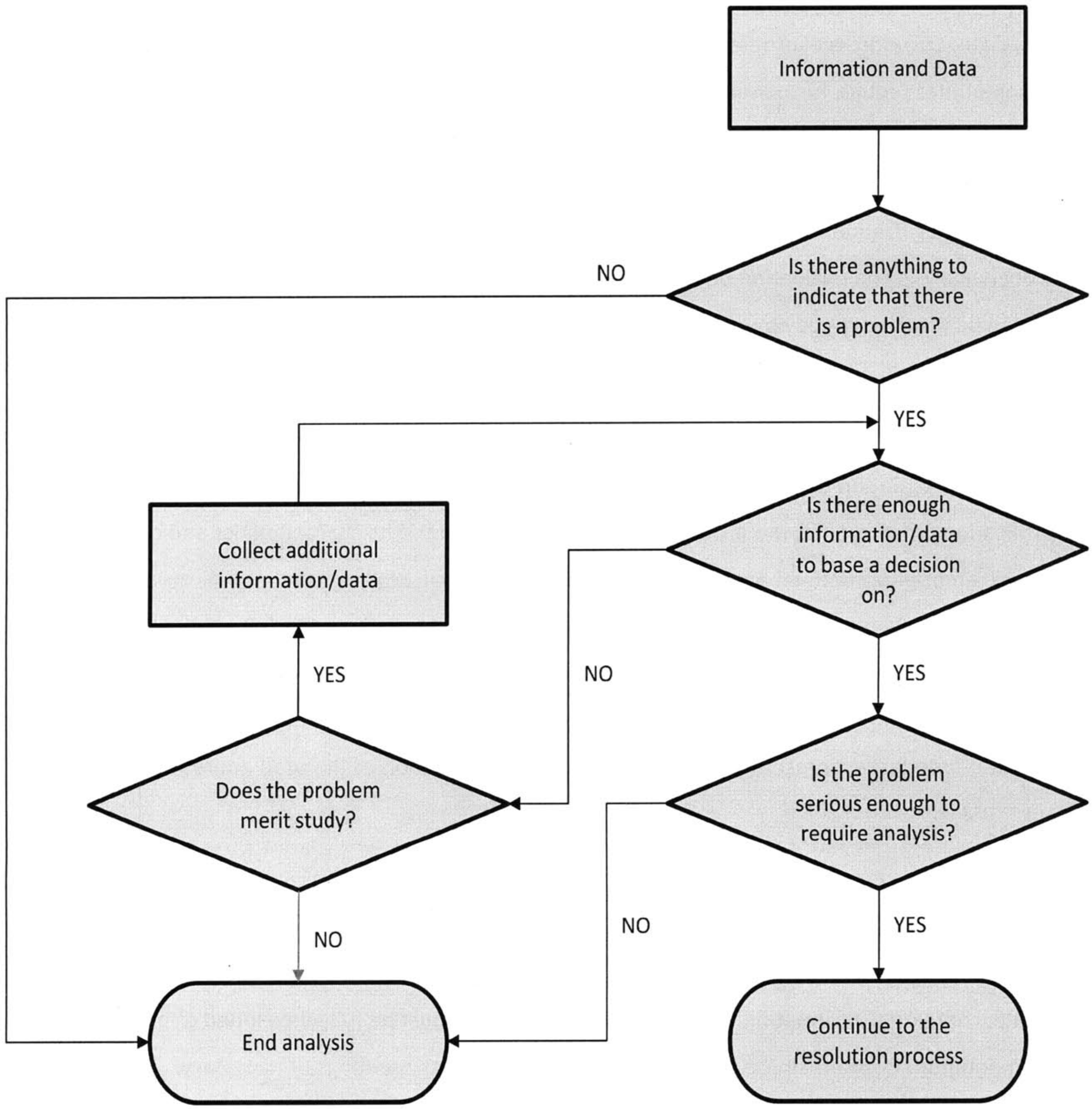
In the problem identification stage, data and information are collected and analyzed to determine if there is a problem at the route, corridor, or system levels and whether identified problems merit further analysis in order to resolve them. Figure 2-1 illustrates the steps taken by planners in the problem identification process.

In the first step, planners obtain data and information from a variety of sources, including routine data collection, complaints and suggestions, special studies, staff recommendations, and mandates from upper management. Planners then analyze this data and contextual information in light of the agency's service standards in order to decide whether the data and information indicate a problem. In some cases, service standards provide clear-cut thresholds that determine when data indicates some problem. Otherwise, planners must exercise their professional judgment to determine whether a problem exists, particularly when potential problems are raised through information such as passenger complaints.

Once a problem is identified, planners move to the next step: considering whether there is sufficient information to make a decision to resolve the problem. If there is not enough information to make a decision, planners consider whether the problem merits further analysis; if yes, planners gather additional information and/or data on the problem. Otherwise, no further action is taken. Once sufficient data and contextual information are obtained for a particular problem, planners consider whether the problem merits a service change. Planners use their professional judgment to determine whether problems are significant enough to advance to the resolution stage.

Throughout the problem identification process, planners must be aware of the characteristics of the data and information available. The completeness and quality of data and information, as well as the reliability of the sources, affect how much is known about the problem and whether planners choose to advance it to the resolution process. Therefore, a planner's professional judgment is critical when analyzing data and contextual information.

Figure 2-1: The Problem Identification Process



Source: Bauer (1981)

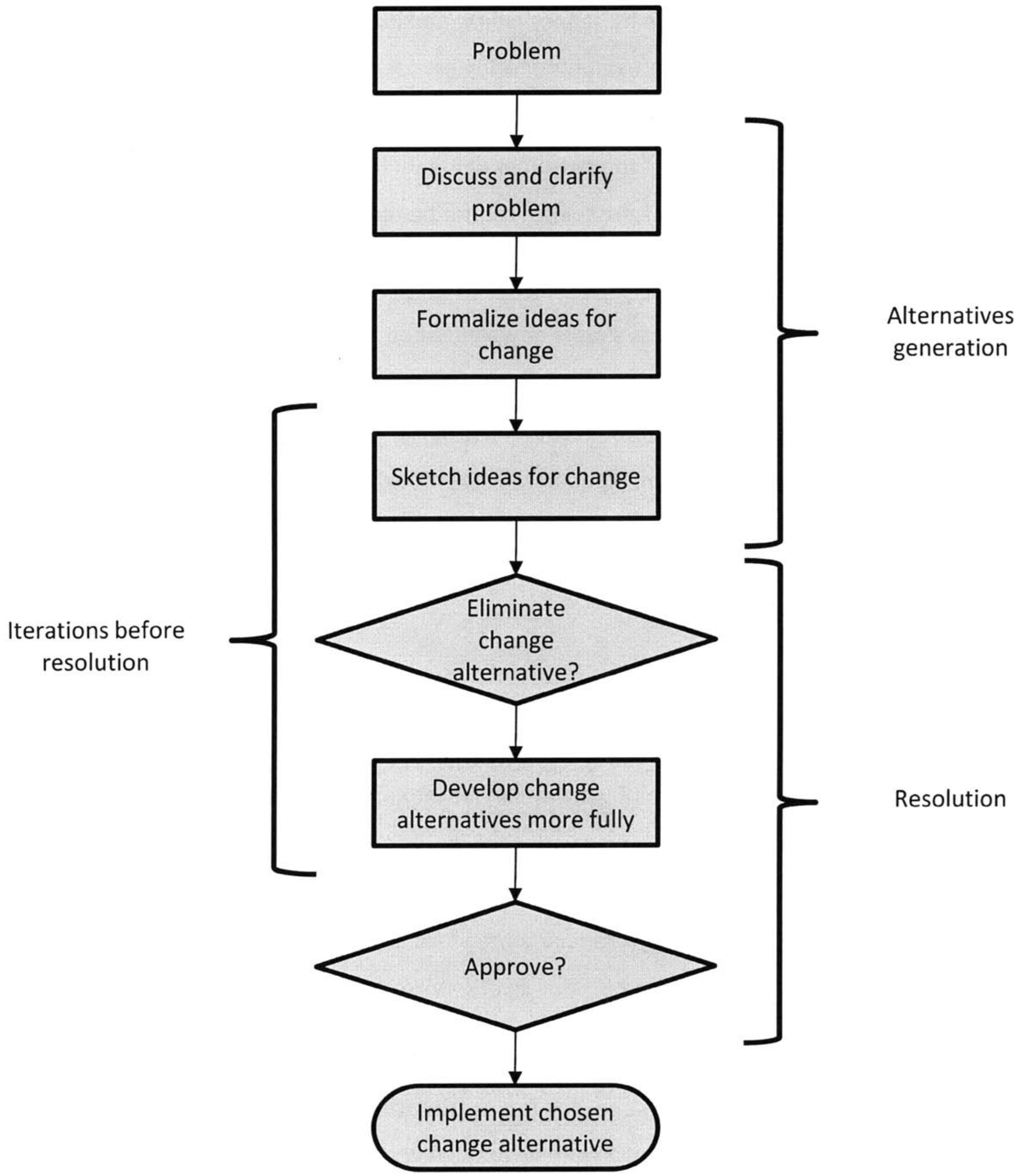
The problem identification process is applicable at the route, corridor, and system levels of analysis, but its application differs across levels. For example, route-level problems are sometimes simple and therefore existing data and contextual information are usually sufficient to allow planners to resolve them without additional data collection. However, some route level problems, such as low ridership, might require greater analysis to determine if corridor-level resolutions, such as routing changes, are appropriate. Corridor-level problems are often more complex than those at the route level. As a result, they sometimes require further analysis, in the form of corridor studies, to flesh out the issues in the area. System level problems, like a budget crisis, may require a reduction in the total amount of service provided. A resource problem at the system level will require resolutions that make changes to service at the route (e.g. frequency of service) and corridor (e.g. routing) levels and may require a more thorough analysis and evaluation beyond the standard service planning process. Alternatively, a budget crisis can be resolved quickly by examining all high-frequency routes for small frequency reductions, saving, for example, five percent of all buses by reducing the frequency of these routes by ten percent.

Problem Resolution Process

The problem resolution process, depicted in Figure 2-2, begins after the conclusion of the problem identification process. First, the problem is clarified to understand its characteristics and causes. The problem is more fully defined based on the data and contextual information that indicated the problem, the planner's knowledge of the route, and agency-wide constraints. Once the full scope of the problem is understood, planners formulate ideas about what solutions may be practical and feasible. Ideas are then defined in more detail and anticipated changes in resources and benefits are considered. Together, these first three tasks represent the alternatives generation portion of the problem resolution process (Bauer, 1981).

After developing a set of alternatives, planners eliminate or alter potential solutions if they are politically, financially, or technically infeasible, if they do not meet agency priorities, or do not solve the problem, or if other solutions better address the problem. Once a worthy alternative is chosen based on the data, contextual information, and planner's judgment, it must be fully developed to prepare for implementation. Planners revise schedules and hold community meetings (if necessary, depending on the magnitude of the proposed service change) in order to prepare the agency and customers for the change. Before the solution is implemented, it must be approved according to the agency's service change approval process (Bauer, 1981).

Figure 2-2: The Problem Resolution Process



Source: Bauer (1981)

Like the problem identification process, the problem resolution process varies at each level of analysis. At the route level, where problems are relatively simple and clearly defined, the solutions are straightforward and easy to develop. This means that the step to formalize an approach to a route level problem is rarely necessary. Solutions to route-level problems are often relatively small and do not require significant public outreach or political involvement (Bauer, 1981). Sometimes, however, the set of available solutions can be constrained by agency policy, making the problem resolution process for route-level problems more complex. For example, the logical solution for a low-frequency route that has a cost effectiveness problem (ridership is low compared to the level of resources required) might be to reduce frequency to more closely reflect the customer demand. If the route's frequency is already at the agency's established minimum, however, frequency cannot be reduced further. The agency must seek other solutions if it chooses to address this problem with a service change.

Corridor-level problems are usually not as simple or well-defined as route level problems, since the problems can affect more than one route and the set of potential solutions is wider (as it includes routing changes). Therefore, the steps of the resolution process that involve developing and evaluating alternatives can be more complex. Often, planners will go through several iterations of developing and evaluating alternatives until a set of feasible and practical solutions are generated. The approval process for corridor-level changes sometimes involves community outreach and approval by upper management (Bauer, 1981).

Since system-level problems are usually caused by resource limitations or major changes in transportation infrastructure, it is imperative that a strong set of priorities guide the resolution process. For example, in the case of an extension of subway service into an area that is currently only served by bus, each affected bus route is analyzed and a variety of changes in routing, frequency, and span of service are considered. A strong set of priorities will help planners decide how to shift resources to best achieve agency goals. Such large problems require a broad set of solutions, so the process to identify and evaluate alternatives is iterative. Like corridor-level service changes, system-level changes usually require community outreach and approval by upper management (Bauer, 1981).

2.2.3 Adapting Service Planning Processes for Application Today

The two processes presented in this section were developed under the manual data collection paradigm, but elements of both processes can be applied to develop data collection and service planning processes using automatically collected data.

Some of the elements of the multi-step data collection process outlined in the Bus Transit Monitoring Study by Multisystems, Inc. (1985) is are applicable with automated data collection. Automated data systems collect data continuously, eliminating the need for agencies to conduct coordinated manual data collection efforts on the street. However, the concept of measuring a baseline of route and system performance against which performance is monitored on a regular basis remains important in order to identify changes in performance. Additionally, the measurement of performance following significant changes in service remains a critical function of performance data collected using automated data systems. These elements of the data collection components of the Bus Transit Monitoring Study should be considered when developing a data collection, processing, and analysis process using automatically collected data. Chapter Five of this thesis incorporates these elements into a recommended service planning process using automatically collected data.

Bauer's recommended short range transit planning process uses a holistic approach to using data and information to address the problems and constraints facing transit agencies. Though it was developed before the widespread use of automatically collected data, the major elements of the process, including the use of data to systematically identify and resolve problems at the three levels of analysis, remain relevant today.

However, as even Bauer suggests, service planning processes developed for application with manual data collection methods should be reevaluated to incorporate new and improved methods for dealing with problems and solutions, including data collection and analysis procedures (Bauer, 1981). Indeed, researchers have identified ways to integrate the large and detailed data sets generated by automated data systems into transit performance measurement. Kittelson and Associates (2003a) provide a guide for transit agencies to develop a comprehensive transit performance measurement system using manually or automatically collected data. The Transit Capacity and Quality of Service Manual developed by Kittelson and Associates (2003b) presents various measures of transit quality of service in the categories of design and availability of transit service as well as passenger comfort and convenience as measured using automated data systems. Though many transit agencies now use automated data systems to measure transit performance, their current processes used to evaluate and make improvements to service tend to reflect the limitations of manual data collection and therefore tend not to reflect the full capabilities of the agencies' investments in new technologies. This thesis contributes to this body of work on bus service planning by presenting a set of recommended performance metrics that take advantage of the capabilities of automatic data collection (in Chapter Four), and presenting recommended improvements to the service planning process that draw on the full capabilities of automatically collected data in a systematic service planning process (in Chapter Five).

2.3 Automated Data Systems

Recently, transit agencies have begun large scale deployment of automated data systems, including automatic vehicle location (AVL), automatic passenger counting (APC), and automated fare collection (AFC) systems to gather data on a continuous basis, giving planners a more detailed and comprehensive view of system performance than manual data collection methods. These automated data collection systems address many of the limitations of manual data collection to evaluate bus performance.

There is extensive research on the use of AVL, APC, and AFC systems to improve and enhance transit operations, performance monitoring, planning, and scheduling (Wilson et al. 1992, Furth 2000, Wile 2003, Furth et al. 2006, Gordilla 2006, Chan 2007, Mistretta et al. 2009). The authors all point to the detailed system performance analyses that transit agencies perform using automatic data systems. The three systems are briefly described below and are summarized in Table 2-4.

2.3.1 Automatic Vehicle Location (AVL)

AVL systems use a combination of GPS signals and dead-reckoning technology to record the location of a bus. Data is recorded in two ways. *Polling data* notes the location of a bus at a certain time, as frequently as several times a minute. This location-at-time data is useful for real-time applications, such as emergency response. *Event data* notes the time at which a bus performed a certain event, such as passing a timepoint. This time-at-location data is useful for off-line analysis of route performance and is the basis for many of the performance metrics used in service planning. Agencies that use AVL systems usually have every bus equipped with the technology for real-time monitoring and off-line analysis, providing a nearly 100 percent sample of bus location data. For more information on the specifications and capabilities of AVL systems, see Furth et al. (2006), Parker (2008), and Mistretta et al. (2009).

2.3.2 Automatic Passenger Counters (APC)

APCs use various technologies to count passengers as they board and alight buses through all doors of a bus. When APC are synchronized with AVL systems, customer boarding and alighting data can be allocated to individual bus stops, enabling agencies to understand passenger demand at a fine level of detail. Unlike AVL systems, which have useful applications besides data collection, APCs are only used for off-line data analysis. Therefore, most agencies have APCs installed on a portion of their fleet (20-30 percent is common) and rotate APC-enabled buses throughout the bus network to obtain a sufficient number of passenger boarding and bus load data samples for each route. For more information on the cost, specifications, and capabilities of APCs, see Furth et al. (2006) and Boyle (2008).

2.3.3 Automated Fare Collection (AFC)

AFC systems, which use various technologies to collect fares electronically, are an emerging source of data that can be particularly valuable in service planning. AFC technology enables transit agencies to link trip segments made by a customer using a single smartcard or magnetic stripe farecard to provide information on passenger journeys. The data that AFC systems collect allows planners to develop detailed origin-destination matrices using statistical inference techniques for various time periods, which are helpful in analyzing network and route design, determining weekday and weekend travel patterns, setting service frequencies, and planning for special events. AFC boarding data can also be used to supplement APC data to provide a more complete picture of passenger demand by route on any particular day. For more information on the applications of AFC technology in transit service planning, see Multisystems (2003), Lobron (2003), Gordillo (2006), Hong (2006), Chan (2007), Mistretta et al. (2009), and Uniman (2009).

Table 2-4: Automated Data Systems

Method	Data Collected	Measurements	Notes
Automatic Vehicle Location (AVL)	Time at which buses pass stops, running time, departure and arrival times	Schedule adherence, headway variability	Installed on all buses, tied to other data systems to provide location information
Automatic Passenger Counters (APC)	Passenger boardings and alightings	Bus load, crowding levels, passenger flow, passenger demand by stop, maximum load	Usually installed on a portion of bus fleet; tied to AVL to provide passenger demand at the stop level
Automated Fare Collection (AFC)	Electronic fare transactions, fare media type, fare paid, passenger journeys	Revenue, origin-destination information	Installed on all buses; used to infer passenger behavior, including origin-destination and transfer information

Sources: Furth et al. (2006), Chan (2007)

2.3.4 Data Processing

Like manually collected data, automatically collected data requires post-processing to be useful in the service planning process. Automatically collected data should be carefully screened by staff for systemic errors. For example, APC data needs to be checked and "cleaned," as the technology sometimes over or undercounts passengers, resulting in non-zero load values at trip endpoints (after all passengers have alighted). Once checked, processed automatic data is assembled into a database which staff can query to produce reports that include tables and graphs in order to allow planners to analyze performance at varying levels of detail. While the initial investments in information technology and staff resources to develop programs to process and synthesize data are significant, this processing is far less time consuming and labor intensive than the post-processing necessary with manually collected data.

2.3.5 Performance Metrics

Automated data systems provide larger and more detailed sets of data than manual data collection methods, enabling transit agencies to measure performance with more precision and detail while minimizing the marginal cost of data collection. Automatically collected data can be analyzed using the same performance metrics used with manually collected data, but doing so would prevent agencies from taking full advantage of the benefits of automatic data collection systems. There are several measures based on the full distribution of performance values that require the large, detailed sets of data that only automated data collection can provide. Table 2-5 provides some suggested metrics to measure performance and the automated data systems that are used to supply the necessary data for each measure.

Table 2-5: Performance Measures Using Automatic Data Systems

Performance Category	Performance Metric	AVL	APC	AFC
Passenger Demand	Ridership		X	X
	Passengers/mile	X	X	X
	Passengers/hour	X	X	X
	Passengers/trip	X	X	X
	Boardings and alightings by stop	X	X	X
Bus Loads	Average bus load	X	X	
	Maximum bus load	X	X	
	Average passenger-experienced load	X	X	
	Percent of overcrowded buses	X	X	
Passenger Behavior	Average passenger trip length	X		X
	Percent of transfers	X		X
Revenue	Total Revenue			X
	Revenue/mile	X		X
	Revenue/hour	X		X
	Revenue per passenger			X
	Revenue by stop	X		X
Service Reliability	Percent of buses on-time	X		
	Scheduled run time-actual run time	X		
	Average and total excess wait time	X	X	
	Reliability buffer time	X	X	
	Percent of big gaps in service	X		
	Percent of bunched intervals	X		

Performance metrics that are not boldface in the table can be calculated with manually collected data but are often more efficiently measured using automatically collected data. Boldface metrics require the large and detailed data sets that automatic data systems. Some of these boldface metrics will be described in detail in Chapter Four.

2.4 Benefits and Limitations of Automatically Collected Data

As referenced above, there are many benefits of using automated data systems over manual data collection methods, including efficiencies in data collection, the quantity and quality of data, and the ability to measure performance from the perspective of customers and for total journeys rather than individual trip segments. However, there are aspects of automated data systems which limit their utility.

First, beside the initial investment, automated data systems allow transit agencies to collect large volumes of data at a fraction of the marginal cost of collecting data manually. Therefore, the tradeoff between data accuracy and cost that was present in the manual data collection paradigm no longer exists with automated data collection. Second, when installed on a significant portion of a bus fleet, automated data systems continuously collect large volumes of data for use in service planning, much more than was typically collected using manual data collection methods. Additionally, the high level of detail of automatically collected data provides transit agencies with more robust data sets, enabling planners to more easily identify specific problems that may have been overlooked with the less comprehensive data sets generated by manual data collection. Third, transit agencies are able to use these large and detailed data sets to measure performance more from the customer perspective. Some of these customer-centric metrics and analysis methods are described in Chapter Four and are included in the recommendations for improving the service planning process in Chapter Five.

Despite these benefits, there are some drawbacks to using automatically collected data. First, the data generated by automated data systems is not perfect. These systems are prone to systemic data collection errors that require a "cleaning" process to make the data useful. Also, automated data systems do not collect detailed information on passengers, such as gender, age, or trip purpose. Since such information is critical to understanding transit performance, agencies must periodically conduct surveys to provide this information for use in some analyses. Finally, while automated data systems can be used to measure performance from the customer perspective, they are not able to capture passengers' perceptions of service quality. Customer-centric performance metrics are, at best, proxies for some aspects of the customer experience. Despite these limitations, automated data systems can greatly improve an agency's data collection and performance review processes.

2.5 Summary

Automatically collected data have the capability of rectifying many of the limitations of manual data collection outlined in Section 2.1.3. The large and highly detailed data sets generated by automated data systems allow transit agencies to collect, process, and analyze data more efficiently and effectively, leading to more in-depth analysis. These benefits will be incorporated into Bauer's framework for service planning to allow agencies to get the most out of their automated data systems.

The next chapter provides an introduction to the data collection methods, performance metrics, and service planning processes of the Chicago Transit Authority (CTA) and the Massachusetts Bay Transportation Authority (MBTA) as outlined in their respective service planning policy documents. Both agencies will be used as case studies throughout the remainder of this thesis, culminating in specific recommendations for each agency to improve its service planning process.

3 CTA and MBTA Service Planning Processes

This chapter describes the data collection methods, performance metrics, and service planning processes as outlined in the service planning policy documents of the Chicago Transit Authority (CTA) and the Massachusetts Bay Transportation Authority (MBTA). The CTA and MBTA are two transit agencies that could realize greater benefits by harnessing the full power of automated data systems to improve performance measurement and analysis, resulting in improved service quality.

3.1 Chicago Transit Authority (CTA)

This section introduces the CTA by providing an overview of the agency including its goals and objectives, an explanation of the service design measures that guide the development of its bus network, and an outline of the agency's service planning process.

3.1.1 Agency Overview

The CTA operates the second-largest public transportation network in the United States, providing an average of 1.7 million rides on its bus and rail networks each weekday. The CTA's service area includes Chicago and 40 of its suburbs, providing transit access to 3.9 million residents in the Chicago metropolitan area (CTA, 2009b). The agency's mission is to "deliver quality, affordable transit services that link people, jobs and communities" (CTA, 2009a).

Bus Network

The CTA has a fleet of 2,053 buses that operate on over 150 routes (CTA, 2009c). The bus network covers 2,517 route miles and includes nearly 12,000 bus stops. Average weekday bus ridership was 1.04 million in 2008 (CTA, 2009b). CTA bus service follows the grid arterial street pattern that dominates the geography of Chicago. There are 46 routes designated as "key routes," which together serve as the core of the bus network. Key routes are typically spaced one mile apart and include the most productive routes as well as others which provide geographic coverage. Key routes operate a minimum of 16 hours per day and provide 47% of all CTA rides (CTA, 2001).

Data Availability and Analysis Tools

The CTA uses automatically collected data generated by AVL, APC, and AFC systems to estimate ridership, running times, dwell times, customer wait times, headways, schedule adherence, passenger load, and other aspects of performance throughout the day for each bus route (Milkovits, 2008). AVL and AFC technology is installed on every bus in the fleet, and APCs are installed on 74 percent of buses

(CTA, 2009c). Together with operating information, these data provide CTA planners with large sets of highly detailed data about route and system performance.

CTA service performance data is automatically entered into an online database, where it is queried directly by planners via a number of online and Microsoft Excel-based tools. Planners input specific parameters to request a particular type of data for a route and/or time period. The data tools then process the query, automatically generating tables and graphs responsive to the planner's request. These tools have streamlined the data analysis process, making it easier for planners to use data to make service planning decisions. While building this database of the supporting query and analysis tools requires considerable staff time and information technology expertise, the opportunities they provide for detailed and systematic analysis of service performance are invaluable.

3.1.2 Goals and Objectives

The CTA Service Standards, adopted in July 2001, are intended to guide the design of service to meet the needs of customers while remaining cost-effective. Additionally, the service standards describe a process of service evaluation and change implementation in order to achieve the agency's goals (CTA, 2001). These goals are summarized below.

The CTA's first goal is to "ensure the design of effective, efficient, and equitable transit service" (CTA, 2001). The CTA lays out four objectives to achieve this goal. First, the CTA intends to provide cost-effective service that supports current and future travel patterns. Second, the agency enhances its key bus and rail networks to provide regional mobility to all neighborhoods. Third, the CTA considers a cost-effectiveness standard while considering the special needs of customer groups. Finally, the CTA intends to distribute resources equitably based on demand and geographic balance.

The second goal is to "provide a uniform and consistent methodology for planning, designing, and evaluating transit services and proposals within applicable laws and regulations" (CTA, 2001). Four objectives help the CTA achieve this goal. First, the CTA uses a consistent, regular process for improving service where there is demonstrated demand or potential for demand. Second, the agency addresses customer needs and requests fairly and thoroughly by engaging customers in the planning process. Third, the CTA's service evaluation process evaluates, recommends, and approves service changes. Finally, the CTA intends to implement services that are consistent with Title VI and ADA requirements.

The CTA's third and final goal is to "provide mobility to our customers by responding to changing travel patterns and new market opportunities" (CTA, 2001). The CTA has three objectives to achieve this goal.

First, the CTA encourages intermodal connections to maximize customers' options. Second, the agency monitors customer survey results to support its service change decisions. Finally, the CTA develops sustainable services that support Chicago's and the region's development plans and initiatives.

The next section will provide insight into how some of these objectives are executed via the CTA's service design measures.

3.1.3 Service Design Measures

The CTA's Service Standards define the service design measures for bus service, which include service coverage, span of service, service frequency, passenger flow, and minimum productivity. These measures help the CTA determine what levels of service should be provided to meet demand and how the agency can most efficiently use staff and vehicles.

Service Coverage

The CTA's service coverage policy is intended to ensure that access to transit service is provided throughout Chicago. The policy is to provide a maximum walking distance of either ¼ or ½ mile to transit service during peak periods within the statutory service area, depending on whether the area is high-density or low-density. During overnight hours, the standard is a walk distance of one mile, and the maximum walk distance is ½ mile during all other times of the day. Table 3-1 shows the distance between bus routes and typical maximum walk distances to bus transit by time of day and population density.

Table 3-1: CTA Bus Service Coverage Guidelines

Time Period	Distance Between Routes	Typical Max Walk Distances
Weekday Peak – High Density	½ mile	¼ mile
Weekday Peak – Low Density	1 mile	½ mile
Weekday Midday/Evening	1 mile	½ mile
Saturday and Sunday/Holidays	1 mile	½ mile
Owl	2 miles	1 mile

Source: CTA (2001)

The service coverage policy is based in part on the network of CTA's 46 key routes, which are primarily spaced one mile apart and cover most of Chicago. Generally, the network of key routes provides customers with a maximum walk distance of ½ mile to a key route.

Span of Service

The CTA's span of service policy defines the minimum period of time during the day that service will be provided at any location in the system. The CTA's 46 key bus routes are operated every day, usually for at least 16 hours. Many routes, even non-key routes, provide service beyond this minimum level; some operate 24 hours a day, seven days a week.

The CTA considers proposals for a span of service extension on a route based on high productivity or measured increases in demand. If the hour immediately before the end of the current service or after the beginning of the current service shows productivity greater than the average bus system productivity *for that hour*, the CTA will consider extending the span of service. Also, when shift changes or extensions of business hours occur at major employers, thereby creating a demand for service, the CTA will consider extending the span of service on routes that operate to and from that employer in order to serve the new demand.

The CTA may also decrease the span of service when warranted and allowed given the statutory minimum spans of service. For example, when existing bus routes experience time periods during which the number of boardings per vehicle hour falls below an established minimum, they become candidates for reducing the span of service.

Frequency of Service/Passenger Flow

The CTA's frequency of service policy states that the longest service interval between successive buses on any route shall be 30 minutes. However, where a bus route splits into branches, there is a possibility that due to low levels of demand, the branch portions of a route may have service intervals longer than 30 minutes.

The frequency of service beyond the established minimum is determined based on customer demand – service should be more frequent on heavily-traveled routes than on low-volume routes. The determination of how much service should be provided above and beyond the required minimum frequency level is based on the demand at the point of maximum passenger flow along each route. Table 3-2 shows the CTA's guidelines for determining service frequencies for standard buses based on loads at the maximum flow point of a route in peak periods. Given the passenger flow in each half hour at the maximum flow point, planners determine the appropriate service level for each half hour. The "average passengers on bus" column shows the average bus load based on the passenger flow and service interval. Similar tables indicate service intervals and average loads for off-peak hours (with lower loads per bus) and articulated buses (with higher loads per bus).

Table 3-2: CTA Bus Service Levels for Standard Buses (60-Passenger Maximum Load) in Peak Periods

Passenger Flow Per ½ Hour	Service Interval (minutes)	Average Passengers on Bus
≤ 30	30	< 30
30-60	20	20-40
60-90	15	30-45
90-125	12	35-50
125-165	10	40-55
165-240	7.5	40-60
240-300	6	45-60
300-360	5	50-60
> 360	< 5	60

Source: CTA (2001)

Maximum scheduled loads during peak periods are 60 passengers on standard buses and 93 passengers on articulated buses. The maximum scheduled load during off-peak periods is 40 passengers per bus (CTA, 2001).

Minimum Productivity

The CTA measures bus productivity in terms of passengers boarding per bus hour. The policy establishes a minimum productivity threshold of 30 passengers per bus hour. If productivity on any route falls below this threshold for a portion of the day, the CTA considers altering the service to increase productivity. In their analysis, CTA planners consider the change in ridership and productivity over time for each route in order to identify trends, which sometimes reveal causes of productivity changes and potential solutions that improve productivity (CTA, 2001).

3.1.4 Service Change Process

The CTA reviews the performance of all routes and services on an ongoing basis. The agency considers, evaluates, and implements "minor" and "moderate" service changes throughout the year. "Major" service change proposals are evaluated and implemented every six months. The components of the service change process are summarized below.

Annual Service Budget Proposal

At the beginning of each fiscal year, the CTA's Planning Department develops an Annual Service Budget Proposal that identifies budget needs for each service change type for the next fiscal year's budget. This proposal is based on a review of the recent performance of all routes and all of the service change proposals received. The budget dictates the level of resources for service changes to be implemented over the budget year.

Service Change Process

The CTA Bus Service Committee, made up of planning, scheduling, and marketing staff, meets monthly to identify and discuss service issues, review service change proposals to ensure that they can be operated reliably and safely, and identify the actions that may be needed to implement changes. Through this process, the committee decides on the minor and moderate service changes to be implemented throughout the year without board approval, as well as which major service changes should be considered by the Board for approval. Table 3-3 outlines the distinctions between minor, moderate, and major service changes, provides examples for each, and explains how each type of change is implemented.

Table 3-3: CTA Service Change Types

Type	Definition	Examples	Implementation
Minor	Routine small changes to better align services with demand	• Running time adjustments • Departure time adjustments • Span of service changes of ½ hour or less • Bus reroutes due to street or bridge detours • Service interval changes to match service levels with ridership • Changes to bus stop locations	Evaluated within Planning & Development through the Service Change Committee. Implemented throughout the year without Board approval.
Moderate	Small changes to routes or service configurations with limited impact and modest costs	• Bus reroutes of less than 1 mile • Route extensions of 1 mile or less • Service changes to reflect changes in street patterns	Evaluated within Planning & Development through the Service Change Committee. Implemented throughout the year without Board approval.
Major	Changes that will have significant impacts on customers and resources	• Route changes that affect more than 25% of a route's passenger route miles or vehicle miles • Changes requiring new facilities and/ or capital expenditures at a cost level that requires Board approval	Board approval required before implementation. Must undergo a semi-annual review, implemented only twice a year.

Source: CTA (2001)

Screening and Evaluation Process

The Service Change Committee reviews service change proposals received from CTA staff, public officials, customers, or the general public. Service planning staff conduct an initial analysis on each proposal to determine whether further study is warranted. The committee uses the following criteria to screen proposals:

- Urgency
- Ease of implementation
- Readiness for implementation
- Level of interest (within and outside of the CTA)
- Feasibility
- Capital and/or land acquisition required, and
- Costs involved (based on a preliminary estimate).

If the committee determines, based on the preliminary analysis, that a proposal should proceed to further analysis, it advances to the evaluation process. Minor and moderate service change proposals move on to evaluation immediately, but major proposals are deferred until the next semi-annual review process (described in the next section).

Table 3-4 outlines the criteria that are used to evaluate the proposals. Criteria differ between service improvements and service reductions. Primary criteria are considered to be more important than secondary criteria. Also, due to their relative simplicity, minor and moderate service changes may not require all analyses outlined in Table 3-4 in order for planners to make informed decisions about potential solutions.

Semi-Annual Review

Major service changes are evaluated and implemented every six months if the annual budget has the capacity to support each change. During the semi-annual review, planners rank major qualified service changes accumulated during the previous six to twelve months against other proposals using criteria similar to those used to evaluate minor and moderate service changes. The expected productivity of each proposal, which is based on estimated passenger demand and the amount of service to be provided, is calculated and compared to the productivity levels of existing bus routes. Proposals that have an expected productivity greater than the average bus system productivity are more likely to be implemented than those which have a below-average expected productivity. However, having an expected productivity above the system average is not a hard constraint.

Table 3-4: CTA Evaluation Criteria

Service Improvement	Service Reduction
Primary • Net cost per new passenger • Available budget • Rationale for the change • Existing and projected ridership • Number of new passengers • Existing and projected operating costs • Existing and projected fare revenue • Implications to service coverage	**Primary** • Net savings per passenger lost • Rationale for the change • Existing and projected ridership • Existing operating costs • Existing fare revenue • Implications to service coverage
Secondary • Market change (past, present, and projected) • Change in travel time for existing passengers • Key characteristics and demographics of the market • Contribution of the achievement of policy objectives • Other factors, as appropriate	**Secondary** • Market change (past, present, and projected) • Change in travel time for existing passengers • Key characteristics and demographics of the market • Contribution of the achievement of policy objectives • Impact on accessibility • Other factors, as appropriate

Source: CTA (2001)

Service changes may be implemented as experimental services, which have a six-month evaluation period. At the end of the evaluation period, the Board of Directors may cancel or adjust the service if it is not meeting expectations. Otherwise, a successful experimental service can be folded into the CTA's regular budget.

3.2 Massachusetts Bay Transportation Authority (MBTA)

This section provides an overview of the MBTA, its service objectives, the service standards that guide development of the bus network, and an outline of the process for making service changes.

3.2.1 Agency Overview

The MBTA is the fifth largest public transit agency in the United States in terms of ridership, providing over 1.25 million trips on its bus, subway, light rail, commuter rail, and commuter boat networks each weekday. The MBTA's service area includes 175 cities and towns in eastern Massachusetts (MBTA, 2009b). Its mission statement reads "the MBTA is a dedicated world-class transit system built upon customer service excellence, accessibility, reliability, state-of-the-art technology, and a diverse workforce that reflects our commitment to the communities we serve" (MBTA, 2009a).

Bus Network

The MBTA has a fleet of over 1,050 buses that provide service on 186 routes. The entire bus network, which includes the Silver Line bus rapid transit service and electric trolley bus service, covers 761 route miles and provides over 366,000 unlinked trips on a typical weekday (MBTA, 2009b).

There are five categories of MBTA bus routes. Local bus routes provide full weekday service with closely-spaced stops and usually provide connections to the rapid transit system. Key bus routes are similar to local routes, but they operate for longer periods during the day and have higher frequencies reflecting higher levels of demand. The 16 key bus routes provide basic geographic coverage and frequent service in the densest areas of the region. Commuter bus routes provide service exclusively in peak periods in the peak direction of travel. Express bus routes are similar to commuter bus routes but operate on high-speed roads without stops for a large portion of the route. Finally, community bus routes offer service during the day and are not oriented toward providing commuter service (MBTA, 2009a).

Data Availability

The MBTA uses automatically collected data generated by AVL and APC systems to estimate ridership, running times, headways, schedule adherence, passenger load, and other aspects of performance throughout the day for each bus route. The MBTA uses its AFC system to provide data on the financial aspects of the bus service, but this data is not used to measure service quality (Dullea, 2010). AVL and AFC technologies are installed on every bus in the fleet, but APCs are installed on only 7.2 percent of buses (MBTA, 2010a). Additionally, the APC equipment is not linked to the AVL systems on APC-equipped buses; APCs have a location-detection technology separate from the AVL system. Therefore, staff must manually link automatic passenger count data with the time and location data of AVL data after both data sets are collected. Due to the low penetration of APC equipment in the fleet, the MBTA supplements its automatically collected passenger load data with data collected manually by hired data tabulators (Dullea, 2010). Because of the reliance on manually collected passenger load data, the quality and quantity of passenger demand and bus load data is much weaker than the data generated by the AVL system.

3.2.2 Service Objectives

In pursuit of its mission, the MBTA outlines four service objectives which represent the most important characteristics of a "world-class" transit system. They include:

- **Accessibility:** services should be geographically available throughout the community and should operate at convenient times and frequencies
- **Reliability:** services should be operated as scheduled
- **Safety:** services should be provided in a safe manner, and
- **Comfort:** services should offer a pleasant and comfortable riding environment (MBTA, 2009a).

These service objectives inform the MBTA's service standards, which are described in the next section.

3.2.3 Service Standards

The MBTA's Service Delivery Policy, which was last updated in 2009, defines the service standards for bus service, which include service coverage, span of service, frequency of service, schedule adherence, vehicle load, and cost effectiveness. These standards establish levels of service that the agency must provide to meet its service objectives and provide a framework for the evaluation of route performance as part of the agency's Service Evaluation Process. Each standard has either a threshold value that must be met or a guideline that the agency strives for (MBTA, 2009a).

Service Coverage

The service coverage standard is meant to ensure geographic coverage of transit service across the entire area. Service coverage is a guideline, not a standard, due to topographical and street network limitations. On weekdays and Saturdays, the guideline is to provide transit service within a ¼ mile walk of all residents where the population density is 5,000 or more persons per square mile. This guideline is increased to a ½ mile walking distance on Sundays.

Span of Service

The Service Delivery Policy outlines the minimum time period that a given service shall operate. The standards vary by bus route type and by day of the week according to typical levels of passenger demand. The standards dictate that at the beginning of the service day, the first bus trip must arrive at the route terminus before the beginning of the minimum span of service for that route type and day. Likewise, at the end of the service day, the last trip must depart the route origin after the end of the minimum span of service for that route type and day. Table 3-5 provides the minimum spans of service by route type and day.

Table 3-5: MBTA Span of Service Standards

Bus Route Type	Day	Minimum Span of Service
Local Bus Routes	Weekday	7:00 AM – 6:30 PM
	Guideline for high-density areas:	
	Saturday	8:00 AM – 6:30 PM
	Sunday	10:00 AM – 6:30 PM
Community Bus Routes	Weekday	10:00 AM – 4:00 AM
Express/Commuter Bus Routes	Weekday	7:00 AM – 9:00 AM and 4:30 PM – 6:30 PM
Key Bus Routes	Weekday	6:00 AM – 12:00 AM
	Saturday	6:00 AM – 12:00 AM
	Sunday	7:00 AM – 12:00 AM

Source: MBTA (2009a)

Frequency of Service

The MBTA's frequency of service standards establish minimum frequencies that limit the scheduled amount of time customers must wait for service. For routes with high ridership, these minimums may not be sufficient to meet demand. In these cases, the agency increases the frequency to meet the level of customer demand based on average bus load levels. Lightly-traveled routes may not require service frequencies above the minimum frequency standards. Table 3-6 shows the minimum frequency standards for each bus route type by time period.

Table 3-6: MBTA Minimum Frequency of Service Standards

Bus Route Type	Weekday Time Periods	Minimum Frequency (Headway)
Local/Community Bus Routes	AM and PM peaks	30-minute headway
	All other periods	60-minute headway (mid-day policy objective of 30-minute headway in high-density areas)
	Saturday and Sunday all day	60-Minute headway
Express/Commuter Bus Routes	AM and PM peaks	3 trips in the peak direction
Key Bus Routes	AM and PM peaks	10-minute headway
	Early AM and midday base/ school	15-minute headway
	Evening and Late Evening	20-minute headway
	Saturday and Sunday all day	20-minute headway

Source: MBTA (2009a)

Schedule Adherence

The MBTA's schedule adherence standards allow the agency to measure how reliably services adhere to the scheduled arrival times or scheduled headways. The schedule adherence standards for bus routes vary based on frequency of service. This is because customers on routes with high-frequency service tend to arrive at the bus stop without consulting a schedule, assuming that a bus will arrive within a reasonable wait time, and customers on routes with low-frequency service tend to refer to the bus schedule before arriving at the bus stop so as to minimize their wait time. Because of the different ways customers plan their arrivals at bus stops between high- and low-frequency services, the MBTA utilizes different standards for each level of frequency. For routes with low frequencies (headways greater than ten minutes), a trip is considered on-time if it meets the following criteria:

- The bus departs its origin timepoint between zero minutes before and three minutes after its scheduled departure time,
- The bus leaves all mid-route timepoints between zero minutes before and seven minutes after its scheduled departure time, and
- The bus arrives at its destination timepoint between three minutes before and five minutes after its scheduled arrival time.

For routes with high frequencies (headways of ten minutes or less), a trip is considered on-time if:

- The bus departs its origin and mid-route timepoints within 1.5 times the scheduled headway, and
- The actual run time for the total length of the route is within 20 percent of the scheduled run time.

These standards are used to determine whether individual trips are on-time. To consider an entire route on-time, 75 percent of all timepoints along a route must be on-time according to the schedule adherence standards (MBTA, 2009a).

Vehicle Load

The MBTA's vehicle load standards dictate the average maximum number of passengers allowed per vehicle that is considered safe and comfortable by time period. Between 6:00 AM and 9:00 AM and again between 1:30 PM and 6:30 PM, the average maximum load of buses on a particular route during a given time period should be no more than 140 percent of the seated capacity of the buses (about 55 passengers). This loading level allows standees but does not overly crowd a vehicle. During all other time periods, the average maximum load of buses on a route during a given time period should be no more than 100 percent of the seated capacity (39 passengers).

In addition to measuring crowding levels, vehicle load is an important indicator of whether the level of service being provided is appropriate relative to passenger demand (MBTA, 2009a). For example, average bus loads greater than 55 passengers suggest that more service is needed, whereas average bus loads of ten passengers may indicate that a route is over served.

Cost Effectiveness

The cost effectiveness standard evaluates the economic productivity of a route against the cost effectiveness of similar routes and the system average. The metric used is bus net cost per passenger, which compares the benefits of a bus route (in terms of passengers) to the public cost of providing the service. The equation is:

$$Net\ Cost\ per\ Passenger = \frac{C_{ij} - R_{ij}}{P_{ij}} \qquad \textbf{Equation 1}$$

where C is operating cost, R is service revenue, and P is boarding passengers for route i during time period j. Bus routes and their net costs per passenger are compared against the system average during the regular service planning process. Routes that have a net cost per passenger equal to or greater than three times the system average are considered deficient and are reviewed to identify potential service changes to improve cost effectiveness (MBTA, 2009a).

3.2.4 Service Planning Process

The MBTA's service planning process is intended to ensure that the agency uses its available resources most effectively by developing strategies to improve performance or by reallocating resources within the system. For the bus network, there are two levels of this process. The MBTA conducts an ongoing evaluation of selected routes and implements incremental service changes for those routes quarterly. The agency also conducts a two-year planning process to develop the biennial service plan, which includes performance reviews of every route to determine whether service changes are warranted. The data for these two processes are collected using automated data systems supplemented by periodic manual data collection efforts. In addition to the same types of minor service changes considered during the ongoing route evaluation process, the biennial service planning process considers major service changes which require additional operating resources and can affect route structure (MBTA, 2009a). The characteristics of minor and major service changes are described in Table 3-7.

Table 3-7: MBTA Minor and Major Service Changes

Magnitude	Type	Resource Implications
Minor	• Running time adjustments • Departure time adjustments • Headway changes to match ridership and service levels (so long as the frequency and loading standards are still met) • Changes to bus stop locations • Alignment changes • Span of service changes within one hour or less • Route extensions of one mile or less • Route variation modifications	Changes that can be implemented with existing equipment and within the adopted budget without significantly affecting route structure
Major	• Major service restructuring • Implementation of new routes or services • Elimination of a route or service • Elimination of part of a route • Span of service changes greater than one hour	Changes that will have a significant effect on resources and may potentially have a significant effect on riders

Source: MBTA (2009a)

Ongoing Bus Service Planning Process

In the ongoing bus service planning process, routes are selected for performance review based on concerns raised through feedback from operations and planning staff, as well as comments from actors outside of the MBTA (customers, regional agencies, etc.). Planners use performance data to evaluate these selected routes, but the data is not used when identifying routes for analysis. Both minor and major service changes are evaluated using the following criteria:

- Performance as measured against the service standards
- The rationale for the change
- Net cost per new passenger or net savings per lost passenger
- Changes in ridership, travel time for existing customers, operating costs, and fare revenue
- Key characteristics and demographics of the market
- Contribution to the achievement of external mandates (Title VI, ADA, etc.)
- Other factors, as appropriate

All proposed minor changes are analyzed and presented to the MBTA Service Committee, which includes representatives from several MBTA departments. The committee approves or rejects each minor service change, and all approved minor changes are implemented during the next quarterly schedule change. Major service changes identified during the ongoing bus service planning process are deferred to the biennial service planning process (MBTA, 2009a).

Biennial Service Planning Process

Through its biennial service planning process, the MBTA develops a new Service Plan every two years that describes system performance and outlines the bus services that will be operated over the next two years. The plan includes a summary of recent performance for all existing services, recommendations for minor and major service changes, discussions of service changes that were considered but not recommended, and a review of the effectiveness of past service changes.

The biennial service planning process evaluates the performance of each route as measured using the service standards described earlier in this chapter. Based on this analysis, planners recommend minor or major service changes that are intended to improve performance of routes that fail at least one service standard. In addition to the sources of information about route performance that guide the ongoing service planning process, the biennial service planning process includes a public outreach component to solicit input from customers about how service can be improved.

Service changes proposed through this process are compared to determine which would result in the most efficient use of resources. To do this, planners rank service improvements based on the expected net cost per new passenger: service change proposals with the lowest cost per new passenger rank the highest. Likewise, service reductions are ranked based on the expected net savings per lost passenger. Other criteria, such as schedule adherence and service coverage, are considered as secondary factors in this evaluation. Once the potential service changes are ranked, staff compares the total cost of service improvements to the total cost of service reductions to select the proposed changes that maximize ridership in a cost-effective manner, subject to an overall budget constraint. Once the recommended changes are determined, they are reviewed again by the Service Committee for feasibility before they are included in the Preliminary Service Plan. Following a public outreach process, the final Service Plan is then presented to the MBTA Board of Directors for approval before the changes are implemented (MBTA, 2009a).

3.3 Summary

This chapter presented the service planning processes of the CTA and the MBTA, as documented in their service planning guidelines. The next chapter provides an overview of the performance metrics and analyses that the CTA and the MBTA currently use to measure performance (some of which have been developed since the adoption of the agencies' respective service planning policies and therefore are not discussed in this chapter) and recommends the metrics and analyses that enable agencies to most effectively measure performance using automatically collected data.

4 Measuring Performance Using Automatically Collected Data

Shifting from manual data collection methods to automated data collection methods can transform the way transit agencies measure system performance. Many transit agencies already use automated data systems which allow data to be collected more frequently, in more detail, and more economically. Automated data systems also allow transit agencies to develop new and enhanced performance metrics which provide a clearer and more accurate picture of bus route performance than those previously available with manual methods.

The CTA and the MBTA are in the midst of transitioning from using a set of performance metrics which were developed when data was scarce to using performance metrics that take greater advantage of automated data systems. This chapter discusses three categories of metrics used by the CTA and MBTA to measure bus performance, including bus loading metrics, service reliability metrics, and metrics that measure customer demand and the cost effectiveness of providing service. Performance metrics within each of the three categories will be described in detail, using examples to illustrate how each agency applies these metrics in service evaluation. The metrics used by each agency will then be critically assessed to determine how well they take advantage of the capability of automatically collected data. Next, this chapter proposes a set of metrics within each category which harness the full power of automated data systems to improve performance measurement and, ultimately, system performance. The proposed performance metrics will be incorporated into the recommended service planning process, which is described in Chapter Five. Finally, this chapter includes an overview of the ways that agencies can measure performance at the origin-destination and network levels using the full capabilities of AFC data.

4.1 Bus Load Metrics

Bus load metrics consider the number of passengers on each bus and are useful in several aspects of bus service planning. At the most basic level, bus load metrics measure whether an agency is providing enough service to carry the customer demand. Bus load metrics also measure passenger comfort; crowded buses provide a less comfortable experience than buses with few passengers. Finally, overcrowded buses have an impact on service reliability because they experience longer dwell times at bus stops, increasing the running time of buses and hence the travel time of customers.

This section describes and provides examples of metrics and analyses that the CTA and the MBTA currently use to evaluate bus loading and crowding levels. This section then critically assesses CTA and

MBTA bus load metrics to identify their strengths and weaknesses, given the opportunities that automatically collected data provide. It then proposes a set of bus loading metrics and analyses that agencies should adopt to take advantage of the capability of automatically collected data. Examples using CTA bus load data are presented to demonstrate the efficacy of the proposed metrics.

4.1.1 Current CTA Bus Load Metric

The CTA's service standards address bus loading via its frequency of service standard, which recommends the appropriate service frequency given passenger demand levels and threshold values for average bus loads by time period. Frequency is determined based on average passenger flow, which is the number of customers on all buses passing a point in a given time period at the maximum flow point averaged over a three-month pick period (see Section 2.4.3). Providing the proper frequency based on demand ensures that bus loads, averaged over 30-minute intervals by pick period, stays below the agency's threshold value, which varies by the level of customer demand and time period (the average maximum bus load based on this metric is 60 passengers).

Since the adoption of the service standards in 2001 and the implementation of automated data systems, the CTA has developed Microsoft Excel-based tools which query a master database to summarize performance in several categories and in various levels of detail. One of these tools focuses on bus loads and passenger crowding. It automatically generates graphs and tables of the average and the 75th percentile of bus loads in two ways. First, the agency measures loading spatially along a route for a given time period. Second, the CTA measures the average of 75th percentile of the maximum load for each bus trip throughout an average day by half hour[1]. The CTA applies the 75th percentile of bus load metric to identify higher levels of crowding than are indicated by the average bus load metric. The agency considers the difference between the average bus load and the 75th percentile of bus load as an indication of the distribution of bus loads: a large difference between the two values implies that bus loads are highly variable and that some buses are likely overcrowded. Examples of these graphs using CTA bus data are shown in Figures 4-1 and 4-2.

Figure 4-1 shows the average and 75th percentile of bus loads across all stops on Route 66 eastbound between 7:30 and 8:00 AM for an average weekday in Fall 2009. The CTA operates headways of 4-6 minutes on Route 66 during the AM peak period. The graph shows that the average and 75th percentile

[1] The CTA also calculates the average passenger-experienced load, which is the load experienced by the average customer. However, this metric is not considered when reviewing route performance during the service planning process. This metric is further discussed in Section 4.1.4.

of bus loads, as measured by the agency's APC-enabled buses, increase gradually as buses move along the route. Both metrics peak at Chicago/Noble: average bus load is 41 passengers and the 75th percentile of bus loads is 53 passengers. Both of these measures are below the CTA's crowding guideline of 60 passengers during peak travel periods. These metrics suggest that the service frequency on Route 66 eastbound during this half hour is adequate and that bus overcrowding is not a serious issue.

Figure 4-1: Current CTA Bus Load Metrics: Average and 75th Percentile of Bus Loads by Stop
Route 66 Eastbound, Weekdays in Fall 2009, 7:30-8:00 AM

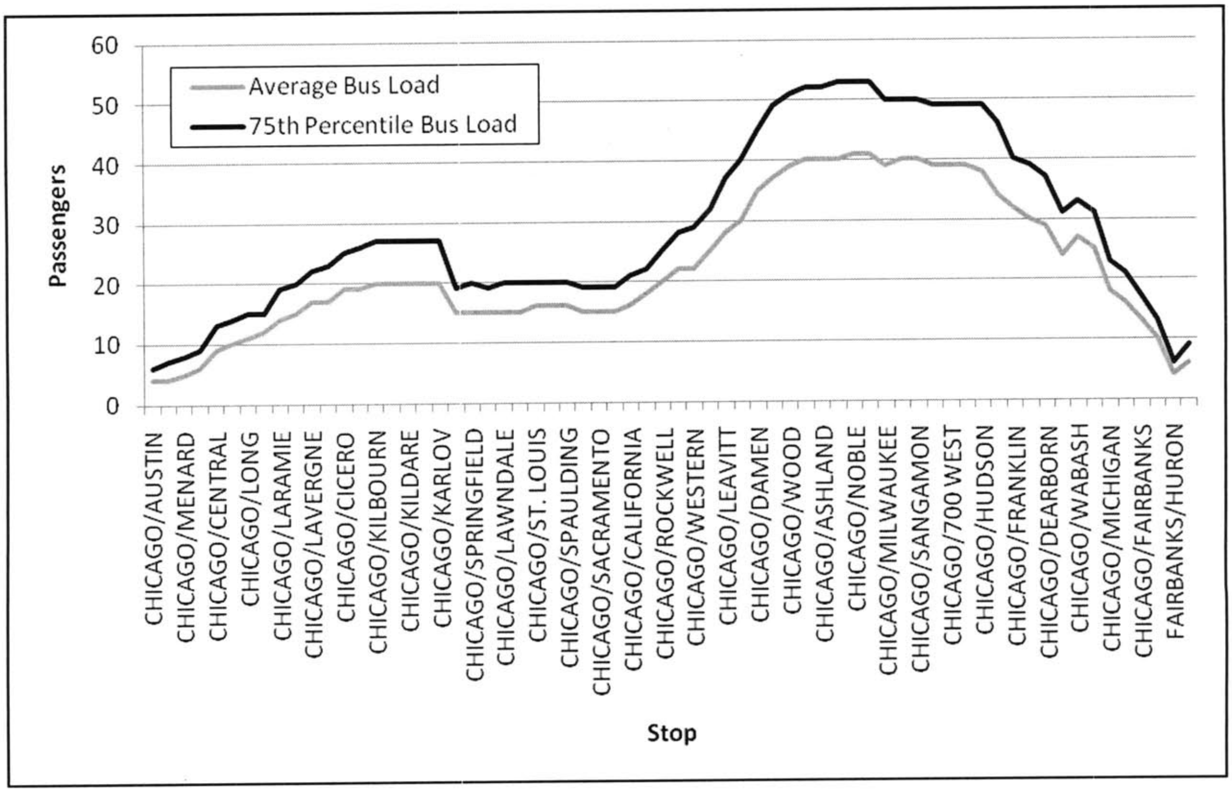
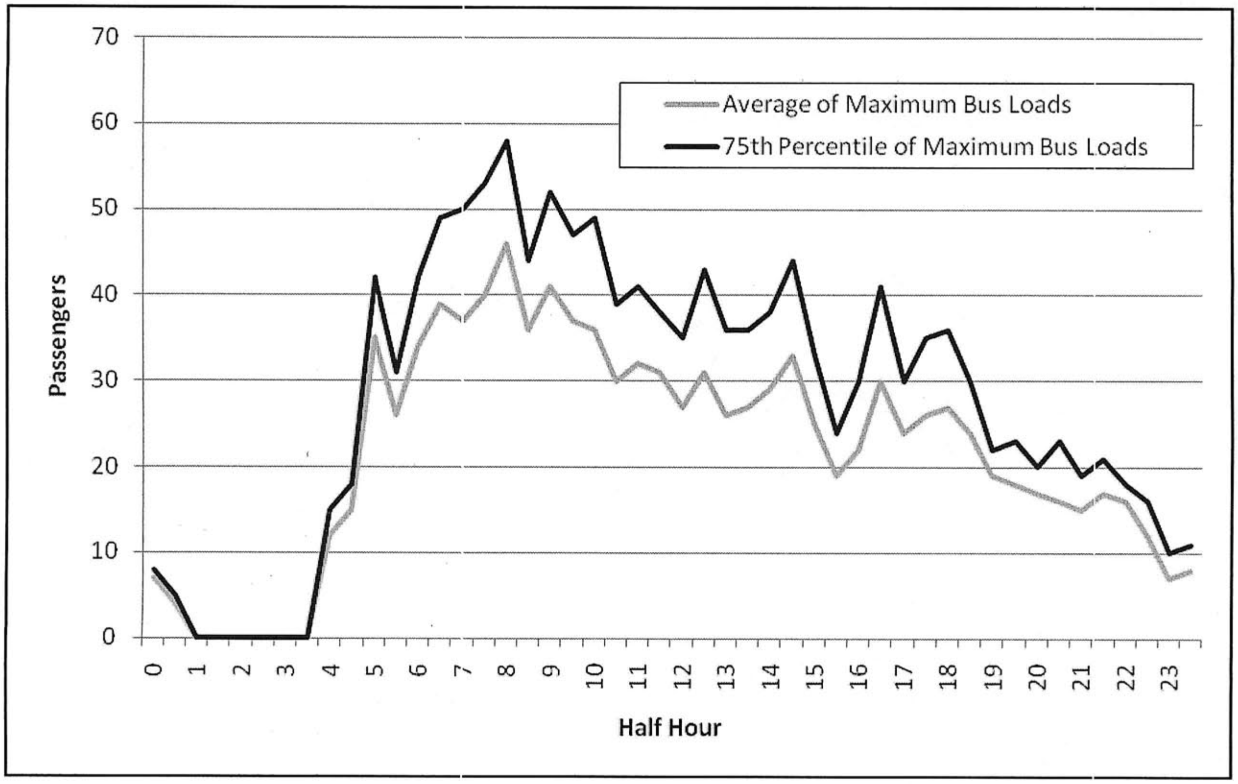


Figure 4-2 shows the average and 75th percentile of maximum bus loads by half hour also for Route 66 Eastbound in Fall 2009. The CTA operates headways of 4-8 minutes during the peak periods and 5-12 minutes during off-peak times on this route. These values are calculated by averaging the maximum loads of each trip (as measured by APCs) during half hour intervals on Route 66 for all weekdays in Fall 2009. As the graph shows, the average and 75th percentile of maximum bus loads peak during the 8:00-8:30 AM half hour: average maximum bus load is 46 passengers and the 75th percentile of maximum bus loads is 58 passengers (eastbound is the peak direction during the AM peak period). Both of these metrics are below the CTA's crowding guideline of 60 passengers during peak travel periods. Therefore, these metrics suggest that, at least in the eastbound direction, the scheduled service frequencies during each half hour interval are adequate given the levels of customer demand. These metrics also suggest that buses are not typically overcrowded, except perhaps during the half hour interval beginning at 8:00 AM, when the 75th percentile of maximum bus loads nears 60 passengers.

Figure 4-2: Current CTA Bus Load Metrics: Average and 75th Percentile of Bus Loads by Half Hour
Route 66 Eastbound, Weekdays in Fall 2009

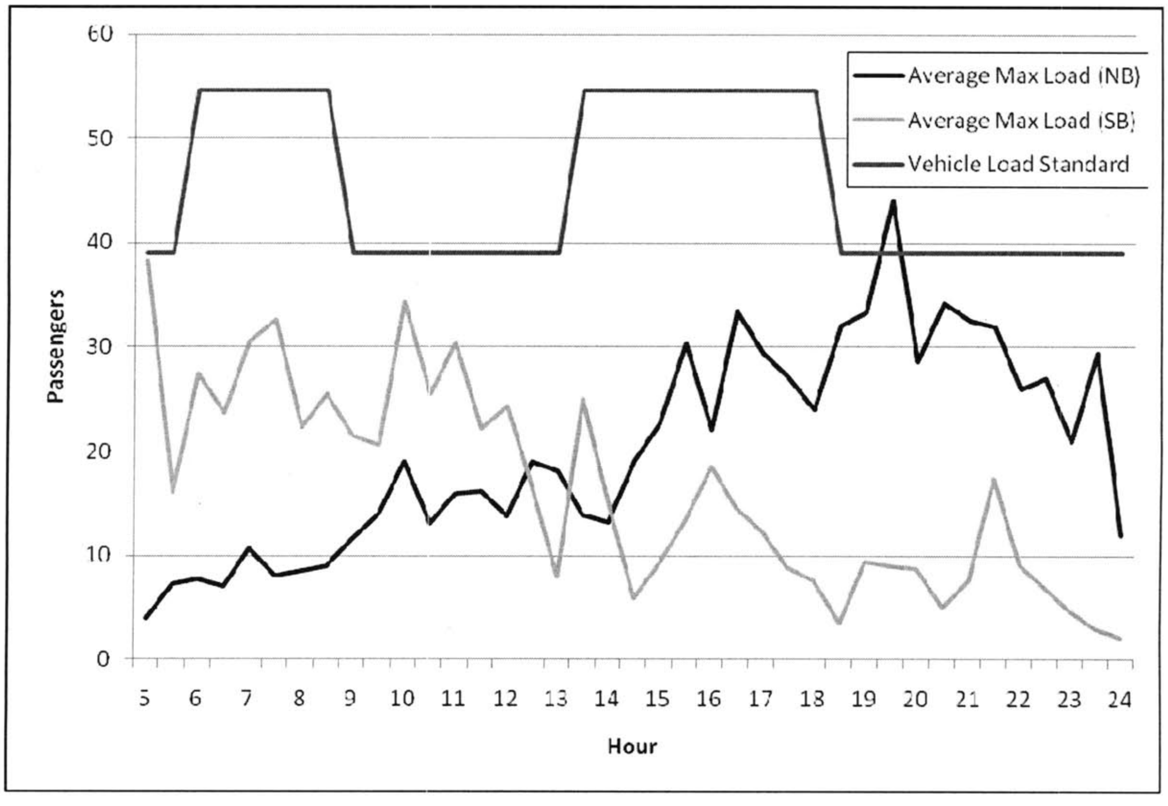


4.1.2 Current MBTA Bus Load Metric

The MBTA's Service Delivery Policy directly addresses vehicle loads, stating that bus loads, averaged over any 30-minute interval, should not exceed certain thresholds defined by time period (see Section 2.5.3). The MBTA applies this standard at the point of maximum flow for each direction for each half hour period. The policy concedes that some individual trips may be crowded, but average maximum bus loads must adhere to the standard. Figure 4-3 provides an example of the measurement of average bus loads for one MBTA bus route at its point of peak passenger flow, which is the same location for service in each direction.

Figure 4-3 shows average bus loads in both directions at the maximum load point by half hour on Route 101 in October and November 2009. The MBTA operates headways of six minutes during the AM peak period, 20-30 minutes in the midday, 12 minutes during the PM peak period, and 40-60 minutes in the evening hours on this route. The graph shows that the highest average bus load in the northbound direction, as measured by the agency's APC-enabled buses, occurs between 7:30 and 8:00 PM (44 passengers, exceeding the vehicle load standard for that half hour) and between 5:00 and 5:30 AM in the southbound direction (38 passengers, just below the vehicle load standard). Since average loads do not exceed the thresholds for most of the day, the average bus load metric suggests that crowding is not an issue, particularly during the peak periods when higher vehicle loads are accepted. Bus loads tend to be close to the threshold values during the shoulder periods surrounding each peak period, but with only one exception, average bus loads do not cross the average vehicle load thresholds.

Figure 4-3: Current MBTA Bus Load Metric: Average Bus Load by Hour at the Maximum Load Point
Route 101, Weekdays in October-November 2009



4.1.3 Critical Assessment of Current Bus Load Metrics

While the average maximum bus load metric used by both the CTA and the MBTA is useful in determining whether the transit agency is providing adequate service frequency to meet customer demand, it does not fully reflect the levels of crowding experienced by a typical customer. For example, the average bus load metric would report a lower average bus load for a pair of bunched buses with widely varying loads than the actual loading conditions experienced by the typical customer. This is because more customers experience the higher loads on the crowded (usually first) bus and fewer customers experience the lower loads on the other (usually following) bus. Similarly, this metric does not identify instances of very crowded buses that have a more significant, negative impact on service quality. This is because averaging the loads of severely overcrowded buses with less loaded buses dilutes the impact of severe crowding. Section 4.1.4 proposes metrics that address these shortcomings.

The CTA's 75th percentile of bus loads metric accounts for some of the shortcomings of the average bus load metric by identifying where and when overcrowding may be occurring on a particular route. Indeed, as shown in the previous examples, the 75th percentile of maximum bus load indicates between two and 13 more passengers than the average maximum bus load metric for the same stop and time period. However, since it is the 75th percentile and not the true maximum bus load, this metric also falls short in identifying the highest levels of crowding and the impacts that highly crowded buses have on customers.

Both the CTA's and MBTA's service standards include threshold values for average bus load which vary by time period. In the CTA's case, its frequency determination process allows for bus loads up to 60 passengers on high-frequency services during peak periods and up to 40 passengers during off-peak hours. The MBTA's standards allow for a passenger load of up to 140 percent of a bus's seated load during peak periods (about 55 passengers) and 100 percent of seated load during off-peak periods (39 passengers). It is logical to have different thresholds for different times of the day, since customers generally have different expectations of comfort during peak travel periods as opposed to off-peak travel periods and the marginal costs of providing service may also vary between peak and off-peak periods. However, the CTA's threshold of 60 passengers during peak periods may be too high, as loads this size can have a significant, negative impact on service quality, particularly in terms of running time. The agency might consider reducing this threshold during peak periods. The CTA should perform an analysis of running times for buses with varying load levels to estimate the load at which running time begins to increase significantly due to overcrowding.

4.1.4 Proposed Loading Metrics

This section presents two metrics that measure bus loads and passenger crowding more from the customer perspective than the metrics currently used by the CTA and MBTA. As described more fully below, the average passenger-experienced load metric provides an indication of load from the perspective of the *average* passenger, and the number or percent of overcrowded buses metric provides an indication of *high* levels of crowding.

Average Passenger-Experienced Load

The average passenger-experienced load metric measures the load experienced by the typical *passenger*, as compared to the average bus load metric, which measures the load on the typical *bus*. By focusing on the customer's view of service, the average passenger-experienced load metric is more customer-centric and more accurately reflects what the typical passenger experiences. The equation for average passenger-experienced load is:

$$Average\ Passenger\ Experienced\ Load = \frac{\sum_{i=1}^{n} {x_{ij}}^2}{\sum_{i=1}^{n} x_{ij}} \qquad \textbf{Equation 2}$$

where x_{ij} is the passenger load at the maximum load point or any selected point for each bus i during time period j.

Although the average passenger-experienced load metric provides a more customer-centric measure of loading, it should complement rather than replace the average bus load metric. When used together, the two metrics can be particularly helpful in exposing service reliability problems. Specifically, the greater the difference between the two resulting values, the more likely it is that unreliable bus service is contributing to higher passenger-experienced loads rather than lack of adequate service frequency or other problems. This is important because it allows transit agencies to identify the causes of two distinct problems – overcrowding and unreliability – rather than simply providing more service to reduce crowding. Therefore, average bus load should be calculated and displayed alongside average passenger-experienced load in order to highlight the difference between the two metrics.

It can be argued that transit agencies should continue to use their current threshold values defining unacceptable levels of passenger crowding when using the average passenger-experienced load metric. However, because the average passenger-experienced load metric generally results in higher values than the average bus load metric, applying the same threshold will initially result in more routes exceeding the threshold. Despite this, transit agencies should not modify their established threshold values because of this difference alone. Agencies' thresholds should identify the point at which bus loads begin to significantly impair service quality regardless of whether the average bus load or the average passenger-experienced load metric is applied.

In order to get the most from this metric, transit agencies should calculate average passenger-experienced load for each route direction in two ways – by half hour at the maximum flow point and by stop for specific time periods. Analyzing this metric by half hour at the maximum flow point will help identify the times of the day in which the highest levels of crowding are experienced, whereas analyzing this metric by stop for specific time periods (AM or PM peak periods, for example) will help identify the route segments that experience the highest levels of crowding. Figures 4-4 and 4-5 demonstrate the usefulness of this metric and these analysis methods using data from Route 66 eastbound in Chicago.

Figure 4-4: Proposed Bus Load Metrics: Average Passenger-Experienced Load and Number of Overcrowded Buses by Half Hour
Route 66 Eastbound, Weekdays in Fall 2009

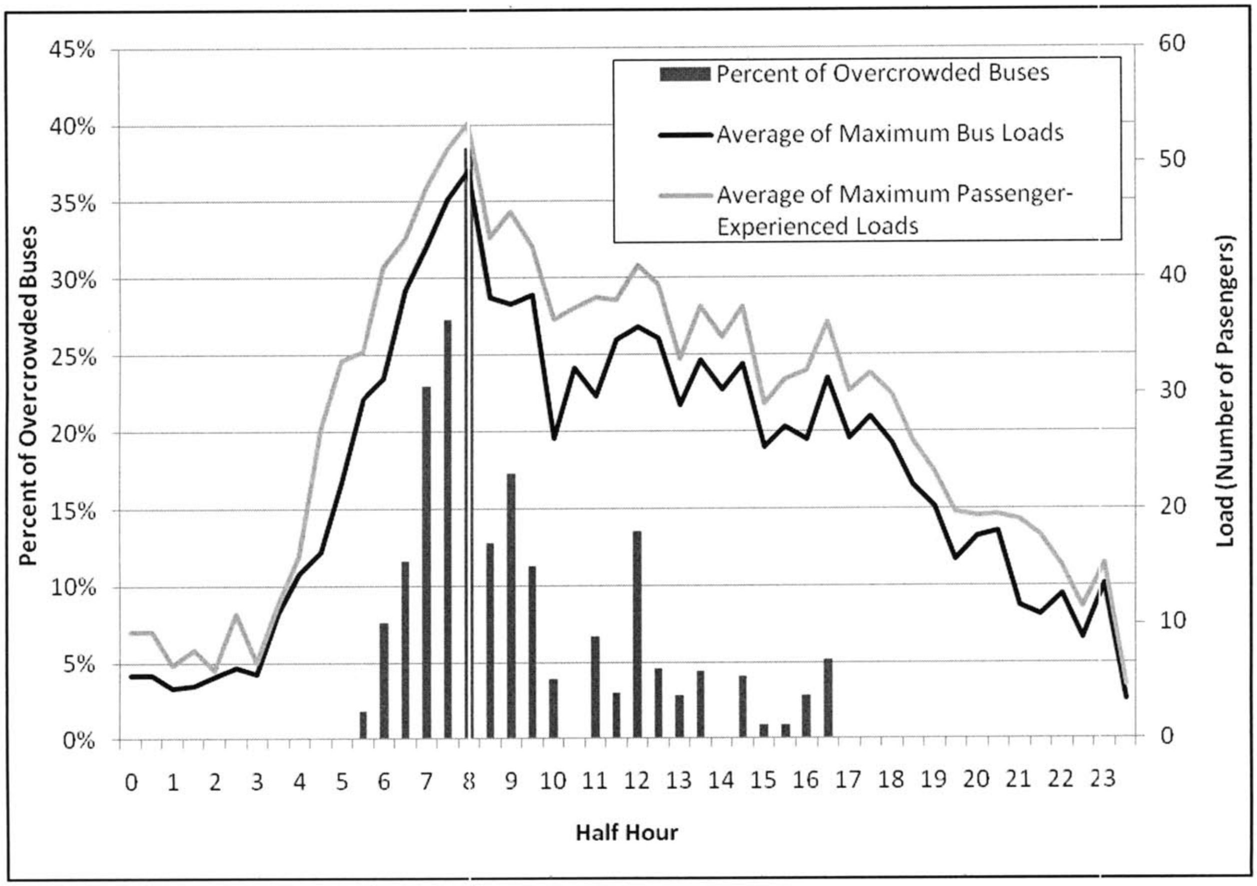


Figure 4-4 shows that the average of maximum passenger-experienced loads peaks between 8:00 and 8:30 AM (when the scheduled headway is 4-6 minutes) at 54 passengers (as measured by APCs). However, the difference between the average of maximum passenger-experienced loads and the average of maximum bus loads, at four passengers, is relatively small during this half hour. The difference is largest between 4:30 and 5:00 AM (headways are 10 minutes during this time interval), when the average of maximum bus loads is 16 passengers but the average customer experiences a bus with 27 passengers. This indicates that unreliable bus arrivals or uneven passenger demand may be causing uneven bus loads during this half hour. The graph shows that the route does not violate the bus load threshold of 60 passengers during the peak periods, but that there are a few instances where average of maximum passenger-experienced loads exceed 40 passengers during off-peak hours.

Figure 4-5: Proposed Bus Load Metrics: Average Passenger-Experienced Load and Percent of Overcrowded Buses by Stop
Route 66 Eastbound, Weekdays in Fall 2009

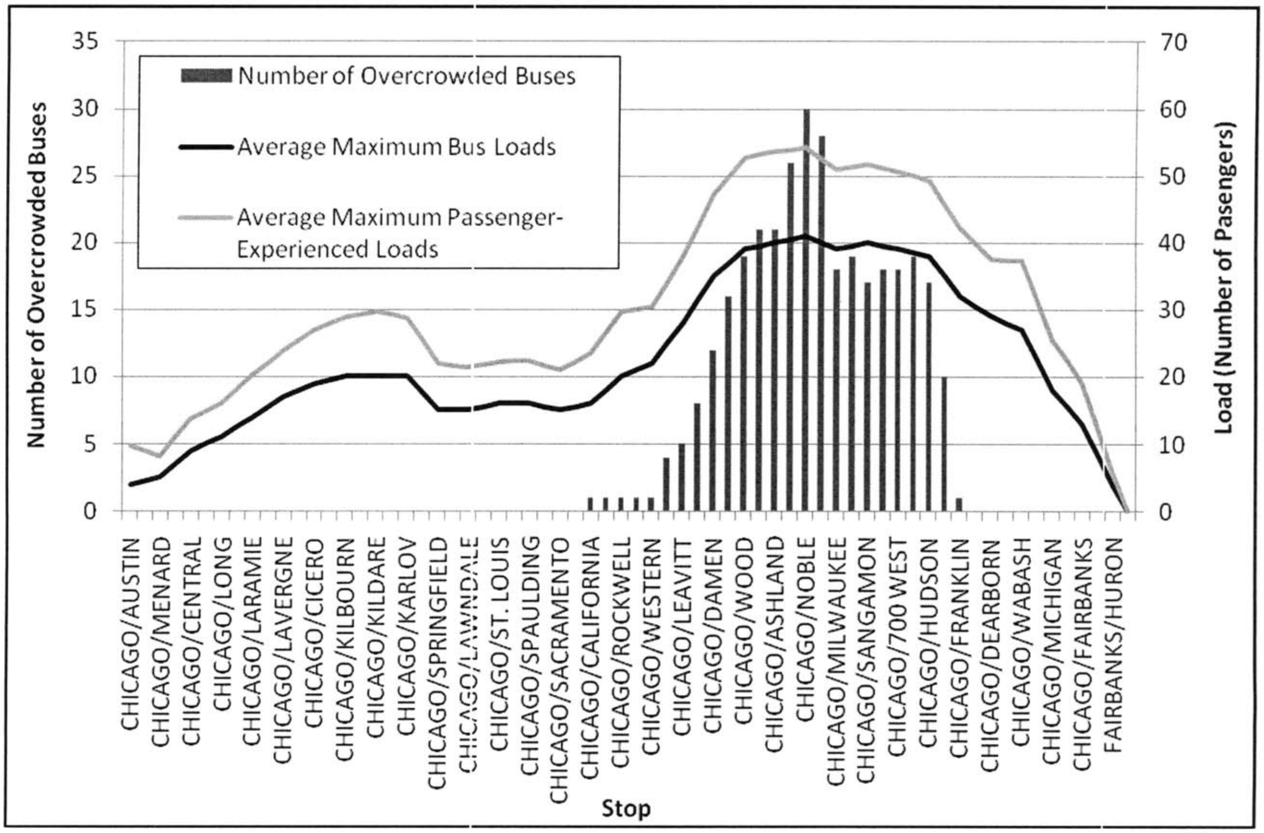


Figure 4-5 shows that the average maximum passenger-experienced load peaks at Chicago/Noble at 55 passengers (as measured by APCs) between 7:30 and 8:00 AM (headways are 4-6 minutes during this time interval). This location is also the point at which the difference between the average passenger-experienced load and the average bus load is greatest, at 14 passengers. This discrepancy means that while the average bus load is 41 passengers at this location during this half hour, the average customer experiences a bus with 55 people on it. Despite the higher values with the average passenger-experienced load metric, the route does not exceed the bus load threshold of 60 passengers per bus at any point along the route during this half hour.

Percent of Overcrowded Buses

The percent of overcrowded buses metric highlights route segments or time periods where overcrowding exists, resulting in significant impairment of service quality and passenger comfort. The metric simply notes the percent of buses on a route in a given time period that exceed the agency's maximum loading standard. If an agency has threshold values that are reduced during off-peak hours, the highest threshold value (e.g. 60 for the CTA) should be applied, since this metric is intended to measure instances of significant overcrowding, not just loading above desirable levels for off-peak times. In contrast to the average passenger-experienced load metric, which measures the load experienced by the *average* customer, the percent of overcrowded buses metric indicates when and where customers are experiencing *overcrowded* buses.

The percent of overcrowded buses metric is meant to supplement the average passenger-experienced load metric in measuring bus loads and therefore an overall threshold value is not necessary for this metric. If an agency does choose to use a threshold standard, however, a sample standard might be "routes with greater than 25 percent of buses that are overcrowded during any half hour period violate the percent of overcrowded buses standard." Additionally, transit agencies should use the same analysis methods recommended to measure average passenger-experienced loads: by stop for specific time periods and by half hour at the maximum flow point.

Figure 4-4 also shows the percent of overcrowded buses metric measured for Route 66 by half hour interval. In this case, the highest percentages of overcrowded buses occur during the AM peak period, as would be expected since eastbound is the peak direction of travel for this route during the morning peak period. However, most of the half hours between 9:00 AM and 5:00 PM also have some overcrowded buses. Overcrowding does not occur before 5:00 AM or after 5:00 PM. As with the previous example, the half hours where the percent of overcrowded buses are high coincide with periods having the greatest average passenger-experienced loads. However, the percent of overcrowded buses metric more acutely identifies the times during which instances of overcrowding, not just high average loads, are occurring. As such, it can be argued that the percent of overcrowded buses is an important supplement to the average passenger-load metric to identify where and when overcrowding is occurring.

Figure 4-5 also shows the percent of overcrowded buses metric by stop during the 7:30-8:00 AM interval. It shows that bus overcrowding is occurring between Chicago/California and Chicago/Franklin, with the highest percentage of overcrowded buses occurring between Chicago/Ashland and

Chicago/Noble. Overcrowding does not occur at any other point on the route in the eastbound direction during this half hour. The locations of overcrowded buses indicated by the percent of overcrowded buses metric coincide with the highest values of average passenger-experienced loads – all stops with greater than 25 percent of buses overcrowded also have average passenger-experienced loads of greater than 50 passengers. However, the percent of overcrowded buses metric is more pronounced, as it measures only very high bus loads, and is therefore a good indication of where and to what extent significant bus overcrowding is occurring along a route.

4.1.5 Summary

The metrics currently used by the CTA and MBTA fail to fully reflect customers' experiences of bus loading because of their focus on average values dilutes the instances of overcrowding that some customers experience. In contrast, the proposed metrics – average passenger-experienced load and the percent of overcrowded buses – focus attention on how customers experience and are affected by crowding. As a result, the CTA and MBTA can take advantage the capabilities of their automated data collection systems and create service planning processes that are more focused on customers, by supplementing the currently used average bus load metric with these customer-centric metrics.

4.2 Reliability Metrics

Measuring service reliability was difficult if not impossible with the small and infrequently collected data samples when transit performance data was collected manually. Because of the limitations of manually collected data, reliability metrics used by many transit agencies measured service reliability in an operator-oriented fashion in terms of how well the agency met its advertised level of service. The advent of automatically collected data has begun to change the way agencies measure reliability. Specifically, new reliability metrics take advantage of the large data samples provided by automated data systems by considering the full distribution of wait and travel time and therefore, more accurately measuring the impact of unreliable service on customers.

This section will explore how automatically collected data can be used to measure service reliability from the customer perspective as well as the agency perspective. First, this section describes the reliability metrics currently used by the CTA and the MBTA, including examples from each agency. These metrics are then critically evaluated to identify their strengths and weaknesses based on the full potential of automatically collected data. Next, several reliability metrics are proposed that take full advantage of automatically collected data. The section concludes by discussing additional applications of

AFC data to measure reliability from the customer perspective at the origin-destination and network levels of analysis.

4.2.1 Current CTA Reliability Metrics

Reliability performance metrics are not included in the CTA's 2001 Service Standards. The document was developed prior to the development of the agency's automated data systems when the CTA collected transit performance data manually. However, since about 2004, the CTA has expanded its use of automatically collected data to measure reliability for all bus routes. Specifically, the CTA now uses its automatically collected data and a variety of database query tools to measure reliability using the following metrics:

- adherence to the scheduled headway (for trips with headways less than 15 minutes),
- adherence to scheduled arrival times (for trips with headways of 15 minutes or greater), and
- excess passenger wait times (for trips with headways less than 15 minutes)

The CTA also measures bus running times (the total amount of time – running time plus recovery time – spent to complete each one-way trip) for each route to determine if there is adequate time allocated in the schedule. These metrics and analyses are introduced in the following sections.

Headway and Schedule Adherence – Successful Headways

The CTA's headway adherence metric identifies the percentage of trips that operated with headways close to the scheduled headway at all timepoints. The agency applies this metric to high-frequency bus routes – routes with headways of less than 15 minutes. The CTA uses this metric because it reflects the general assumption that passengers do not consult a schedule before departing to wait for high-frequency bus services. As a result, the time interval between buses is of greater concern to customers than adherence to the scheduled arrival times. For low frequency bus routes – routes with headways of 15 minutes or more – the CTA applies the schedule adherence metric, which identifies the percentage of trips that do not meet the agency's schedule adherence threshold at each timepoint. The CTA uses this metric because it reflects the general assumption that customers generally refer to the scheduled arrival times for lower frequency routes before departing for the bus stop. The CTA combines these two metrics into a single metric called "successful headway." A trip has a successful headway at each timepoint if it meets the headway or schedule adherence standards, respectively, as outlined in Table 4-1 below.

Table 4-1: CTA Successful Headway Metric Thresholds

Scheduled Headway	Successful Headway Threshold
<= 10 minutes	± 3 minutes
Between 10 and 15 minutes	± 5 minutes
>= 15 minutes	On-time (1 minute early to 2 minutes late)

Source: CTA (2010a)

The CTA does not use a threshold value (e.g. a route that has more than 25 percent of timepoint-trip pairs with unsuccessful headways during a defined time period shall be considered "unsuccessful") to indicate reliability problems relating to the successful headway metric. Rather, the metric is used by CTA scheduling staff to determine which routes are the least reliable. When analyzed spatially along a route, the metric provides an understanding of where reliability issues occur in order to determine whether additional resources should be allocated to improve reliability. The metric is therefore generally used to make minor adjustments in service. Figure 4-6 provides an example of the successful headway metric being applied at the route segment level.

Figure 4-6: Current CTA Reliability Metric – Successful Headway by Route Segment
Route 66 Eastbound, 8:00-8:30 AM, April 2009

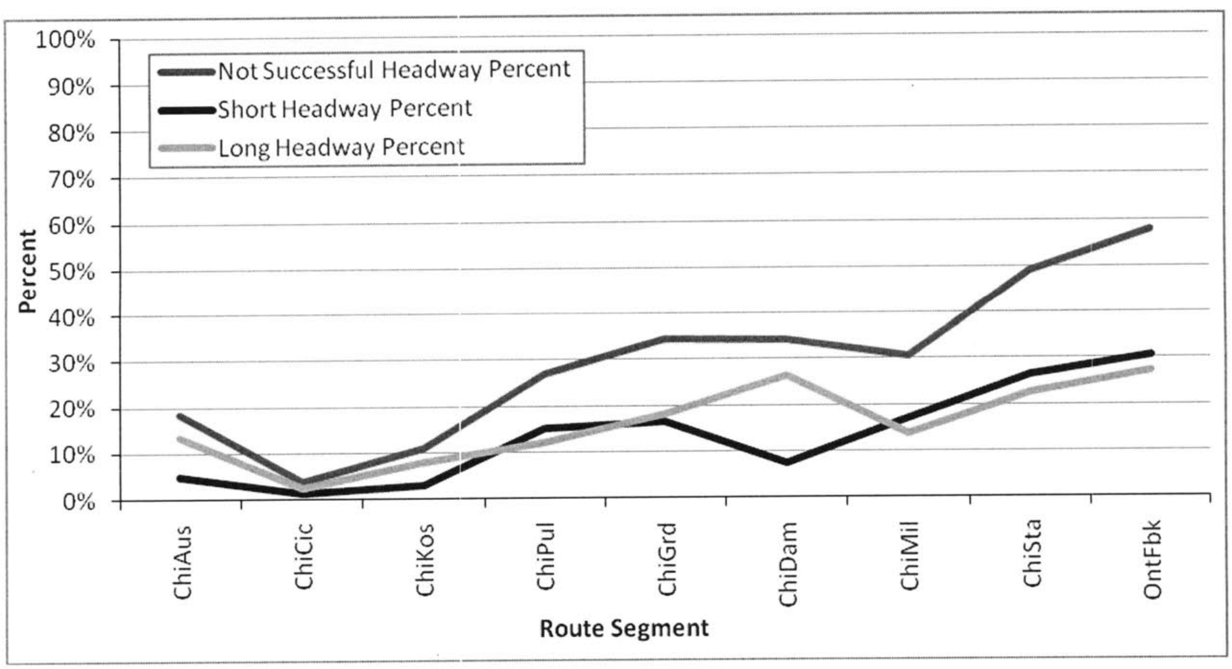


Figure 4-6 shows the percent of short and long headway buses and the percent of not successful headway buses (the combination of short and long headway buses) on Route 66 in the eastbound direction between 8:00 and 8:30 AM in April 2009. This data is collected by AVL equipment on every bus. High-frequency service is provided on this route during this time period (headways are 4-6 minutes), so the successful headway metric only considers long and short headways in this example. The graph shows that the percent of not successful headways increases as buses move along the route, peaking at 59 percent at Ontario and Fairbanks at the end of the route. This analysis indicates that unreliability becomes a greater problem as buses move along the route, particularly east of Milwaukee Avenue.

Average and Total Excess Wait Time

Excess wait time is a customer-centric metric that measures the impact of unreliable bus arrivals on customers. It represents the extra time, beyond the expected wait time based on the scheduled headway, that passengers wait on average for buses to arrive due headway variability. The equation for average excess wait time is:

$$Average\ Excess\ Wait\ Time = \frac{\overline{h_a}}{2}[1 + cov^2(h_a)] - \frac{\overline{h_s}}{2}[1 + cov^2(h_s)] \qquad \textbf{Equation 3}$$

where $\overline{h_a}$ is the average actual headway and $\overline{h_s}$ is the average scheduled headway (Wilson et al., 1992). To calculate total excess wait time, which is the total amount of time that all customers wait beyond the expected average wait time, one can multiply average excess wait time by the number of boarding passengers.

As with the successful headway metric, CTA scheduling staff uses the excess wait time metric to identify when and where along a route running time should be reallocated to make minor adjustments to service that are intended to improve reliability. However, a distinct advantage of excess wait time is the ability to quantify the average and total impacts experienced by customers due to the unreliability of bus arrivals. Figure 4-7 provides an example of the average excess wait time and total extra wait time metrics by route segment for one half hour period, and Figure 4-8 shows the two metrics applied at the route level over the course of an average weekday.

Figure 4-7 shows the average excess wait time, total excess wait time, and passenger boardings by route segment on Route 66 eastbound between 7:30 and 8:00 AM for an average weekday in October 2009 (during which scheduled headways are 4-6 minutes). Excess wait time is calculated based on AVL data, whereas passenger boarding data is collected by APCs. The route segment with the highest total excess wait time (nearly 12,000 minutes) is Chicago/Milwaukee to Chicago/State. This segment also has the highest number of boardings. The total excess wait time metric shows that excess wait time due to unreliable bus arrivals has the greatest impact on the eastern portion of the route near the Blue, Brown, and Red Line stations. The graph also shows that average excess wait time is relatively steady at 35-40 seconds for the first two thirds of the route before increasing to one minute at Ontario and Fairbanks.

Figure 4-7: Current CTA Reliability Metric – Excess Wait Time by Route Segment
Route 66 Eastbound, Weekdays in October 2009, 7:30-8:00 AM

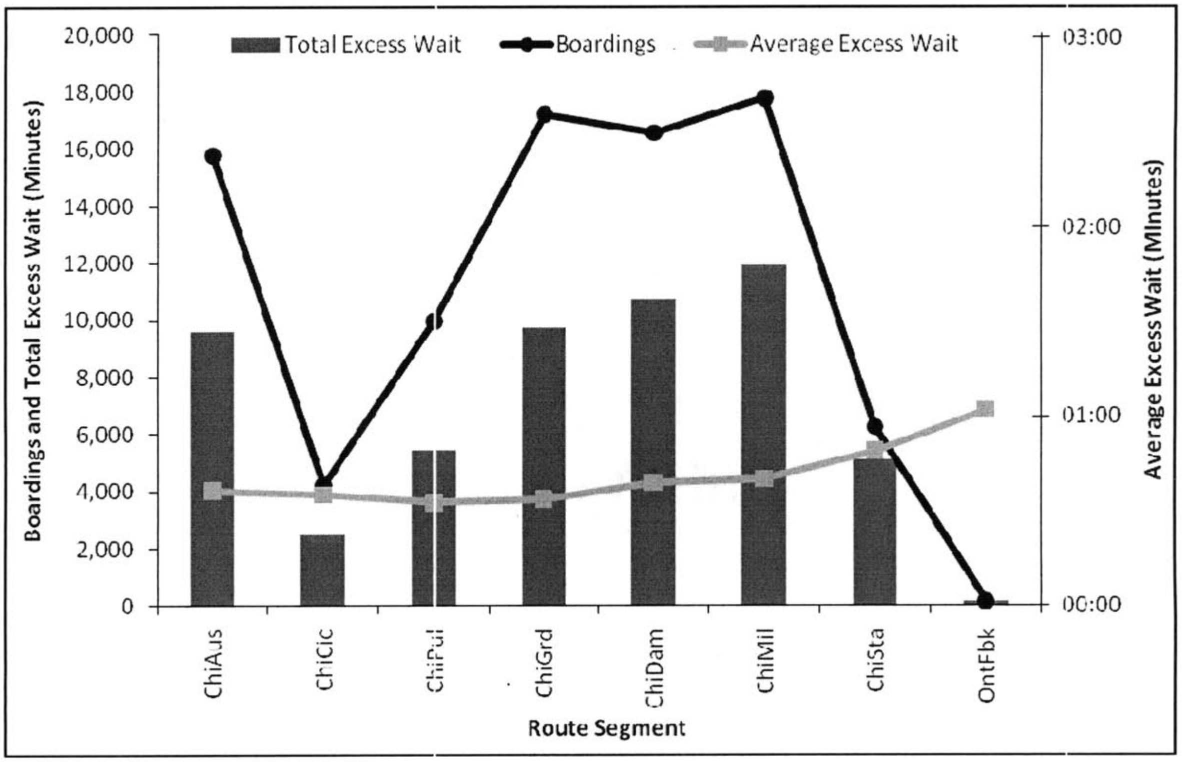
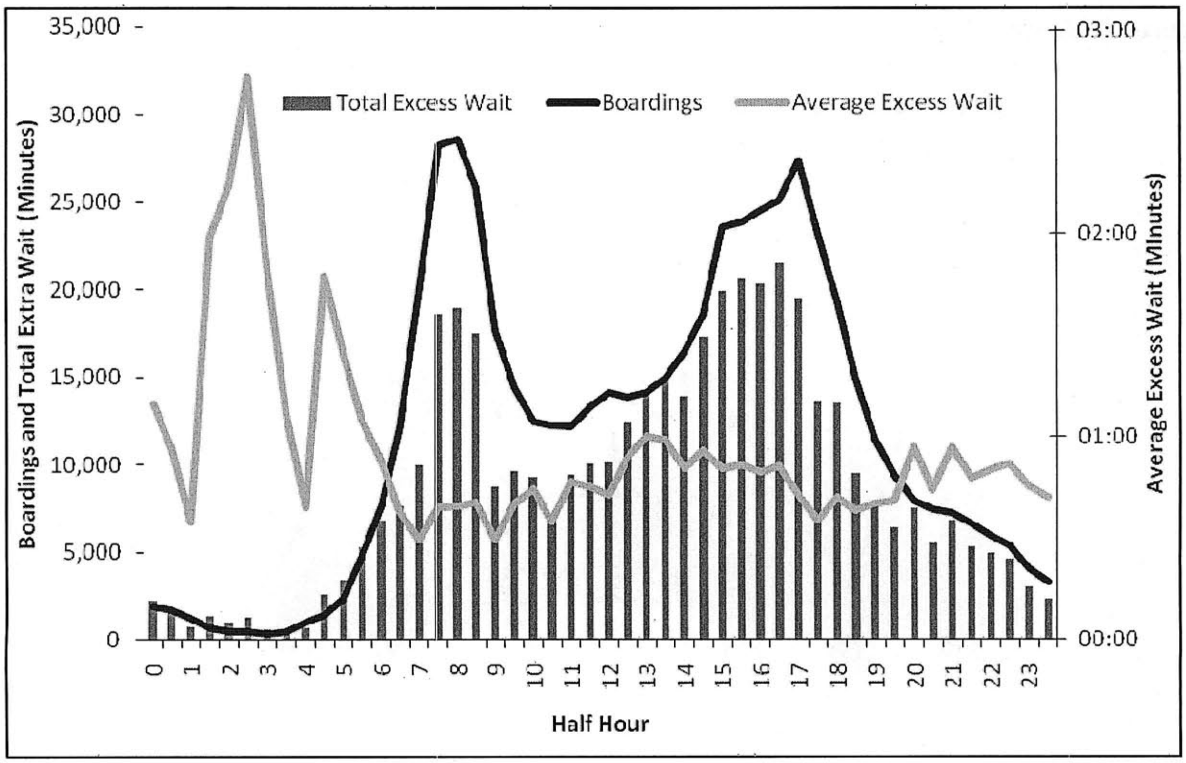


Figure 4-8 shows how average and total excess wait times vary throughout the day on Route 66 for an average weekday in October 2009. The CTA operates headways of 4-8 minutes during the peak periods and 5-12 minutes during off-peak times on this route. In this example, average excess wait times are highly variable during the overnight hours when headways are 20 minutes, ranging from 35 seconds at 1:00 AM to almost three minutes at 2:30 AM. The high average excess wait times values during the overnight hours are likely due to the relatively long headways and variations in customer demand during these times. Since there are relatively few late-night passengers, however, the total excess wait times during these times are very low. In contrast, average excess wait times for the rest of the half hours on Route 66 are relatively low, all below one minute. Because ridership is high during the peak periods, more people experience these average excess wait times during these times, resulting in high total extra wait times during the peaks. Graphs like this could help planners identify the times of day during which unreliable bus arrivals cause the longest average wait times. These types of graphs also identify when unreliable bus arrivals are having the greatest total impact on passengers.

Figure 4-8: Current CTA Reliability Metric – Excess Wait Time by Half Hour
Route 66, Weekdays in October 2009



The CTA does not use threshold values (e.g. average excess wait time should be less than 20 percent of a route's expected wait time for a given time period) for average excess wait time. However, it may be helpful to compare average excess wait time at the route level to the systemwide average excess wait time. In October 2009, the systemwide average excess wait time was 46 seconds across all time periods. The average excess wait time for Route 66 in this direction and during this half hour is below the systemwide average from Chicago/Austin to Chicago/Milwaukee, with the aforementioned exception between Chicago/Kostner and Chicago/Pulaski. While the CTA does not use threshold values for its total excess wait time metric, it could rank routes by total excess wait time. This would encourage the agency to make changes to the routes where reliability problems have the greatest overall impact on customers.

Bus Half Cycle Time Analysis

The CTA recognizes that when buses have insufficient running and recovery time (which together make up half cycle time) to travel the length of a route, buses run behind schedule, causing increased customer wait times, and, in some cases, delays in the departure of the return trip. Likewise, providing too much half cycle time could result in buses running early, causing bus bunching or otherwise reducing service reliability. Since running time is a significant source of unreliable bus arrivals, the CTA directly measures actual bus travel times to determine if the half cycle time allocated to a route in a given time period is adequate. If the percentage by which half cycle time must be increased to ensure that 95 percent of all trips in a given half hour are completed within the scheduled half cycle time is greater than five percent, the CTA determines that half cycle time should be increased. A similar calculation is made when actual bus travel times indicate that half cycle time should be reduced. Table 4-2 provides an example of the CTA's half cycle time analysis for Route 66 by half hour and direction.

Table 4-2 shows the percentage by which half cycle times should be changed during each half hour to achieve the agency's half cycle time standard (half cycle times should be the 95th percentile of actual running times) in either direction on Route 66 (headways are 4-8 minutes during peak periods and 5-12 minutes during off-peak times). This is based on the actual end-to-end bus travel times (as measured by AVL) and the scheduled half cycle times during each half hour on weekdays in Fall 2009. In this example, the metric indicates that half cycle times should be increased during a few half hours in the AM and PM peak periods and decreased during a few late night/early morning half hours in the eastbound direction. The westbound direction shows similar results, except that running times should be increased between 1:00 and 4:00 PM. This corresponds with the results of the excess wait time analysis in Figure 4-8: the average excess wait time between 1:00 and 4:00 PM is relatively high compared to the other half hour periods between 7:00 AM and 7:00 PM. This indicates that insufficient half cycle times may be causing some of the unreliable bus arrivals in the afternoon on the typical weekday.

4.2.2 Current MBTA Reliability Metrics

The MBTA's Service Delivery Policy reflects the agency's current practice of measuring service reliability. The agency measures schedule adherence for low-frequency service and headway variability for high-frequency service (see Section 2.5.3). These two metrics are measured together in the same way that the CTA determines "successful headways." The MBTA applies these metrics at the origin, mid-route, and destination timepoints for each route. To determine whether entire routes violate the standard, the MBTA considers the percent of all timepoints on a route for each day type (e.g. weekday) that meet the schedule/headway adherence standard. Figures 4-9 and 4-10 provide examples of this standard being applied to Route 28 in each direction.

Table 4-2: Current CTA Running Time Analysis – Percent of Run Time Change Needed by Half Hour
Route 66, Fall 2009

Eastbound

Half Hour (AM)	Run Time Change Needed	Half Hour (PM)	Run Time Change Needed
0	0%	12	3%
0.5	-5%	12.5	2%
1	-15%	13	2%
1.5	-12%	13.5	1%
2	-4%	14	2%
2.5	0%	14.5	4%
3	0%	15	5%
3.5	3%	15.5	2%
4	-2%	16	-1%
4.5	-4%	16.5	0%
5	1%	17	0%
5.5	1%	17.5	-1%
6	-1%	18	2%
6.5	0%	18.5	0%
7	3%	19	4%
7.5	6%	19.5	4%
8	5%	20	0%
8.5	0%	20.5	0%
9	1%	21	-1%
9.5	3%	21.5	0%
10	3%	22	-3%
10.5	1%	22.5	-2%
11	3%	23	0%
11.5	5%	23.5	-6%

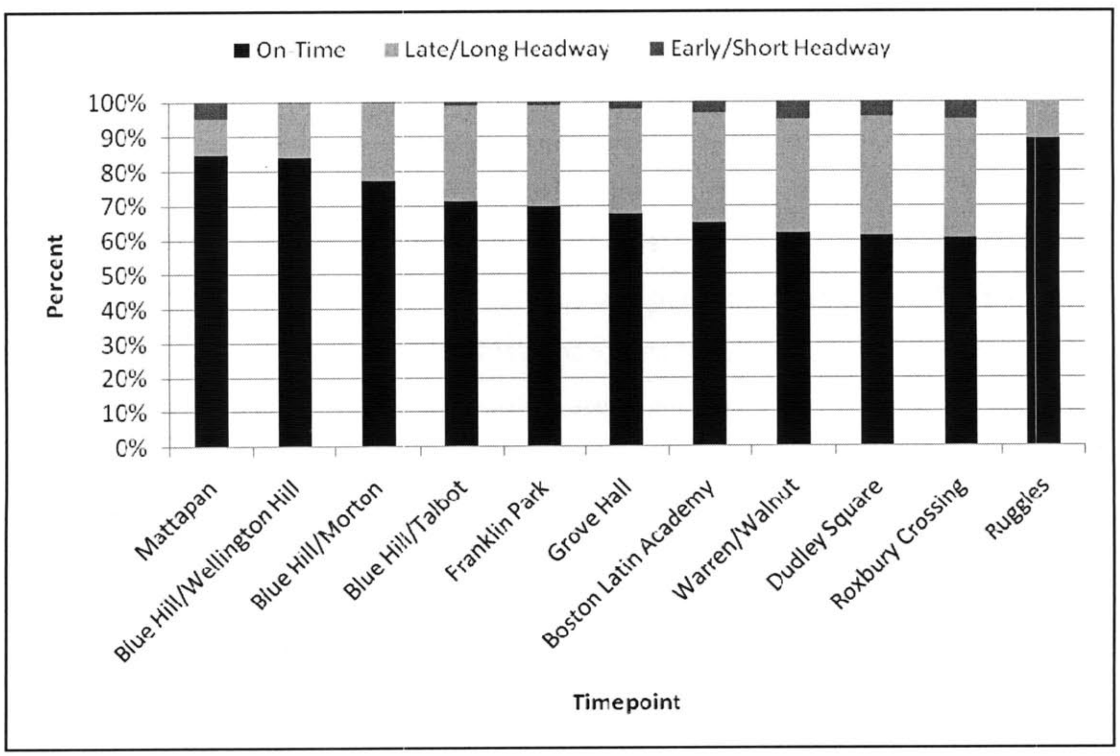
Westbound

Half Hour (AM)	Run Time Change Needed	Half Hour (PM)	Run Time Change Needed
0	0%	12	4%
0.5	0%	12.5	2%
1	-5%	13	5%
1.5	1%	13.5	8%
2	0%	14	10%
2.5	0%	14.5	5%
3	0%	15	6%
3.5	-9%	15.5	5%
4	-3%	16	4%
4.5	-1%	16.5	2%
5	-1%	17	4%
5.5	-1%	17.5	1%
6	-1%	18	1%
6.5	0%	18.5	-1%
7	2%	19	0%
7.5	6%	19.5	4%
8	6%	20	5%
8.5	4%	20.5	0%
9	-1%	21	1%
9.5	-4%	21.5	5%
10	1%	22	4%
10.5	2%	22.5	3%
11	4%	23	6%
11.5	6%	23.5	2%

Key: Increase | Decrease

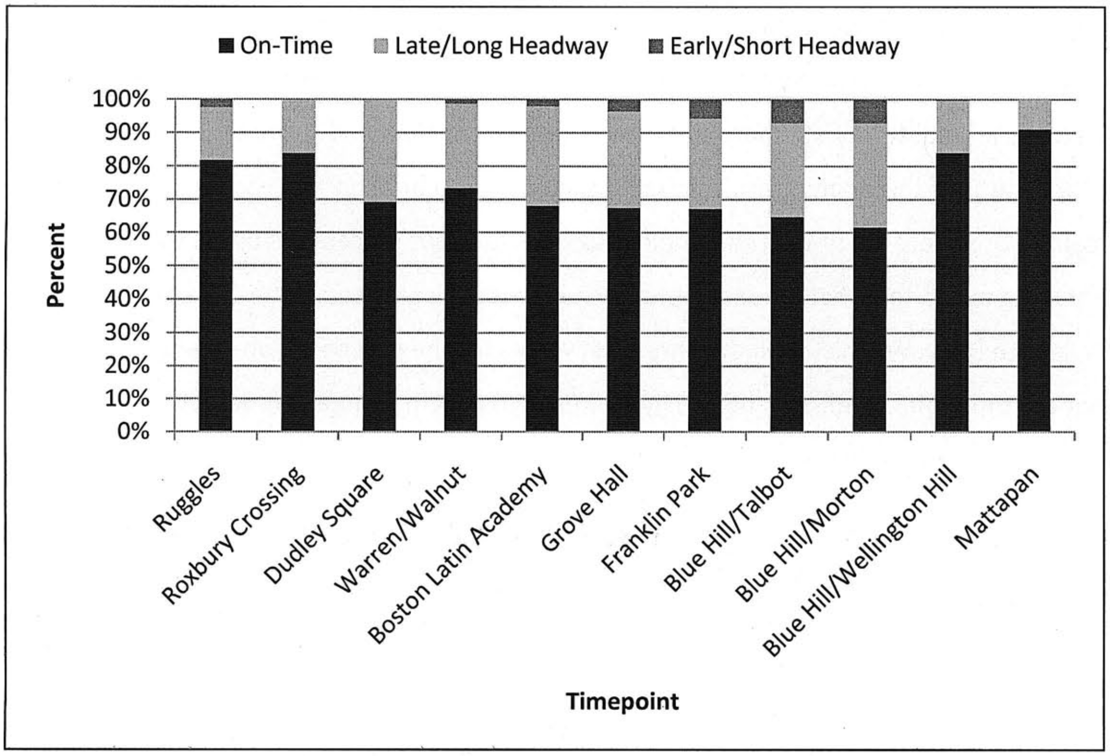
Figure 4-9 shows the percentage of buses at each timepoint on Route 28 inbound that meet the reliability standard, the percentage that are late or have long headways, and the percentage that are early or have short headways. Values for these metrics are calculated based on AVL data. The MBTA operates headways of six minutes during the AM peak period, 20-30 minutes in the midday, 12 minutes during the PM peak period, and 40-60 minutes in the evening hours on this route. At the origin timepoint (Mattapan), nearly 85 percent of buses meet the standard, but the percentage of on-time buses decreases steadily as buses move along the route, mainly due to an increase of the percentage of late/long headway buses. At Roxbury Crossing, only 60 percent of buses are considered on-time. The percentage of on-time buses rebounds to 89 percent at the terminal timepoint (Ruggles) only because the MBTA applies a different standard to terminal timepoints than mid-route timepoints (see Section 2.5.3). The results of this analysis are similar for the outbound direction, as shown in Figure 4-10: nearly 82 percent of buses are on-time at the origin (Ruggles), but that percentage drops to a low of 62 percent before arriving at the terminal timepoint with 91 percent of buses arriving on-time at Mattapan. The MBTA's Service Delivery Policy includes threshold values for the percent of on-time buses at the route level, not the timepoint level. Still, this analysis is used to inform planners about where reliability problems are occurring along a route.

Figure 4-9: Current MBTA Reliability Metric: Percent of Buses Meeting Schedule Adherence Standard
Route 28 Inbound, May 2009



As previously mentioned, the MBTA's route-level threshold for schedule adherence is that 75% of buses passing timepoints must be on-time, according to the Service Delivery Policy. Route 28 violates this standard, as only 71.6 percent of buses passing timepoints are on-time. Therefore, the MBTA's reliability metric indicates a reliability problem on this route.

Figure 4-10: Current MBTA Reliability Metric: Percent of Buses Meeting Schedule Adherence Standard
Route 28 Outbound, May 2009



4.2.3 Critical Assessment of Current Reliability Metrics

Both the CTA and the MBTA currently use reliability metrics that take advantage of some of the benefits of automatically collected data. The percent of successful headways (CTA's metric) and the percent of buses meeting the schedule/headway adherence standard (MBTA's metric) consider the reliability of bus arrivals on every trip at every timepoint. These metrics take advantage of the large volumes of highly detailed data that automated data systems provide for nearly every trip.

However, there are three drawbacks to the CTA's and MBTA's applications of the successful headway and schedule/headway adherence metrics. First, the threshold values used to determine whether headways are too short or too long (in the case of high-frequency service) and if buses are early or late (in the case of low-frequency service) are arbitrary and binary and may not be strict enough. In particular, the CTA's thresholds for short and long headways are very lax, especially for very short headways. For example, the threshold for service with a four-minute headway considers headways as low as one minute and as high as seven minutes to be "successful." Likewise, the MBTA's threshold for on-time performance for low-frequency service is not very strict. For example, a bus with a 12-minute scheduled headway is considered on-time if it arrives at a mid-route timepoint up to seven minutes late.

Making these thresholds more stringent would result in a higher percentage of trips that do not meet the standard, but would more accurately reflect service reliability. Second, these metrics do not distinguish between buses which barely exceed the thresholds and those which are extremely late or have very long headways. Although instances of very long headways and very late buses have a much greater negative impact on reliability than slightly long headways and barely late buses, these metrics consider them to be equal in impact. Finally, the successful headway and schedule adherence metrics used by the CTA and MBTA are not weighted by the number of passengers that experience unreliable bus arrivals. These shortcomings will be addressed by some of the metrics proposed in the next section.

The *excess wait time* metric uses automatically collected data to measure the reliability of bus arrivals from the perspective of customers. Since it measures average and total wait times, the metric takes into account how very late buses or very long headways affect more customers more significantly than less severely unreliable buses. Additionally, the metric considers the lower impact that slightly late buses have on customers in terms of increased wait times. However, the excess wait time metric is limited to measuring the reliability of bus arrivals – any variation in in-vehicle travel times is not reflected in this metric. Travel time makes up a large part of a customer's total journey, but the excess wait time metric does not take into account the impact that variable travel times have on customers' journeys. This problem will be addressed with two proposed metrics in the next section.

The *half cycle time* analysis conducted by the CTA as a component of its evaluation of service reliability is intended to identify the intervals during which scheduled half cycle time is either excessive or insufficient. While excessive or insufficient run times are correlated with bus arrival unreliability, this analysis should not be used to *identify* reliability problems. Instead, it should be a tool to determine whether the *cause* of a reliability problem identified by other reliability metrics is too much or too little half cycle time. This will be addressed in the recommended service planning process, outlined in Chapter Five.

4.2.4 Proposed Reliability Metrics

This section recommends a set of metrics that, together, use automatically collected data to measure service reliability both from the agency and customer perspectives. Specifically, the *percent of successful headways* metric (currently used by both the CTA and the MBTA) measures reliability from the perspective of the agency, indicating the extent to which service is provided according to the scheduled arrival times or headways. *Excess wait time* (currently used by the CTA), *excess journey time*, and *reliability buffer time* measure reliability from the perspective of customers, indicating how the variability of bus arrival and travel times impact customer waiting and journey times.

Percent of Successful Headways

The percent of successful headways metric is an effective measure of how reliably an agency is providing service, according to either the scheduled headways or the scheduled bus arrival times. It is a hybrid of the schedule adherence and headway variability metrics that apply to low-frequency service and high-frequency service, respectively. Since service frequencies vary throughout the day, routes that have high-frequency service during peak periods and low-frequency service at other times can be evaluated using the percent of successful headways metric over the course of the day without requiring two separate metrics. Therefore, it is recommended that transit agencies use the percent of successful headways metric to measure reliability from the agency perspective.

As described in Sections 4.2.1 and 4.2.2, the CTA and the MBTA use similar metrics to measure reliability, tailored to include their desired threshold values, which determine whether buses are considered late or early or if headways are too long or too short. Determining appropriate threshold values for the successful headways metric that define whether or not service is sufficiently reliable is critical for this metric's use in the service planning process. If the thresholds are too lax, the metric overlooks instances where customers experience large gaps in service. If the thresholds are too tight, a large percentage of bus trips on many routes will be deemed unreliable and it will be difficult to distinguish slightly unreliable services from very unreliable services. This shortfall is addressed by the excess wait time, excess journey time, and reliability buffer time metrics described below.

Excess Wait Time

The excess wait time metric complements the percent of successful headways metric by measuring the impact of unreliable bus arrivals on customers in the form of increased waiting times. Excess wait time can be measured as an average value to quantify the *average* amount of time that the each customer is delayed by unreliable bus arrivals, or as a total value to measure the *total* amount of time that *all* customers are delayed by unreliable bus arrivals.

The excess wait time metric does have disadvantages, however. Because the calculation of average excess wait time assumes that customers arrive randomly at bus stops, the metric can only be applied to high-frequency bus services, where customers tend not to consult a schedule. While the metric is a good indication of unreliable bus service, it does not take into account the variability of bus travel times.

Despite these shortcomings, average and total excess wait time are measures that do reflect reliability from the customer perspective.

Excess Journey Time and Reliability Buffer Time

Like excess wait time, the excess journey time and reliability buffer time metrics measure reliability from the customer perspective. However, both excess journey time and reliability buffer time measure the variability of in-vehicle travel times in addition to the variability of wait times, providing a more complete measure of reliability as experienced by customers.

The excess journey time metric is the difference between observed journey times (wait time plus in-vehicle travel time) between a specific origin and destination on a route and the scheduled journey time (expected wait time plus scheduled running time) for that segment (Ehrlich, 2010). This calculation is similar to the calculation of excess wait time except that in-vehicle travel time distributions are combined with wait time distributions to represent customers' experienced total journey time. Average excess journey time denotes the average amount of time that passengers' journeys are lengthened by unreliability, and total excess journey time calculates the total impact, in terms of time, that unreliable bus arrivals and travel times have on customers' journeys. A high excess journey time value indicates that the combination of waiting and in-vehicle travel times are highly variable, resulting in unreliable customer journeys. For more information on excess journey time, see Furth et al. (2006b), Chan (2007), Uniman (2009), and Ehrlich (2010).

The reliability buffer time metric measures the difference between the observed 95th percentile of total journey time (wait time plus in-vehicle travel time) and the median observed total journey time between given origins and destinations (Ehrlich, 2010). This metric measures how service unreliability affects the time a passenger budgets for their journey, and is based on the range of experienced journey times (including extreme values) including wait time and in-vehicle travel time. For example, in order to arrive on-time at their desired destination 95 percent of the time (19 times out of 20), passengers must budget the 95th percentile of the total travel time into their plans. Reliability buffer time represents the time that customers lose (either as excess journey time or as extra time at their destination due to arriving early) due to variations of waiting and in-vehicle travel time. For more information on reliability buffer time, see Furth et al. (2006b), Chan (2007), Uniman (2009), and Ehrlich (2010).

Ehrlich (2010) describes a methodology for using AVL data to calculate excess journey time and reliability buffer time. The author applies the two metrics to a set of London bus routes as case studies to demonstrate the efficacy of these two metrics in measuring service reliability from the customer perspective. These metrics complement operator-oriented reliability metrics to provide a more comprehensive view of service reliability. Though these metrics are not yet commonly measured, agencies should consider applying excess journey time and reliability buffer time to provide a more comprehensive measure of service reliability from the customer perspective.

4.2.5 Summary

Due to small and infrequent data samples, manual data collection made it nearly impossible for transit agencies to assess bus service reliability. Automated data systems provide the large data sets needed to measure reliability from both the agency and customer points of view, both of which should be considered when making decisions about allocating resources to improve service reliability. The proposed metrics – *percent of successful headways* (which addresses the agency perspective) and *excess wait time*, *excess journey time*, and *reliability buffer time* (which capture the perspective of customers) – enable transit agencies to more easily identify reliability problems at the route level.

4.3 Passenger Demand and Cost Effectiveness Metrics

Thus far, this chapter has demonstrated the ability of automatically collected data to measure bus transit performance from the customer perspective in addition to the agency perspective. The customer perspective is important for the measurement of bus loads and reliability because these aspects of service quality affect customers' experiences and may be considered when customers decide whether to ride transit. However, service performance is also evaluated using metrics that do not measure service quality impacts on customers, such as overall passenger demand ("service consumed") and cost effectiveness. Analysis relating to passenger demand measures how well a bus service is utilized and are important inputs for the evaluation of service using other performance metrics. Cost effectiveness metrics measure how efficiently bus services are provided, which allows agencies to address problems created by inefficient routes. These analyses are presented in this section.

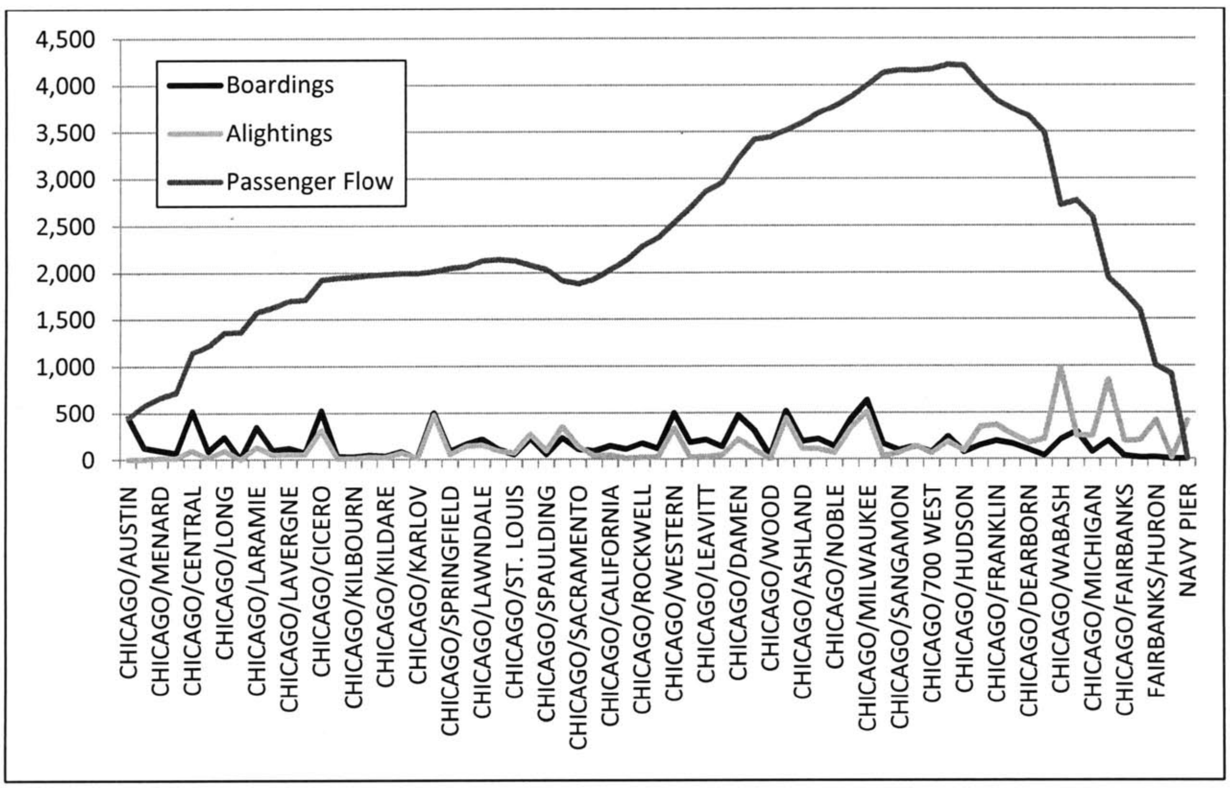
4.3.1 Passenger Demand

There are various measures of passengers' demand for a particular service, including total route ridership, the number of passengers that board and alight buses on a route by stop, and the flow of passengers along a route by time period. These analyses are operator-oriented, in that they measure the performance of the agency in terms of how many customers it attracts. These analyses are also important inputs into other metrics relating to passenger demand, including excess wait time. These measures also provide input for other metrics. For example, bus loading problems might be explained by high passenger demand on a specific route segment.

Today, transit agencies collect passenger demand data using APC and/or AFC systems, which provide highly accurate and detailed data on passenger demand at the system, route, and stop levels. Figure 4-11 provides examples of the application of several passenger demand metrics on Chicago's Route 66 in the eastbound direction for an entire average weekday in Spring 2009. This data was collected by APCs and was linked to AVL data to determine the locations of passenger boardings and alightings.

Figure 4-11: Passenger Demand by Stop

Route 66 Eastbound, Weekdays in Spring 2009



This passenger flow analysis shows that the maximum flow point along the route is at Chicago Avenue and Larrabee Street, which lies between the Blue Line and the Brown Line. Since ridership patterns are input into loading and (some) reliability metrics, the shape of the passenger flow line corresponds to the average bus load and average passenger-experienced load lines in Figure 4-5, as well as the graph of total excess wait time in Figure 4-7. Figure 4-11 also shows boardings and alightings by stop. In this example, the stops with the greatest number of boardings are at transfer points with intersecting bus or rail service. This is also the case for alightings, though a large amount of passengers also alight close to

Michigan Avenue at the eastern end of the route, where there are many employment and retail centers in addition to other transit services. These types of analyses help transit planners understand customer travel behavior at the route and stop levels, including where customers are coming from and going to.

In addition to identifying customer demand patterns, these metrics can be used to gain insight into problems identified by bus load, reliability, or cost-effectiveness metrics. Passenger demand data can provide additional information about a problem to determine its cause and develop potential solutions. For example, the excess wait time metric may indicate a high average and total excess wait time for the 3:00-3:30 PM time interval. This may be explained by a spike in boardings due to students leaving school at the end of the school day.

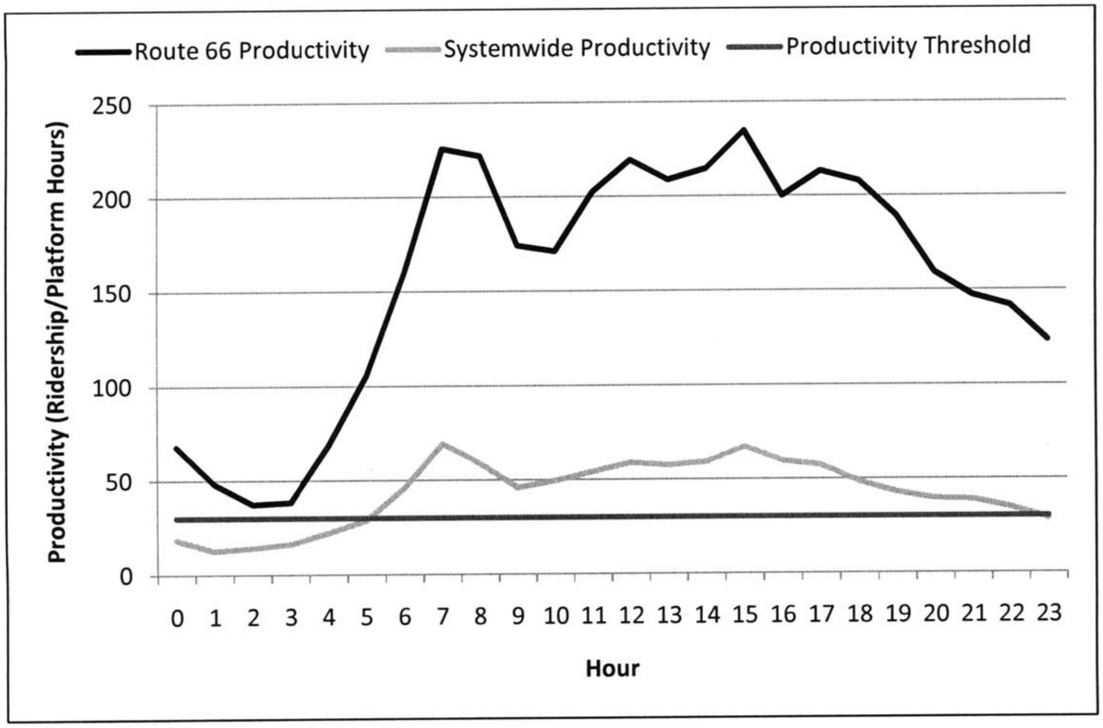
4.3.2 Cost Effectiveness

Cost effectiveness metrics quantify the extent to which bus services use resources efficiently. Transit agencies are limited in the frequency and span of service that they can provide due to budget constraints. Therefore, providing service in the most cost effective manner ensures that agencies can maximize the amount of service they provide while operating within their budgets. The analyses described in this section are aimed at identifying routes that use a large proportion of agency resources relative to the number of customer trips they provide. They show areas in the system where resources could be reduced to provide more cost effective service elsewhere.

There are several metrics that measure cost effectiveness. The MBTA uses the net cost per passenger metric, which compares the benefits of a bus route (in terms of passengers) to the public cost of providing the service (see Section 3.2.3). The CTA uses productivity, which compares the number of passenger boardings (measured by APCs) to the amount of service provided in terms of service hours (see Section 3.1.3). The CTA uses a threshold of 30 passengers per service hour to determine if actions should be taken on a particular route to improve cost effectiveness. Figure 4-12 provides an example of the productivity metric as applied to Route 66 in Chicago.

Figure 4-12 shows the productivity of Route 66, the systemwide productivity, and the CTA's productivity threshold for an average weekday by hour in Fall 2009. The graph shows that productivity on this route is highest during the AM peak period and much of the afternoon and PM peak periods; productivity is above 200 passengers per bus hour between 7:00 and 9:00 AM and between 11:00 AM and 7:00 PM. These levels of productivity are very high compared to systemwide productivity, which peaks at 69 passengers per bus hour. Additionally, the productivity of Route 66 is above the CTA's productivity threshold during every half hour. Route 66 is, therefore, significantly more productive than the system average during every hour of the day.

Figure 4-12: Productivity by Hour
Route 66, Weekdays in Fall 2009



When applied to a less productive route, the above analysis might show that productivity falls below the productivity threshold, indicating a potential problem that the agency might need to address. While the low-productivity route may be an important link in the transit system, it uses scarce resources that might be reallocated to a more productive route, potentially increasing overall system ridership. Agencies must weigh the benefits provided by a low-productivity route with the potential benefits that could be realized from reallocating those resources to a more productive route. This tradeoff is addressed in the recommended service planning process outlined in Chapter Five.

4.3.3 Summary

Metrics that address passenger demand and cost effectiveness, which are agency-oriented, are important complements to the recommended bus load and reliability metrics, which are largely aimed at measuring service quality from the customer perspective. Passenger demand metrics are helpful in clarifying problems identified by other metrics and providing a better understanding of customer behavior. However, because passenger demand metrics do not identify problems, these analyses should be used in a subsequent process to clarify already-identified problems and help identify solutions. This process will be described in more detail in Chapter Five. Cost effectiveness metrics such as net cost per passenger and productivity are indicators of how well an agency is allocating its resources. One or more of these metrics should be used in the problem identification process, along with the proposed bus load and reliability metrics, in order to identify agency efficiency problems to be addressed in the problem resolution process.

4.4 Network-Level Analysis using AFC Data

This chapter has focused on current and proposed performance metrics that rely on AVL and APC systems to supply data about bus location and passenger demand. This section will discuss the use of AFC systems in service evaluation. As described in Section 2.3, AFC systems are commonly used to measure passenger demand and the characteristics of customers' transactions, including the type of fare media used for each transaction. AFC data has additional capabilities that most transit agencies are not yet utilizing. This section will present some of these capabilities, including the ability to measure service performance from an origin-destination and network-based point of view, as opposed to the route-level analysis that is typical of current service evaluation processes. Then, examples of the types of advanced analysis that are enabled by AFC data will be discussed as potential additions to a systematic service planning process.

4.4.1 Capabilities of AFC Data

Although AVL and APC systems are useful for measuring performance at the route level, without information on passenger transfers, which can be provided by AFC systems, these systems are limited to considering customers' individual trip segments, rather than their entire journeys throughout the system. AFC systems are similar to AVL and APC systems in that they produce large, highly detailed data sets. Therefore, AFC data, like AVL and APC data, can be used to measure transit performance with a finer grain of detail using metrics that consider the distribution of performance values, not simply relying on average values. However, AFC systems also have the unique ability among automated data systems of being able to link individual passenger trips across the entire transit network. AFC systems can provide information about passengers' entire journeys on transit by linking individual trip segments made by a customer using a single transit smartcard or magnetic stripe farecard. Since virtually no transit agency requires customers to "tap out" when alighting buses, AFC systems do not directly record passenger's destinations. However, passenger destinations can often be inferred based on the origin of the next trip made by the same customer using the same smartcard or farecard. This information also provides agencies with data that shows when, how, and to where customers are transferring to other transit services. The following sections provide a brief overview of how agencies can use their AFC data to measure performance.

4.4.2 Origin-Destination Matrices Based on AFC Data

Passenger origin-destination (OD) data from AFC systems is an important supplement to route-level data provided by AVL and APC systems. AFC data can be used to develop route- and network-level OD matrices by time period to show how customers travel throughout the system and how travel patterns change throughout the day and over longer periods. OD matrices have a wide range of applications in service planning, operations analysis, service change evaluation, and service management (Cui, 2006).

Many transit agencies, including those with established AFC systems, collect passenger OD data manually using passenger surveys, which are costly to conduct and yield data on only a small portion of passenger journeys. AFC systems, when paired with AVL and APC data, can provide robust sets of OD data for all customers using AFC fare media (Cui, 2006 and Chan, 2007). The development of OD matrices using automatically collected data is significantly less expensive, uses much larger samples, and is more easily automated than creating OD matrices using survey data. Of course, the investment in information technology and staff required to develop and maintain the software to create these matrices is not trivial.

Cui (2006) developed an algorithm for estimating bus passenger trip OD matrices using automatically collected data. Cui's three step process involves the preparation of AVL, APC, and AFC data, the estimation of route-level OD matrices for all routes, and the development of a network-level OD matrix which combines the route-level matrices with information on transfers from AFC Data. Developing the algorithm is a large effort, but once it is in place, developing time period OD matrices using the algorithm and AFC data is a relatively quick, semi-automated process. Wang (2010) extends this research using Oyster data to estimate passenger ODs on the London bus network.

OD matrices are useful tools in several aspects of transit planning. Cui (2006) notes that OD matrices are useful when considering new or modified transit services. For example, when deciding which stops to include on a new limited-stop bus service along a corridor that is currently served by local buses, OD matrices provide data on passenger trip lengths, major origins and destinations, and transfer points of current customers and can help planners decide how to operate the limited-stop service. Route- and network-level OD matrices at the time period level are also useful in monitoring changes in customer behavior over time (Chan, 2007). It is important for transit agencies to understand where customers want to travel in order to serve the areas with the greatest demand. Naturally, however, customer travel behavior changes over time as development patterns change. OD matrices can provide data on customer travel patterns so that agencies can better react to changes in customer demand. While OD matrices are useful in the evaluation of performance, these tools should be developed outside the service planning process.

4.4.3 Service Performance Evaluation using AFC Data

Data on customer travel patterns gathered through AFC systems can enable transit agencies to apply customer-centric performance metrics at the network and customer journey levels of analysis. Chan (2007) introduces a methodology for using AFC data to measure reliability buffer time and excess journey time (these metrics are described earlier in this chapter) at the passenger-OD level for trips on the London Underground that do not involve transfers to other lines. Uniman (2009) builds upon this work by showing how measuring these reliability metrics at the OD level, including passenger journeys with transfers, can identify the sources of reliability problems and enable agencies address them in order to improve performance. This research could be extended to include the measurement of service quality for OD pairs that require customers to transfer among bus and rail lines.

4.4.4 Summary

Altogether, passenger OD data collected automatically using AFC systems, in conjunction with AVL and APC systems, provides agencies with a highly detailed and accurate picture of customer travel behavior at the route and network levels. Time-period-level OD matrices provide agencies with insight into customer travel behavior in order to make decisions that improve service and benefit customers. Transit agencies should develop these tools for use in the service planning process to provide clarifying information for problems identified by the recommended bus load, reliability, and cost effectiveness metrics.

AFC data also holds significant promise to measure performance from the perspective of customers and in the manner that they experience service – from their origin to their destination whether or not they transfer between transit services. The ability to measure performance in this way will enhance the service planning process by more precisely measuring how customers experience transit service. Transit agencies should look to emerging AFC research, including Uniman (2009) and Wang (2010), to determine how best to incorporate origin-destination-based analysis into the service planning process.

4.5 Summary

This chapter presented the metrics currently used by the CTA and the MBTA to measure service quality in the categories of bus load, reliability, and passenger demand/cost effectiveness. Some of these metrics take advantage of the benefits of automatically collected data to measure performance from the perspective of customers and consider the full distribution of performance values rather than simple averages. However, these agencies also use metrics that were developed based on the assumption that data was scarce.

This chapter then presented a set of proposed metrics, which collectively take full advantage of automated data systems and recommended that they replace the earlier performance metrics. The proposed metrics include:

- Bus load: average passenger-experienced load (measured alongside average bus load) and percent of overcrowded buses
- Reliability: percent of successful headways and excess wait time, reliability buffer time, or excess journey time (half cycle time time analysis is proposed for determining the cause of reliability problems once a reliability problem has been identified by the other metrics)
- Passenger demand: productivity or cost effectiveness (ridership by stop and passenger flow analyses provide data for other metrics and are useful in clarifying problems) and various measurements of passenger demand, including passenger flow and passenger boardings and alightings by stop.

The proposed metrics will be incorporated into the recommended service planning process, described in the next chapter.

5 Recommended Improvements for Service Planning Processes

The metrics and analyses recommended in Chapter Four are at the core of the ongoing and periodic processes by which transit agencies should evaluate service performance, identify problems, and implement solutions. This chapter recommends steps that transit agencies can take to incorporate these new metrics and analyses into the service planning process and, as a consequence, realize greater benefits from their investments in automated data systems.

This chapter first provides a set of general recommendations for using automatically collected data in ongoing and periodic service planning processes. Next, it provides several specific recommendations for the Chicago Transit Authority (CTA). Because the CTA already makes significant use of automated data systems, these recommendations will provide guidance to the CTA in updating its service planning process so that it can more consistently benefit from its substantial investment in automated data systems. Next, specific recommendations are made for the Massachusetts Bay Transportation Authority (MBTA). Because the MBTA is still developing its automated data systems and processing capabilities, these recommendations are intended to guide the agency to invest strategically in information technology and staff resources to realize the greatest benefit possible from its automated data systems.

5.1 General Recommendations

The general recommendations for the bus service planning process outlined in this section are designed to be applicable to all agencies that use automatically collected data to measure bus performance. This section discusses the processing of automatically collected data, the evaluation of systemwide performance, and the process of reviewing service on both ongoing and periodic bases. It concludes by recommending methods for sharing customer-oriented performance data and information with customers.

5.1.1 Data Processing

Automated data systems generate very large data sets that must be processed, checked for errors, and catalogued to enable planners to review performance at the route, corridor, and system levels. Much of the processing of automatically collected data can be done automatically using database software custom-developed to meet the needs of the transit agency. Transit agencies should take the following steps to prepare automatically collected data for analysis.

Transit agencies first upload the raw data collected by automated data systems, generally at the garage via wireless internet connections at the end of the day. The raw data is then aggregated into a database.

See Furth et al. (2006) for a discussion of the essential design elements of databases that enable agencies to effectively archive automatically collected data. The raw data generated by automated data systems often has systemic errors that must be identified and corrected. This "data cleaning" process uses computer algorithms to remove data outliers or data entries that otherwise do not reflect actual performance (e.g. bus loads of over 150). The data cleaning process is highly specialized for each agency and is therefore beyond the scope of this thesis; Furth et al. (2005) provides a summary of how to use algorithms to control for systemic data errors. Once data is cleaned, transit agencies should link the data sets from each automated data system to one another to allow planners to conduct analyses of performance. For example, bus load data from the APC system must be connected to vehicle location data from the AVL system to measure bus load and passenger boardings by time of day. Furth et al. (2006) discuss how these types of data can be linked to enable agencies to perform such analyses.

The processing, cleaning, and cataloguing of raw data requires a serious investment in information technology resources, appropriately trained staff, and a commitment from agency leadership to focus on performance measurement. These investments are critical for enabling transit agencies to be able to perform the detailed analyses recommended in this chapter.

5.1.2 Summarization of Data and Information

Once data is automatically analyzed at the route and system levels using the performance metrics recommended in Chapter Four, transit agencies should summarize the results in route and system profiles in order to facilitate performance review during the service planning process. Route profiles should contain all the relevant data analyses and contextual information for each route and serve as the basis for route-level performance evaluation. System profiles, which provide an overview of systemwide performance using operator- and customer-centric metrics, should be developed and analyzed to understand performance. This section provides an overview of the development and contents of route and system profiles.

Route Profiles

Transit agencies should develop tools that query the transit performance database to populate each route profile. These tools will perform the necessary data processing to measure route performance in the context of the recommended performance metrics and cause-identifying analyses discussed in Chapter Four. Table 5-1 presents a summary of the performance metrics and data analyses that should be included in a route profile.

Table 5-1: Data Analyses in Route Profiles

Performance Category	Performance Metrics	Presentation of Data Analysis
Bus Loading	Average passenger-experienced load, average maximum bus load, and percent of overcrowded buses	Graphs and tables containing values of all metrics at the points of average maximum load (varies over time) by half hour in each direction (see Figure 4-4)
		Graphs and tables containing values of all metrics by stop during each time period (e.g. AM peak) in each direction (see Figure 4-5)
Service Reliability	Percent of successful headways (including percent of late/long headways and percent of early/short headways) and excess wait time, excess journey time, or reliability buffer time	Graphs and tables by half hour in each direction (see Figure 4-8) (values for each metric should be displayed in separate graphs but can be in a single table)
		Graphs and tables by route segment (based on timepoint locations) during each time period (e.g. AM peak) in each direction (see Figures 4-6 and 4-7) (values for each metric should be displayed in separate graphs but can be in a single table)
	Half cycle time analysis	Table comparing actual running time (e.g. average and 95th percentile) to scheduled half cycle times by half hour (see Table 4-2)
Passenger Demand	Passenger boardings, passenger alightings, and passenger flow	Graphs and tables containing values of all metrics by half hour in each direction
		Graphs and tables containing values of all metrics by stop during each time period (e.g. AM peak) in each direction (see Figure 4-11)
Cost Effectiveness	Route productivity, net cost per passenger, or subsidy per passenger (compared to agency threshold)	Graph and table by half hour in each direction compared to the agency's cost effectiveness threshold value (see Figure 4-12)

Ideally, these data **processing** tools will perform these analyses automatically, requiring little staff intervention once they are developed. Of course, the development of the data processing tools implied by Table 5-1 requires a significant investment in staff time and expertise, as well as information technology. However, this investment reduces the staff time required to perform these analyses individually for each route, which is critical for being able to perform the recommended ongoing service review process on a regular basis. The CTA is an industry leader in the development of data processing tools and can serve as a benchmark for other transit agencies wishing to automate the data processing and analysis components of the service planning process.

As was the case in Bauer's (1981) recommended short range transit planning process, contextual route information is a critical component of the service evaluation process. Therefore, in addition to route-level performance data, route profiles should also contain contextual information that helps planners understand route characteristics to be able to more accurately identify the causes of problems and develop potential solutions. Various types of information can be provided by the route schedule, comments from staff and customers, and automated data systems. Table 5-2 provides a list of the types of contextual information that route profiles should contain, the purpose that each serves in reviewing performance, and the source of each type of information.

Transit agencies should ensure that the contextual information included in route profiles is current so as to best support the analysis of route performance data. Some types of information, such as customer comments, change over time. In this case, transit agencies should update customer comments in each route profile quarterly by querying the agency's database of comments. Other types of information, such as roadway geometry, are relatively static and do not change frequently.

System Profiles

As with route profiles, transit agencies should use database query tools to create monthly profiles of system performance using the performance metrics recommended in Chapter Four. Table 5-3 lists the performance metrics that should be included in a system profile[2].

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[2] System profiles here only address performance in the categories of bus loading, service reliability, passenger demand, and cost effectiveness. However, transit agencies can include other measures of agency performance (e.g. percent of buses with defective AVL equipment, number of road calls, serious complaints, accidents, etc.) in system profiles if so desired.

Table 5-2: Contextual Information in Route Profiles

Type of Information	Purpose	Source of Information
Schedule, Routing, and Span of Service	The route schedule provides information about the agency's operating plan for a route, including the scheduled frequencies and span of service. Routing is also important, particularly if there are routing variations throughout the day.	Route schedule
Customer Comments	Customer comments are useful in identifying potential problems on routes that data and performance metrics do not capture, such as instances of customers being left behind at bus stops due to overcrowding.	Customers via mail, phone, and email
Routes with Significant Transfer Activity	The performance of a route should be evaluated with passengers' entire journeys in mind. Therefore, passenger transfer activity should be summarized to show to which routes passengers are connecting.	AFC
Major Trip Attractors	The locations of major trip attractors (e.g. shopping malls and schools) help explain locations and times of day with high customer demand. This information is useful when considering changes in routing, particularly when trip attractors open or close.	Passenger boardings and alightings from APC/AVL, review of land use along corridor
Traffic Conditions	Route profiles should contain as much information about traffic conditions (particularly at intersections) to explain the extent to which external factors may be causing poor performance.	Anecdotal reports from operators, City/State DOT
Roadway Geometry	The design of a roadway (e.g. roadway width and the presence of on-street parking) is a critical element in determining whether some routing changes are feasible.	Field surveys, maps
History of Past Service Changes	A history of past service changes provides context for reviewing trends in performance. For example, a sudden decrease in ridership might be the result of a past reduction in the span of service. Information about this service change is critical to explaining changes in route performance.	Service change database developed by service planners

Table 5-3: Performance Metrics in System Profiles

Performance Category	Performance Metrics
Bus Loading	Percent of overcrowded buses
Service Reliability	Percent of successful headways (including percent of late/long headways and percent of early/short headways) and wait time (including scheduled wait time, average wait time, and excess wait time)
Passenger Demand	Systemwide ridership
Cost Effectiveness	Route productivity, net cost per passenger, or subsidy per passenger

The data for each performance metric should be displayed for each of the most recent 12-24 months as trends to show how performance has been changing over time. Additionally, system profiles should display the percent change in each performance metric between the most recent month and the same month one year earlier. These analyses will help planners and the Board of Directors determine how the agency is currently performing compared with past performance. Figures 5-1 and 5-2 provide examples using MBTA data of how transit agencies could display monthly ridership trends and the percentage change in ridership on a monthly basis over the past year.

Figure 5-1 is helpful in understanding how ridership changes over time, but more importantly, it also shows seasonal ridership trends. For example, the graph shows that average weekday ridership is highest in September. With this type of data, transit agencies can adjust overall levels of service to more closely match seasonal demand. The graph in Figure 5-2 is useful in determining how monthly ridership levels have changed over the same month in the previous year. In this example, monthly weekday ridership levels were lower in 2009 than in 2008 with one exception. This type of information is important when evaluating the impacts that past service changes have had on route ridership.

Systemwide performance analysis can provide insight into how public transit is affected by external and other factors that are not directly related to performance. For example, the losses in ridership shown in Figure 5-2 may be explained by two separate factors: lower gasoline prices in 2009 compared to 2008 which may have shifted some transit customers to autos, and the economic downturn may have reduced ridership in 2009 more than in 2008. Similar analysis could also be conducted to measure the impacts of internal forces (e.g. fare increases). When conducted at the system level, these types of analysis can inform transit agencies about how both external and internal forces affect systemwide performance.

Figure 5-1: Systemwide Analysis – Average Weekday Ridership by Month
MBTA, Weekdays, January 2007-September 2009

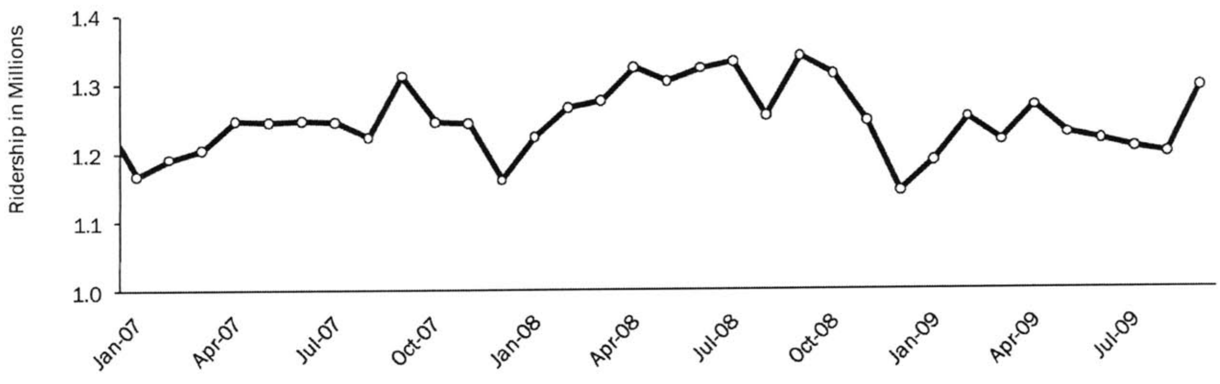
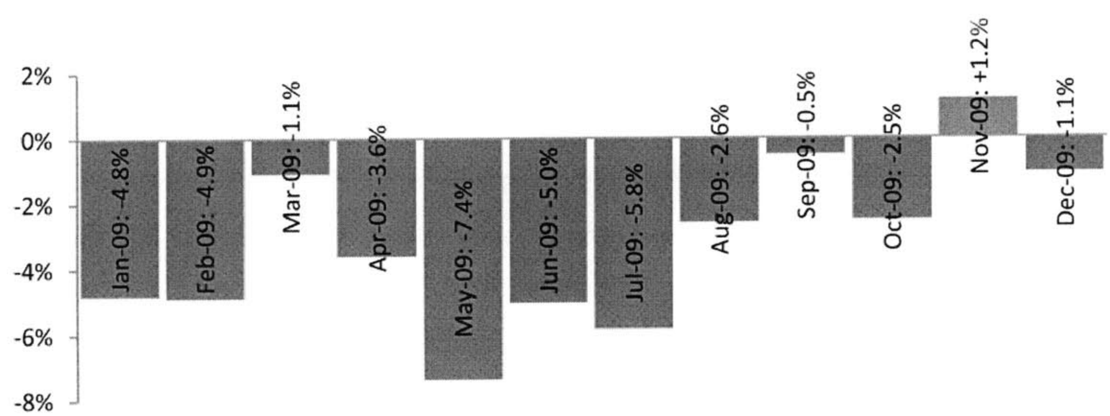
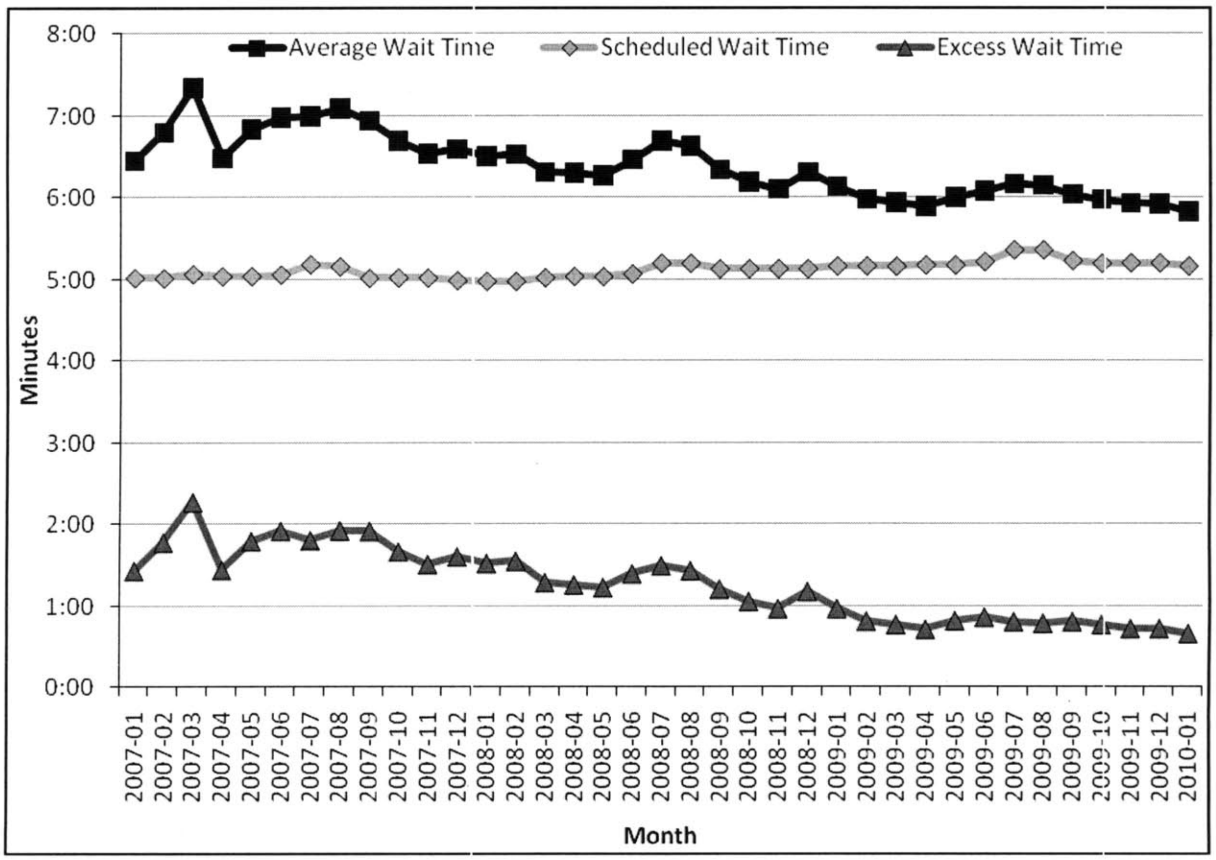


Figure 5-2: Systemwide Analysis – Percent Change in Ridership over Prior Year
MBTA, Weekdays, January-December 2009



While ridership and other operator-oriented measures of performance are important components of systemwide service evaluation, transit agencies should also use the capabilities of automated data systems to analyze systemwide trends in service quality as experienced by customers. Doing so provides a view of changes in the collective experience of customers in terms of the agency's customer-oriented performance metrics. Figure 5-3 is an example of service reliability trend analysis using CTA's systemwide excess wait time metric. It shows that excess wait time has steadily decreased since January 2007, which is likely a result of the CTA's systematic efforts to adjust scheduled bus half cycle times with the goal of improving reliability. Despite small increases in scheduled wait time over this period, the average wait time has continued to decrease because excess wait time has fallen faster than the increase in scheduled wait time. This type of analysis can help the CTA determine whether its systemwide half cycle time adjustment initiative has had the intended effect on reliability at the system level. Based on this analysis, it appears that the initiative has had its intended impact at the CTA. Transit agencies should conduct similar analyses to determine how service quality from the perspective of customers changes over time.

Figure 5-3: Systemwide Trend Analysis – Average, Scheduled, and Excess Wait Time
CTA Bus Network, Weekdays, January 2007-March 2010



As was the case when developing route profiles, data processing tools should perform these analyses automatically in order to populate system profiles. In order to minimize development costs, agencies might create tools that populate both route and system profiles simultaneously. Again, the cost of developing such tools is significant, but the capabilities that these tools provide for effectively summarizing route and system performance is critical in realizing the greatest benefit possible from an agency's investment in automated data systems.

Like route profiles, system profiles should include supplementary information to provide context for the various data analyses. Agencies should develop an annotated database of past policy changes (e.g. a fare increase) as well as external events that have significant effects on systemwide ridership or performance (e.g. high gasoline prices in the summer of 2008).

5.1.3 Evaluation of Past Service Changes

Transit agencies should evaluate the impacts that past service changes have had on bus crowding, service reliability, passenger demand, and cost effectiveness in order to understand the effectiveness of specific service change strategies at resolving problems. This analysis should be performed at two levels. First, agencies should perform a route-level service change evaluation for each route that had a service change implemented in the past six to twelve months to determine whether the service change resolved the problem it was intended to address. Second, agencies should conduct a service change type evaluation periodically to determine the impacts that specific types of service changes (e.g. increased running time) have on the typical performance of affected routes.

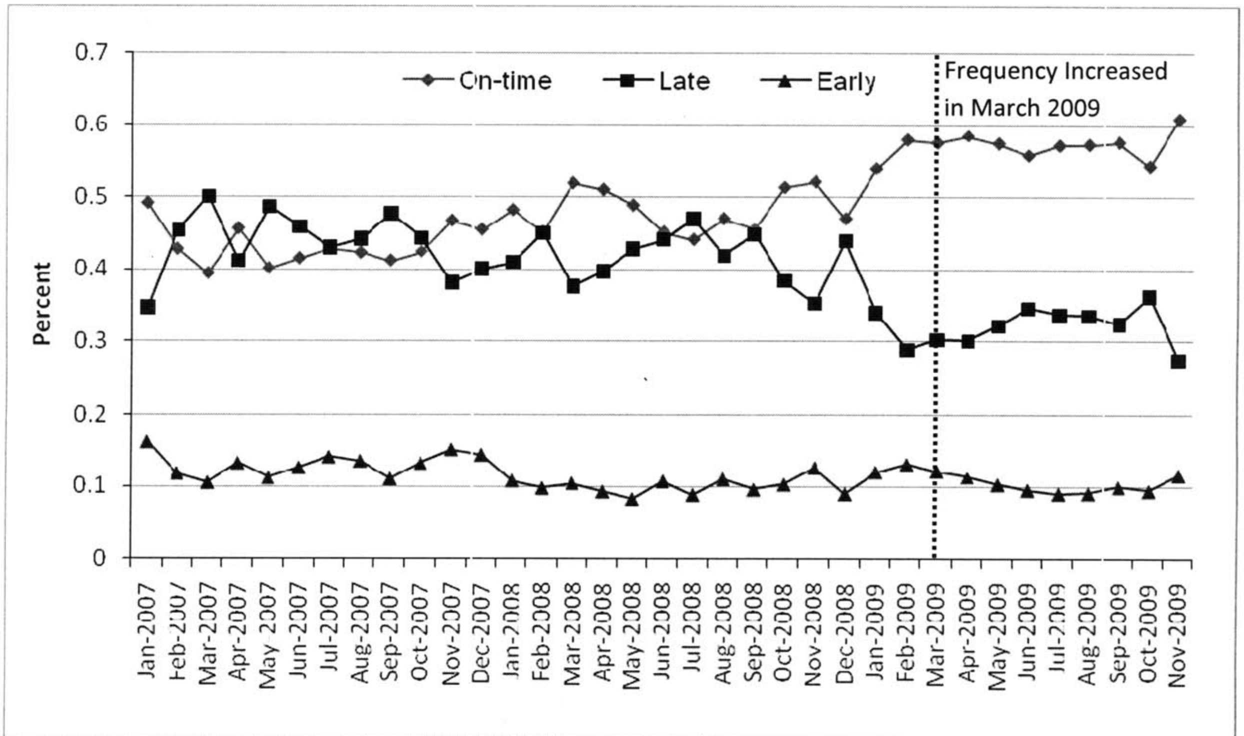
Route-Level Service Change Evaluation

A route-level service change evaluation measures the impacts that a specific service change has had on the performance of the affected route. Planners should analyze the impacts that the service change had on ridership, crowding, reliability, and cost effectiveness to determine whether the service change resolved the problem it was intended to address. Route-level service change evaluations can easily be conducted using the large volumes of data generated by automated data systems.

It is important to evaluate route performance over a sufficiently long period of time before and after the implementation of a service change. This is because it can take several months for customers to begin to adjust their behavior after a service change and trends in route performance that are unrelated to the implementation of the service change could impact the results of the service change evaluation. At a minimum, the time period of evaluation should be twelve months before and at least six months after the service change. This allows planners to consider month-to-month changes in service quality as well as the percentage change in each category of service quality in the same month of successive years (e.g. comparing ridership between May 2008 and May 2009). Reviewing route performance by month over time also allows planners to identify trends in route performance that may be independent of the service change. For example, the opening of a large shopping center along a route could increase passenger demand; this ridership change is not related to a service change and therefore should be accounted for in such analyses.

Figure 5-4, adapted from Hickey (2010), provides an example of one component of a route-level service change analysis. Here, the percentage of on-time, late, and early buses is analyzed before and after a March 2009 change in frequency. This analysis shows that the percentage of late buses decreased to around 30 percent after the service change. Similar graphs depicting the change in ridership, productivity, and average passenger-experienced load would provide insight into the effects that this service change had for those categories of performance.

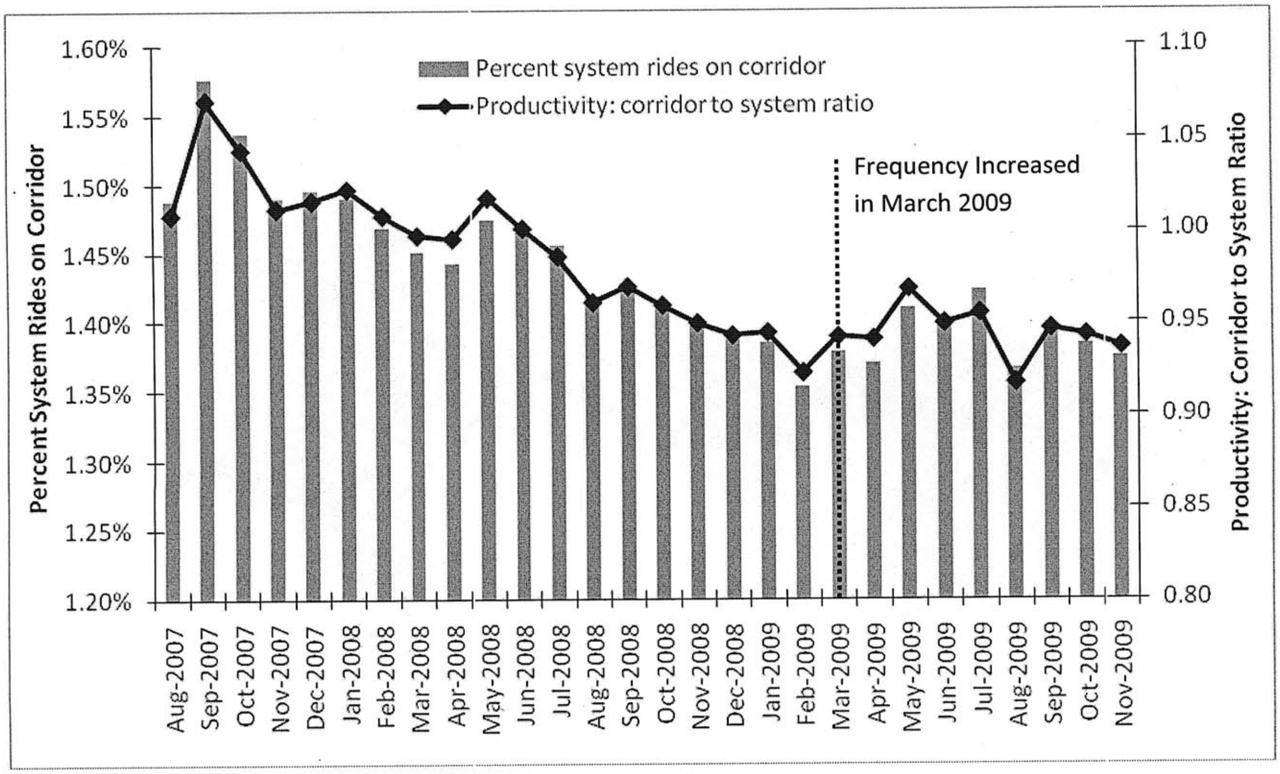
Figure 5-4: Percent of On-Time, Late, and Early Buses
Route 55/Route X55 Corridor, January 2007-November 2009



Source: Hickey (2010)

In addition to route-level changes in performance that are independent of the service change (e.g. increase in passenger demand due to a new shopping center), systemwide trends in ridership can have impacts at the route level. For example, the spike in gasoline prices in mid-2008 resulted in increased ridership throughout Chicago's transit network. Because the ridership increase resulted from an external event, this increased demand should not be attributed to any service changes implemented at this time. For this reason, systemwide trends should be controlled for when evaluating the impacts that service changes had on ridership and cost effectiveness. Hickey (2010) demonstrates a simple and effective way of accounting for systemwide trends by analyzing the monthly ratio of route ridership to systemwide ridership and the ratio of route productivity to systemwide productivity, as shown in Figure 5-5. This analysis removes the influence of systemwide ridership trends from the evaluation of ridership and productivity impacts of an increase in frequency.

Figure 5-5: Ratios of Corridor Ridership and Productivity to System Ridership and Productivity
Route 55/Route X55 Corridor, August 2007-November 2009



Source: Hickey (2010)

Once a route-level service evaluation is complete, planners should determine, based on the results of the analysis, whether the service change was effective in resolving the problem it was intended to address. If so, no action is necessary and the service change should remain in effect. If the service change did not have the intended impact, for example if the underlying problem still exists, planners should suggest modifications to the service change that could improve performance. Alternatively, the problem can be reintroduced into the problem resolution process to determine another course of action.

Service Change Type Evaluation

During service change type evaluations, planners analyze the impacts of each *type* of service change on route performance to determine how specific strategies (e.g. extending span of service, increasing running time) affect the bus loading, service reliability, passenger demand, and cost effectiveness of the *typical* route to which each type of service change was applied. In this analysis, the performance of all routes that had the same type of service change is aggregated to measure the overall impact of the service change. The results of this analysis should guide planners in choosing service change strategies to resolve specific problems during the problem resolution stage of the ongoing and periodic service review processes. Service change type evaluations should be updated annually, adding new evaluations and, perhaps, dropping results that were observed more than four to five years before the last update in order to keep the analyses current.

In Summer 2009, the CTA conducted a series of service change type evaluations to determine what effect different service change strategies had on route ridership. The analysis considered four categories of service changes: scheduled running time changes, frequency changes, span of service changes, and routing changes. Each change type was further split between service changes that increased the resources allocated to the route (e.g. increased frequency) and service changes that decreased the resources on a route (e.g reduced span of service). The analysis considered service changes implemented between December 2007 and March 2009. Because the analyzed service changes were implemented over different months, it was important to account for seasonal and systemwide trends in ridership to isolate the changes in these metrics that resulted from the implemented service changes. The CTA took the following steps in this analysis, which can be implemented by any agency using automatically collected data:

1. Categorize a set of past service changes by type and whether they increased or decreased levels of service (e.g. increased frequency).
2. For each service change, measure route performance in the relevant categories (e.g. ridership) during three time periods: the month before a service change was implemented (e.g. February 2009 for a service change implemented in March 2009), the same month one year earlier (February 2008), and the same month one year later (February 2010). This shows the change in each performance category leading up to a service change and 11 months after the change. Calculate the percent change between each measured month for each route included in the analysis.
3. Measure systemwide performance in the same categories (e.g. ridership) for each month that is included in Step 2 for all service changes. Calculate the percent change in systemwide performance for the same month pairs. Subtract the systemwide percent change for each performance category from the route-level change for the same category for each service

change to determine the percent change in each performance category normalized for the systemwide change. For example, if ridership on a particular route increased by five percent while systemwide ridership increased by two percent, the normalized ridership change on that route would be three percent.

4. Aggregate (by averaging, perhaps using a ridership-weighted average) the normalized percent change in each performance category by service change type. This shows the overall change in each performance category (e.g. ridership), normalized for systemwide ridership changes, for each service change type.

After implementing this process, the CTA found that, when normalized for systemwide ridership changes, 64 percent of routes that received frequency increases between December 2007 and March 2009 also saw increases in ridership. Combined, these frequency increases resulted in over 33,000 additional riders per weekday, over and above any ridership changes caused by factors external to the CTA (e.g. increases in gasoline prices). The CTA could compare these results to the results of other service change categories to determine which types of service change are most effective at increasing ridership. The results of the service change type evaluation should be documented in a summary report to guide future service change decisions made in an agency's problem resolution processes.

There are some commonalities between the route-level service change evaluation and the service change type evaluation. For both processes, performance should be evaluated over a sufficiently long period of time before and after the service change was implemented (at least twelve months before and six months after) to allow for the full impact of service changes to take effect. Also, it is important in both processes to control for systemwide changes in ridership by month, particularly when aggregating service changes by type that were implemented at different times of the year.

5.1.4 Ongoing Service Review Process

Transit agencies using automated data systems should implement an ongoing service review process to evaluate route performance in order to identify and ultimately resolve route-level problems. As Section 5.1.1 noted, if investments in information technology and staff are made, automatically collected data can be processed and summarized automatically using various software and analytical tools. These tools allow planners to observe a wide variety of data about route performance all at once in route and system profiles. Depending on their information technology and staff resources, as well as the quantity of routes, transit agencies should be able to cycle through the ongoing service review process every three to six months, allowing for the implementation of service changes at the beginning of each pick.

The ongoing service review process has three components. First, planners evaluate the performance of the bus system as a whole to provide insight into systemwide performance trends. Next, during route review/problem identification, planners use the analyses of automatically collected data and contextual route information in each route profile to review route performance and identify potential problems. Once problems are identified, they are advanced to the problem resolution phase, where planners develop and evaluate potential service changes to resolve each problem. These processes are described in the following sections.

Systemwide Performance Analysis

Generally, transit agencies conduct systemwide analyses regularly and present them to the Board of Directors to explain how well the agency is meeting its overall service goals. Under the manual data collection paradigm, these reports focused on attributes that could be easily measured or estimated and were generally operator-oriented (e.g. mean miles between breakdowns). However, automated data collection provides the large data samples needed to accurately measure and evaluate performance in terms of crowding, reliability (service and equipment), cost effectiveness, and passenger demand at the system level from both the agency and customer perspectives. Agencies should use both agency-and customer-oriented analyses to evaluate systemwide performance in order to identify problems or trends that impact the entire system or the annual budget. These analyses should be presented to the Board of Directors monthly. Systemwide performance analysis using automatically collected data, therefore, allows staff to guide the Board of Directors in making well-informed resource allocation decisions that consider customers' experience and perceptions of service quality.

Route Review/Problem Identification

The steps to be undertaken within the route review/problem identification process outlined by Bauer (see Section 2.4.2) are fundamentally unchanged with the use of automatically collected data, and therefore are recommended here. The main contribution of automatically collected data to this process is that it provides more robust data sets which allow planners to more clearly identify problems and their potential causes using the performance metrics and cause-identifying analyses recommended in Chapter Four. This section reviews the steps of the route review/problem identification process in the context of automatically collected data.

Route profiles provide all of the relevant data and contextual information for the route review/problem identification process and should eliminate the need for planners to collect additional data or information during this process. Planners analyze the data and information in route profiles to identify route-level problems and identify trends in performance that negatively impact customers or the achievement of the agency's goals. Table 5-4 provides guidelines for identifying route-level problems by performance metric. In the event that an agency has not identified a clear threshold value, planners should use their professional judgment to determine whether the data and contextual information indicate a problem. Problems that are indicated by staff and customer comments that are documented in a route's profile should be verified by comparing each comment with data summaries of actual performance.

Table 5-4: Potential Problems Identified in the Route Review/Problem Identification Process

Performance Category	Performance Metric	Potential Problems
Bus Loading	Average passenger-experienced load and average bus load	Exceeds agency threshold (e.g. 60 passengers during peak periods) on a specific route segment or during a specific time period
	Percent of overcrowded buses	Exceeds agency threshold on a specific route segment or during a specific time period
Service Reliability	Percent of successful headways (including percent of late/long headways and percent of early/short headways)	Exceeds agency threshold (e.g. 75 percent of trips should be on-time) at a specific timepoint or during a specific time period
	Excess wait time, excess journey time or reliability buffer time	Exceeds agency threshold on a specific route segment or during a specific time period (if no agency threshold, planners use judgment to identify instances of particularly high values)
	Half cycle time analysis	Scheduled half cycle time is too short to allow certain percentage of trips to be completed on-time, or is too long (allowing efficiencies to be made)
Passenger Demand	Passenger boardings, passenger alightings, and passenger flow	Observed ridership changes that are not in line with systemwide ridership changes (e.g. sharp decline in ridership on a particular route segment)
Cost Effectiveness	Route productivity, net cost per passenger, or subsidy per passenger	Does not meet agency threshold (e.g. route's net cost per passenger exceeds three times the systemwide average)

Once a problem is identified, the next step is to determine if there is enough data and information to be able to decide on a course of action to rectify the problem. Under the manual data collection paradigm, it was common to collect additional data to further clarify a problem once it has been identified. However, the large and highly detailed data sets generated by automated data systems that are summarized in route profiles are generally sufficient to use to identify appropriate resolutions to problems. Therefore, the need to collect additional data and information relating to a potential problem beyond what is detailed in route profiles is reduced.

Before advancing to the problem resolution process, planners must decide if identified problems are significant enough to warrant a service change. This step relies heavily on planners' judgment and can be influenced by the level of resources available to improve service. For example, when an agency is reducing overall levels of service systemwide to deal with a budget deficit, planners may choose not to address relatively unimportant problems that would require additional resources. Problems that are expected to require only minor or moderate service changes (e.g. running time adjustments) should move to the problem resolution component of the ongoing service review process. Problems that planners anticipate will require major service changes (e.g. major rerouting of service) should be deferred to the problem resolution component of the periodic service review process, which is discussed in Section 5.1.5.

Once the route review/problem identification process is complete, planners should document the results in each route profile. Planners should record any noticeable changes in performance or service quality and other important information about the route, as well as problems identified by the analysis. These results should be noted in the route profile to provide background information for consideration during the next cycle of the route review/problem identification process.

Problem Resolution

As with the route review/problem identification process, the steps in Bauer's (1981) problem resolution process (see Section 2.4.2) are fundamentally unchanged with the use of automatically collected data.

The set of route-level problems for consideration in the problem resolution component of the ongoing service review process is developed during the route review/problem identification process. The first step of the problem resolution process is to clarify each problem to better understand its scope and identify potential causes. However, because of the detailed data sets and comprehensive data analysis performed in the previous step, problems entering the problem resolution process are generally well-defined, resulting in a more effective and efficient problem resolution process. Next, planners consider potential solutions to each problem. Table 5-5 provides examples of potential service changes for various route-level problems. If it becomes clear during this step that a problem requires a major service change (e.g. a major rerouting or large increase in service), the problem should be deferred to the problem resolution component of the periodic service review process, which is described in Section 5.1.5.

Table 5-5 Potential Solutions Considered in the Problem Resolution Process

Problems	Potential Service Changes
Bus Overcrowding	• Increase service frequency • Improve reliability (by implementing one of the service reliability strategies)
Poor Service Reliability	• Increase half cycle time • Enforce on-time departures at terminals • Implement a mid-point holding policy • Implement prepaid boarding scheme • Reroute service around congested areas
Low Ridership at Beginning or End of Service Day	• Reduce span of service • Short-turn buses before current trip endpoints during early and late hours
High Ridership at Beginning or End of Service Day	• Extend span of service • Eliminate short-turns in the schedule during early and late hours
Low Cost Effectiveness	• Decrease frequency (to reduce total hours of service) • Increase frequency (to increase passenger demand) • Reroute buses to serve areas of greater demand • Eliminate service on a route

Once a set of possible service change solutions for a particular problem has been identified, planners should evaluate each potential solution for its feasibility and estimate how well each addresses the problem. The level of analysis that this step requires will vary based on the complexity of the problem; the identification of the best solution to simple a problem may be straightforward, whereas complicated problems may require several iterations of the service change evaluation step in order to identify the best solution to a problem. Planners must consider whether additional operating resources are available to implement a particular service change. If operating resources are not available, planners should consider whether the problem should be addressed by reallocating existing resources in order to implement the desired service change.

After planners identify the best service change to address a particular problem, planners should once again consider whether the service change is minor, moderate, or major, according to the agency's definition of service change types. Major service change proposals should be deferred to the problem resolution component of the periodic service review process for further evaluation, whereas minor and moderate service changes should be prepared for implementation. The recommended changes along with the needed set of minor and moderate service changes should be finalized and any necessary approvals should be sought. Agency staff then modifies the corresponding route schedules to incorporate the recommended service changes. The recommended service changes should be implemented during the next pick. Planners should also document the implemented service changes in a database of past service changes. This database is used during the evaluation of past service changes, as described in Section 5.1.3.

5.1.5 Periodic Service Review Process

In addition to the ongoing service review process, which identifies problems at the route level, transit agencies should conduct a periodic service review process to analyze performance in selected transit corridors or subareas to identify and resolve corridor-level problems. This process also involves analyzing and implementing major service changes that were identified during the ongoing service review process. Due to the fact that service changes that result from this process may require significant additional operating resources, a cycle of the periodic service review process should be completed at least once a year to coincide with the development of the annual budget.

The periodic service review process has two components. First, during the corridor and subarea analysis/problem identification process, planners use the automatically collected data and contextual information to analyze the performance of transit services in specific corridors or subareas to identify potential problems. These problems, along with route-level problems that require major service changes (identified during the ongoing service review process) are addressed during the problem resolution component of the periodic service review process. These components are described in the following sections.

Corridor and Subarea Analysis/Problem Identification

The problem identification process proposed by Bauer (1981) (see Section 2.4.2) can be adapted for corridor-level analysis using automatically collected data. During this process, planners should conduct corridor and subarea analyses to identify problems that impact routes in a particular location. Since service planning staff generally do not have the resources to analyze every corridor at once, agencies should develop a list of corridors and subareas for future analysis. During each cycle of the corridor and subarea analysis/problem identification process, agencies should select several corridors for analysis, addressing areas with the most urgent concerns first. The prioritization of corridors and subareas can be based on priorities identified by planning staff based on route reviews, concerns raised by operations staff, and information about problems gleaned from customer comments.

The scope of a corridor or subarea analysis can be broad or narrow. For example, the CTA conducted a subarea analysis of the South Loop area of Chicago that was initiated by a concern that significant residential and commercial development had changed the transit needs of the area. Because the concerns were broad, planners analyzed all aspects of each service in the area, including service frequency, span of service, routing, running time, and transfer activity. The study resulted in a number of service changes that addressed corridor-level problems. Alternatively, corridor or subarea analyses can be narrowly focused on a single aspect of performance. For example, planners could analyze a corridor with multiple overlapping transit services to identify reliability problems among all routes. Such analysis would result in service changes aimed specifically at improving service reliability in the corridor.

Once the corridors and subareas are selected, planners should perform analyses similar to those recommended for inclusion in route and system profiles (as presented in Section 5.1.2). Some corridor or subarea analyses, like the CTA's South Loop study, are based on reviewing the performance of related routes individually and identifying problems by route, similar to the route review/problem identification process. During such analyses, the problems identified for all routes in the study area are considered together and service changes are developed during the problem resolution process to address multiple problems at once. Other analyses, like the example with multiple transit services along the same corridor, involve reviews of the combined performance of all routes. In these cases, performance data for all routes along the corridor is aggregated to represent the performance of the entire corridor. Then, the performance of the entire corridor is analyzed using the analysis methods presented in Chapter Four to identify problems to be addressed in the problem resolution component of this process.

The corridor and subarea analysis/problem identification process results in a set of route- and system-level problems for each analyzed corridor or subarea. Planners should record the problems identified within each corridor or subarea to be addressed in the problem resolution component of the periodic service review process. Additionally, planners should update the route profiles of routes included in corridor-level analyses to reflect the findings of the analysis as it pertains to each individual route, as this information could also be useful during the ongoing service review process.

Problem Resolution

The problem resolution component of the periodic service review process is very similar to that of the ongoing service review process. First, problems, including those identified through corridor or subarea analysis and those deferred from the ongoing service review process, are clarified to determine the scope of the problem and to identify potential causes. Next, planners use their judgment and the results of route- and corridor-level data analyses to develop a set of potential solutions to address the cause of each problem. Because some of the problems in this process affect multiple routes or entire corridors, these solutions often involve moderate or major restructuring of schedules or routes. After planners have developed a set of possible service change solutions for a particular problem, potential solutions should be evaluated for feasibility and to determine how effectively each service change might resolve the problem. When evaluating service change alternatives for problems identified through corridor and subarea analysis, planners should consider how service changes to address one problem have an impact on performance (and other identified problems) on routes in the same area. Once a set of alternatives is evaluated, planners choose the service change which they believe will most effectively resolve each problem. The set of proposed service changes resulting from the periodic service review process should be selected based on the available operating resources to implement significant changes in service. Once finalized, the proposed service changes should be approved by the Board of Directors and implemented for the next pick.

At the conclusion of each cycle of the periodic service review process, planners should prepare a report that summarizes the analyses performed, the problems identified, and the proposed and implemented solutions. This report should be presented to the Board of Directors and should be reviewed as necessary to provide background information for the next cycle of the periodic service review process.

5.1.6 Communicating Route Performance Information to Customers

As previously discussed, a major benefit of automated data systems is the ability to measure transit performance from the perspective of customers. Because of this, as well as the ability to easily share information over the internet, transit agencies should use their websites to provide customers with data and information about transit performance that reflect the customer perspective. Providing this information will allow customers to review the performance on the routes they use in order to be better equipped to make informed decisions about their travel. Additionally, providing such information bolsters an agency's image of being a responsive and transparent public entity.

Agencies should begin by sharing system-level performance data in the categories of bus loading, service reliability, passenger demand, and cost effectiveness on a web page aimed specifically at customers. Agencies can use the same summaries that are presented monthly to the Board of Directors, as recommended in Section 5.1.2, which include both operator- and customer-oriented measures of performance. Graphs like those shown in Figures 5-1, 5-2, and 5-3, which show trends in systemwide performance by month, can be easily understood by customers and provide a clear view of current service quality and how it has changed over time. These summaries should be accompanied by descriptions that provide background information on each analysis method and performance metric in language that is easily understood by customers. The systemwide performance summaries should be posted monthly and may be a static document (e.g. a PDF report) or an interactive element that customers can use to request specific types of analysis instantly. Additionally, agencies that have implemented specific initiatives aimed at improving systemwide performance in a certain category (e.g. systematically increasing running times to improve reliability) could highlight the effects that such strategies have had on systemwide performance. Once the customer-based performance summaries have been made available, agencies should make a concerted effort to inform customers about this information and should actively solicit feedback from customers.

Once a transit agency has established a customer-focused performance reporting web page containing systemwide performance reports, it should work to incorporate route-level performance summaries online. Because of the large amount of data analyses that are involved, agencies should develop an online database for customers to query to instantly generate the requested information. For example, customers should be able to query the route-level performance database to view all performance summaries pertaining to a single route. Such a query would generate a web page consisting of all of the graphs and tables pertaining to the performance of the selected route. These elements would be updated quarterly in conjunction with the generation of route profiles, as described in Section 5.1.1.

Providing route- and system-level performance data to customers does not necessarily require significant additional information technology or staff resources. Agencies can simply adapt the data analyses generated for route and system profiles to be published online. Though initial development of the website will require significant information technology resources and staff time, updating the website with new data on a regular basis will require little in terms of resources.

5.2 Recommended Strategies for the Chicago Transit Authority (CTA)

The recommendations outlined Section 5.1 are generally applicable to any large transit agency equipped with automated data systems. This section focuses on specific recommendations for the CTA to improve its service planning process. Due to its prior and ongoing investment in automated data systems, data processing technology, and data analysis tools, the CTA is capable of going beyond the standard recommendations to maintain its position as a leader in the use of automatically collected data in service planning. The following sections recommend changes to the CTA's resource investments, service standards, service planning processes, and provision of customer information.

5.2.1 Resources

The CTA has made a large investment in information technology and staff that has both technological and service planning expertise. As a result of these investments, the CTA has the resources to be able to collect, process, and analyze large volumes of highly detailed transit performance data. These investments have also enabled the agency to become an innovator in the use of automatically collected data to measure transit performance. The CTA's technical abilities in the area of service planning allow the agency to realize great benefit from its automated data systems. The CTA's data collection, planning staff, and data processing and analysis resources are summarized below, along with recommendations for improvement in each area.

Data Collection

As described in Section 3.1.1, the CTA has AVL and AFC technology installed on every bus in its fleet; 74 percent of the agency's bus fleet has APC equipment. Such a large percentage of its fleet outfitted with each of the three automated data systems enables the agency to collect data relating to all aspects of performance on a very high proportion of bus trips. Therefore, the data that planners analyze to measure performance is more representative of actual performance than if its APC penetration rate was 20 percent or less, which is typical of large transit agencies. The CTA's policy of ordering new buses with all three automated data systems preinstalled will ensure that the agency's performance measures will become even more accurate in the future.

Planning Staff

The CTA's Planning Department has three groups that use automatically collected data in the context of service evaluation. The Planning Analytics Group has three staff members (who work with information technology staff in other departments) whose time is dedicated exclusively to the maintenance of current data analysis tools and the development of new programs to process data. The online and Microsoft Excel-based analytical tools developed by these staff are used by the other Planning Department groups to assess performance on an ongoing basis. The Planning Analytics Group is constantly working to meet a high level of demand for new tools to analyze performance (Wainwright, 2010). Though the CTA is an industry leader in the processing and application of automatically collected data, the agency might consider increasing the staffing level of this group to create more tools to use automated data systems more systematically in the service planning process.

The Planning Department's Service Planning Group has a staff of seven, four of whom perform quarterly bus route reviews by garage in addition to conducting periodic corridor analyses. This staff is sufficient for performing the recommended ongoing service review process. Additionally, the Service Planning Group generally has the staff resources to conduct corridor studies and various systemwide analyses on a periodic basis. However, when systemwide problems require an evaluation of all bus services, such as the February 2010 service reductions required by a budget deficit, service planners are unable to perform periodic analyses like corridor analyses or evaluations of past service changes (Czerwinski, 2010). Therefore, the CTA might consider increasing the staffing levels of the Service Planning Group to be able to conduct more detailed performance analyses at the route, corridor, and system levels (though the increase in resources in the Planning Analytics Group should take precedence).

The CTA's Scheduling Group currently has ten schedulers, six of whom are dedicated to bus schedules. CTA schedulers make the necessary changes in the schedules of routes that are slated to receive service changes identified through the quarterly route reviews and corridor analyses performed by the Service Planning Group. Additionally, the Scheduling Group engages in a process to systematically evaluate bus running times to determine if schedule adjustments are necessary in order to improve reliability or conserve operating resources. The Scheduling Group's workload can be very heavy when large numbers of service changes are needed and this can delay the systematic running time analyses (Czerwinski, 2010). Therefore, the CTA might consider increasing the staffing levels of the Scheduling Group slightly (again, the increase in resources in the Planning Analytics Group should take precedence).

Data Processing and Analysis

The CTA's investment in automated data systems and capable planning staff has allowed the agency to develop numerous data processing and analytical tools that enable service planners to easily review performance data. The Planning Analytics Group has developed several tools that query the agency's databases to summarize route performance and perform cause-identifying analyses in all aspects of performance. These tools and their analysis capabilities are summarized in Table 5-6. While these tools are useful in evaluating route performance, analyses covering bus loading, service reliability, passenger demand, and cost effectiveness are spread among the six tools, requiring service planners to conduct multiple queries to view graphs and tables pertaining to all aspects of route performance. To streamline the route review process, the CTA should combine some of the analyses in each query tool into a single, simplified query tool which generates analyses that address bus loading, service reliability, passenger demand, and cost effectiveness.

In addition to the tools in Table 5-6, the Planning Analytics Group is currently using AFC data, in concert with AVL and AFC data, to develop single-route origin-destination matrices for the entire bus system (Cui, 2010). These matrices will enable planners to observe the origins and destinations of customers on a particular bus route during a given time of day and time period (e.g. AM Peak on weekdays in January 2010). Staff should incorporate the measurement of the recommended performance metrics at the route origin-destination level into the analytical tools that supply data analyses for route profiles. The CTA should also explore the use of AFC data to measure performance at the network level, taking into account the transfers that customers make between transit routes, as discussed in Section 4.4.3. In doing so, the CTA could begin to link individual trip segments, forming complete journeys within the transit system, to measure service quality as experienced by customers who make transfers.

5.2.2 Summarization of Data and Information

This single tool recommended above should be used to generate route profiles for each route, providing the necessary analyses to support the route review/problem identification process (Table 5.1 lists the data analyses that should be included in each route profile). This will streamline the ongoing service review process and allow planners to observe all aspects of route performance at once. Besides routing and schedule information, the CTA does not have a systematic process for cataloging information about routes. Planners currently use what information is available (or what is known based on planners' past experiences) while evaluating route performance, but it is theoretically easy for information to be lost. Therefore, the CTA should develop a database of route-level contextual information to populate route profiles as recommended in Section 5.1.2.

Table 5-6: CTA Analytical Tools

Analysis Tool	Performance Category	Analyses
Service Standards Tool	Bus Loading	• Average and 75th percentile of bus loads by time period, half hour, and stop • Maximum load point by half hour
	Service Reliability	• Half cycle time analysis by half hour
	Passenger Demand	• Comparison of scheduled headway and recommended headway based on demand by stop and half hour • Average and maximum passenger flow by half hour and stop
	Cost Effectiveness	• Route productivity and ratio of route productivity to system productivity by half hour
Big Load Tool	Bus Loading	• Average, 25th percentile, and 75th percentile of bus loads and average passenger-experienced load by time period and half hour • Standard deviation, coefficient of variation, and range of bus loads by time period and half hour • Percent of low and big load buses by time period and half hour
Metric Reports	Service Reliability	• Average actual wait time, average scheduled wait time, average excess wait time, and total excess wait time by route and day type • Percent of successful headways, "big or small" early buses, and "big or small" late buses by route and day type • Percent of big gap and bunched bus intervals by route and day type
Reliability Tool	Service Reliability	• Average excess wait time, total excess wait time, and boardings by route segment, time period, and half hour • Percent of early and late buses by route segment, time period, and half hour
Short Run Time Tool	Service Reliability	• Percent of trips completed within the scheduled half cycle time by time period and half hour
Ridership by Stop Tool	Passenger Demand	• Passenger boardings, alightings, and flow by stop, time period, and half hour

5.2.3 Service Standards

The CTA's Service Standard document was developed before the agency had fully deployed its automated data systems for performance evaluation. Since then, the CTA has invested in information technology and staff resources to be able to measure transit performance using the performance metrics recommended in Chapter Four. The CTA should update its Service Standards to incorporate the full benefits of automatically collected data in the measurement of route performance. Specifically, the Service Standards should include the recommended bus loading, service reliability, and cost effectiveness metrics, presented in Chapter Four. Table 5-7 summarizes the proposed changes which are tailored specifically to the CTA and its Service Standards.

In addition to incorporating the recommended performance metrics, the CTA should update the Service Standards to reflect the recommended improvements to the service planning process, as outlined in Sections 5.1.3, 5.1.4, and 5.1.5. The following sections discuss additional improvements to the CTA's service planning process that were specifically developed for the agency based on its advanced data collection, processing, and analytical capabilities.

Table 5-7: Recommended Changes to the CTA Service Standards

Performance Category	Recommended Change
Bus Loading	• Add "bus loading" to the set of service design measures using the average passenger-experienced load, average bus load, and percent of overcrowded buses performance metrics • Reduce the bus loading threshold during peak periods (currently 60 passengers) to 55-58 passengers, which more accurately represents the load at which bus crowding begins to significantly deteriorate service
Service Reliability	• Add "service reliability" to the set of service design measures using the percent of successful headways and excess wait time performance metrics • Establish threshold values for each service reliability metric (e.g. a route exceeds the excess wait time threshold if the ratio of excess wait time to expected wait time exceeds 0.5)
Cost Effectiveness	• Replace the static productivity threshold value (30 passenger boardings per hour) with one that is relative to the systemwide productivity during each time period (e.g. a route exceeds the productivity threshold if any time period has a productivity value below the 15^{th} percentile of the productivity for all routes in the same time period)

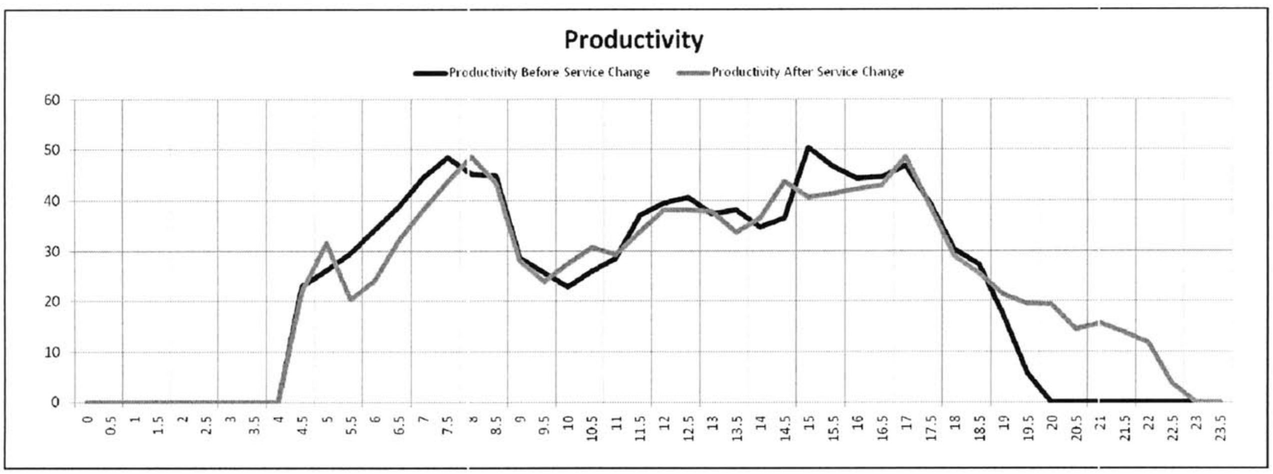
5.2.4 Evaluation of Past Service Changes

The CTA does not currently conduct evaluations of past service changes systematically at the route level or systemwide for each type of service change. As discussed in Section 5.1.3, measuring the impacts of past service changes helps agencies determine the effectiveness of each type of service change to inform future problem resolution processes.

Route-Level Service Change Review

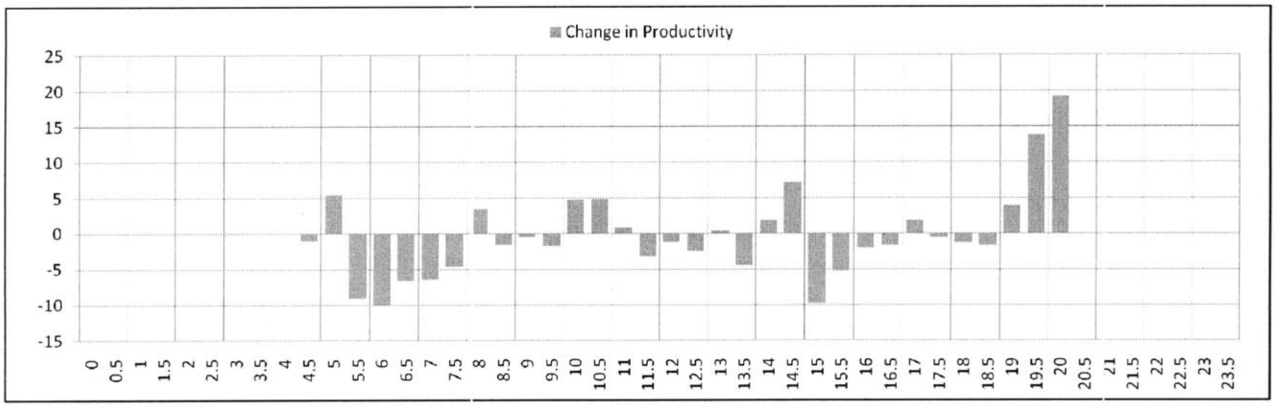
The CTA has the resources necessary to conduct evaluations of the impacts of past service changes on some aspects of route-level performance. However, this analysis is not conducted systematically for all service changes. The Planning Analytics Group developed a tool called the "Bus Productivity Tool" which allows planners to perform analyses that measure changes in ridership and productivity for a given route over a specified length of time. Figures 5-6 and 5-7 provide examples of some of the outputs of this analysis. Figure 5-6 shows route productivity by half hour both before and after the time that service on Route 65 was extended from 8:00 PM at 11:00 PM. Figure 5-7 shows the change in productivity between February 2009 and February 2009 by half hour in terms of passenger per service hour.

Figure 5-6: CTA Comparison of Productivity Before and After a Service Change
Route 65, Weekdays in February 2008 and February 2009



The CTA should expand the scope of the Bus Productivity Tool in several ways in order to make it more useful during route-level service change evaluations. First, the tool should measure the changes in all aspects of performance (bus loading, service reliability, etc.) relating to a given service change. Second, the tool should simultaneously measure the *systemwide* changes in performance during the same two time periods that are analyzed based on the timing of the given service change. This will allow planners to determine the extent to which changes in route-level performance are caused by external factors that affect the entire system. Finally, the tool should be linked to the agency's database of past service changes and should automatically identify which routes should be analyzed based on the timing of each service change. This further investment in software development will help automate the route-level service change evaluation process, reducing the amount of staff time devoted to performing these analyses.

Figure 5-7: CTA Change in Productivity After a Service Change
Route 65, Weekdays in February 2008 and February 2009



Service Change Type Evaluation

As with the route-level service change review, the CTA has the information technology resources needed to evaluate the overall effectiveness of each type of service change with respect to ridership, bus loading, reliability, and productivity. However, this type of analysis is not conducted on a regular basis. Additionally, the CTA currently does not have an analytical tool to aggregate the performance of all routes that experienced certain types of service changes to perform the service change type evaluations described in Section 5.1.3 (the analysis presented in Section 5.1.3 was performed manually). The Planning Analytics Group should develop a tool to further assist planners to systematically perform the recommended service change type evaluation process periodically. The agency should review the results of the service change type evaluation analysis to guide the development of service change strategies during the problem resolution process.

5.2.5 Ongoing and Periodic Service Review Processes

The CTA's Service Standards document outlines the agency's ongoing performance review and semi-annual review processes (see Section 3.1.4). This section outlines specific steps that the CTA should take to improve these processes to systematically measure route, corridor, and system performance to identify problems to address.

Ongoing Service Review Process

As previously discussed, the CTA has developed several advanced database query tools which allow planners to analyze large and highly detailed data sets. Once the CTA implements the recommendations in Section 5.2.2 to develop a single analytical tool and an information database to populate route profiles, the agency will be able to create comprehensive route profiles containing relevant data analyses and route information. Planners will then be able to systematically evaluate performance to identify route-level problems according to the recommended ongoing service review process outlined in Section 5.1.4. The CTA Planning Department has the necessary resources to complete a cycle of the recommended ongoing service review process every three months in conjunction with the pick schedule Planners currently review route performance quarterly, indicating that this is an attainable goal with current staffing.

Periodic Service Review Process

The CTA should replace its semi-annual review process (see Section 3.1.4) with the recommended periodic service review process (outlined in Section 5.1.5) to analyze performance and identify problems in selected corridors and subareas for analysis and to resolve the identified problems through service changes. First, the agency should develop a list of potential corridors and subareas for analysis based on known problem areas and geographic coverage (to ensure that, eventually, all problem corridors receive this level of analysis). This list should be updated periodically as new corridor-level problems arise. Next, the CTA should select the corridors and subareas to analyze in depth for each periodic review process based on addressing the areas of greatest need first. Once the analysis of the selected corridors and subareas is complete, the agency should present its findings, including the identified problems and proposed service changes, to the Board of Directors.

5.2.6 Customer Information

The CTA uses its website to provide performance data and information in two formats. First, the agency publishes monthly performance reports that are provided to the Board of Directors. The reports explain systemwide performance using mainly operator-oriented measures such as ridership, percent of big gap intervals, and miles between reported bus service disruptions. Second, the CTA provides real-time bus location and arrival information for each bus route on its CTA Bus Tracker website. CTA Bus Tracker provides an important service to customers by allowing them to access real-time transit information in planning their travel (CTA, 2010b). The CTA should enhance its sharing of performance data by developing a section of the CTA website dedicated to route- and system-level performance using the metrics and analyses contained in route profiles, as recommended in Section 5.1.6. Specifically, the agency should focus on displaying graphs that demonstrate trends in route and system performance, such as in Figures 5-1, 5-2, and 5-3. Since these graphs are already developed quarterly to populate each route profile, the sharing of these analyses on the website should not require significant staff resources. Once developed, the CTA should make a concerted effort to inform customers of this information and encourage customers to provide feedback regarding route performance and/or the presentation of performance data.

5.2.7 Summary

Due to the CTA's significant investments in information technology and capable planning staff, the agency is well-positioned to implement the general and CTA-specific recommendations for incorporating the full benefits of automatically collected data into the service planning process. Additionally, the agency has the resources to go beyond these recommendations to reap even greater benefits from its automated data systems.

5.3 Recommended Strategies for the Massachusetts Bay Transportation Authority (MBTA)

In contrast to the CTA's significant information technology and staff resources, the MBTA currently does not have sufficient resources to conduct the recommended service planning process using automatically collected data. The following sections highlight the areas in which investments in additional resources and other improvements to the current practice will best position the agency to improve its data collection, processing, and analysis capabilities in order to implement a systematic and comprehensive service planning process.

5.3.1 Resources

The MBTA's ability to efficiently use automatically collected data in the service planning process is limited by insufficient resources. Investments in data collection, planning staff, and data processing and analysis capabilities, discussed in this section, will allow the agency to implement the recommended service planning process outlined in Section 5.1. An increase in the level of operating resources available to implement service changes is also proposed.

Data Collection

As noted in Section 3.2.1, the MBTA has AVL and AFC technology on every bus but has a relatively small percentage of APC-enabled buses in its fleet, which limits the quality and quantity of passenger demand data available to the agency. Table 5-8 displays the agency's distribution of APC-enabled buses by garage. It shows that seven of the ten MBTA bus garages have fleets with less than ten percent of APC-equipped buses. Because of this low penetration rate, the MBTA continues to hire data tabulators to collect passenger demand and bus loading data manually (Dullea, 2010).

According to Furth et al. (2006), a ten percent penetration rate of APC-enabled buses is sufficient for collecting accurate passenger demand data on each route. However, a larger penetration rate yields more accurate measurements of bus loading by trip. Therefore, the MBTA should invest in additional APC equipment to increase the percentage of APC-enabled buses to 20 percent. This percentage fulfills Furth et al.'s guidelines for collecting passenger demand data while allowing the MBTA to collect sufficiently large samples of bus loading data. To achieve a 20 percent penetration rate, the agency should purchase 135 additional APC systems, nearly tripling its APC-enabled bus fleet. This can be achieved most cost-effectively by requiring that all new buses that the agency purchases come with APC equipment preinstalled (this is less costly than purchasing APCs separately and retrofitting existing buses). The cost of this investment in technology will be partially offset by a reduced need to hire data tabulators to collect passenger demand data. This investment in data collection technology would enable the agency to perform all of the performance analyses recommended in Chapter Four.

Table 5-8: MBTA Total and APC-Enabled Buses by Garage
March 2010

Garage	Total Number of Buses	Number of APC-Enabled Buses	Percent of APC-Enabled Buses
Charlestown	217	21	9.7%
Cabot	194	23	11.9%
Arborway	118	5	4.2%
Albany	114	0	0.0%
Lynn	96	10	10.4%
Southampton	88	7	8.0%
Quincy	84	10	11.9%
Fellsway	75	0	0.0%
Everett	39	0	0.0%
North Cambridge	31	0	0.0%
TOTAL	**1056**	**76**	**7.2%**

Source: MBTA, (2010a), MBTA, (2010b)

In anticipation of the delivery of new APC-enabled buses, the MBTA should develop and implement a schedule to systematically rotate its current APC-enabled buses among all routes. For example, the agency could assign its APC-enabled buses to a selected set of routes for one three-month pick. This will allow the agency to collect sufficiently large bus loading data samples for these routes during this time period. At the start of a new pick, the buses should be reassigned to other routes in the system. Over the course of a year, bus loading data will have been collected for a significant portion of the agency's routes, allowing planners to measure bus loading and passenger demand on these routes using the recommended performance metrics for at least one three month period.

Rotating buses among routes within garages that have some APC-enabled buses is relatively straightforward, but moving buses from one garage to another poses some challenges. For example, the North Cambridge garage houses the agency's fleet of electric trolley buses, none of which have APCs installed. Since no other buses serve these routes on weekdays, the agency is unable to collect passenger load data automatically for routes served by buses in this garage. Additionally, moving buses from one garage to another has implications for ongoing maintenance procedures. Therefore, the MBTA should first focus on increasing its fleet of APC-enabled buses. As more of these buses become available, the number of routes being served by APC-enabled buses during each pick can be increased until bus loading data is collected on all routes year-round.

Planning and Scheduling Staff

In contrast to the robust staffing levels of the CTA's Planning Department, the MBTA's Service Planning Department is small, consisting of four planners. While the current Service Planning staff are highly capable and are able to implement the agency's current ongoing and biennial service planning processes as outlined in its Service Delivery Policy, this staffing level is insufficient to conduct the recommended ongoing and periodic service review processes outlined in Section 5.1. The MBTA's Scheduling Department is similarly small (two schedulers) and does not have the resources to perform running time analyses to address service reliability issues systematically. Therefore, the MBTA should increase the staffing level of the Service Planning and Scheduling Departments. Since the CTA's bus system is nearly twice the size of the MBTA's system (in terms of the number of buses), the MBTA should hire one additional service planner and one additional scheduler to have a planning-staff-to-bus-network ratio similar to that of the CTA. The investment in additional staff will ensure that there are enough planners to evaluate performance on all of the agency's routes on an ongoing basis in addition to conducting the recommended periodic service review process annually.

Data Processing and Analysis

The MBTA has limited data processing capabilities to allow for efficient and systematic performance analyses. The reports that the MBTA uses to analyze performance at the route, corridor, and system levels (see Table 5-9) generally summarize performance at the trip level. For example, the AVL database report displays trip-level service reliability data and automatically determines if buses on low frequency routes are early or late or if intervals between buses on high frequency routes are too short or too long. However, planners must aggregate this data to the appropriate level (e.g. Route 28 northbound during the AM peak period) to be useful when analyzing route-level performance (Dullea, 2010). This is a time-consuming process and limits the number and level of detail of analyses that planning staff can perform. Therefore, the MBTA should modify its existing performance reports and develop new analytical tools that summarize route performance using the performance metrics in Table 5-1. Any added investment in information technology will reduce the burden on staff to manually process automatically collected data, freeing up staff time for other analyses.

The MBTA's Service Planning Department currently does not use AFC data to measure performance. The agency is concerned that the use of electronic fare transaction data to measure passenger demand would undercount demand, particularly on crowded trips where bus operators sometimes allow passengers to board without paying in order to minimize loading and dwell times. However, as is the case with AVL and APC data, AFC data can be cleaned and adjusted (using factors developed from APC data on the same trips) to produce accurate measures of passenger demand. The MBTA should take advantage of this rich data source by exploring this and other ways to account for the undercounting of passengers in order to make AFC data useful in the service planning process.

Operating Resources

The MBTA's current budget does not provide funding for service changes that require an increase in overall operating resources (Dullea, 2010). Service planning staff have adapted to this limitation by "funding" service changes by reallocating resources among bus routes. This practice limits the agency's ability to address a significant portion of the performance problems its routes experience. If the operating resources to implement the recommended service changes are lacking, the agency will not realize the benefits of the recommended investments in data collection, planning staff, and data processing and analysis capabilities. Therefore, the MBTA should seek additional operations resources in the annual budget in order to fund a backlog of service changes that are expected to positively impact service quality.

Table 5-9: MBTA Data Reports and Data Summaries

Report	Performance Category	Data Summaries and Analyses
AVL-APC Database Report	Bus Loading	• Bus load by stop for each trip served by APC-enabled buses
	Service Reliability	• Actual arrival times by stop for each trip • Scheduled arrival times by timepoint for each trip • Actual and scheduled running times by timepoint for each trip • Dwell times by stop for each trip
	Passenger Demand	• Passenger boardings and alightings by stop for each trip served by APC-enabled buses
Manual Passenger Counts	Bus Loading	• Bus loads by stop for each trip
	Passenger Demand	• Passenger boardings and alightings by stop for each trip
Route Performance Report	Service Reliability	• Average actual running times and scheduled running times aggregated by hour for each route segment • 15^{th}, 50^{th}, and 85^{th} percentile of actual running times aggregated by hour for each route segment • Scheduled and average actual departure and arrival times aggregated for each scheduled run • Distributions of actual bus arrival times by timepoint aggregated for each scheduled run
AVL Database Report	Service Reliability	• Scheduled and actual arrival times by timepoint for each trip • Schedule deviation by timepoint for each trip • Scheduled and actual headways by timepoint for each trip • Determination of adherence to schedule adherence/headway standard (e.g. too early or long headway) for each trip

5.3.2 Summarization of Data and Information

As discussed in the previous section, the MBTA should invest resources in modifying the existing performance reports and developing new data analysis tools to improve the way performance data is summarized and displayed. The outputs of these tools should then be used to populate route profiles for each route, providing the necessary data analyses for consideration during the route review/problem identification process (Table 5-1 lists the data analyses that should be included in each route profile). This will reduce the need for planning staff to create performance summaries manually, freeing up staff time to analyze the performance of more routes in more detail than is done currently.

Like the CTA, the MBTA does not have a systematic process for cataloging information about routes. Planners generally use what information is available (or what is known based on planners' past experiences) while evaluating route performance. In some cases, staff seek additional information by visiting the route in the field or contacting operations staff for anecdotal information about a problem. While such information gathering is important, it should be done in a systematic way for all routes to reduce the need to collect additional information during route review/problem identification process. The MBTA should develop a database of route-level information to populate route profiles with relevant contextual information about each route according to the guidelines in Section 5.1.2.

5.3.3 Service Delivery Policy

The investments in data collection, planning staff, and data processing and analysis resources recommended in Section 5.3.1 would enable the MBTA to measure performance using the performance metrics presented in Chapter Four. Once these investments are made, the MBTA should modify the service standards element of the agency's Service Delivery Policy to include the recommended bus loading, service reliability, and cost effectiveness metrics. Table 5-7 summarizes the specific modifications to the service standards that the agency should implement.

Table 5-10: Recommended Changes to the MBTA's Service Standards

Service Standard	Recommended Change
Bus Loading	• Add the percent of overcrowded buses performance metric to the set of vehicle load standards • Use the average passenger-experienced load metric (instead of the average bus load metric) to determine if routes violate the vehicle load standards by hour
Service Reliability	• Add the excess wait time performance metric to the reliability service standards, as recommended in Section 4.2.4. • Modify the thresholds for determining whether buses are on-time or have successful headways to be more stringent. In particular, the threshold for low frequency buses at timepoints (0-7 minutes late is considered on-time) should be tightened.
Service Frequency	• Establish a systematic process for determining service frequencies above the minimum frequency thresholds based on passenger flow and desired maximum average bus loads by time period (The MBTA might use the CTA's frequency determination procedures as a reference)

Along with the incorporation of the recommended performance metrics, the MBTA should update its Service Delivery Policy to include the ongoing and periodic service review processes that are described in Sections 5.1.3, 5.1.4, and 5.1.5.

5.3.4 Evaluation of Past Service Changes

The MBTA currently does not systematically evaluate the impacts of past service changes on performance at the route level, nor does the agency measure the overall impact of each type of service change on performance. While the analysis of specific service changes is occasionally conducted as part of the biennial service plan, due to a lack of tools to process and summarize route performance over time, planners must perform these analyses manually, requiring large amounts of staff time. With the recommended investments in data and planning resources, the MBTA will be better equipped to develop tools that perform analyses of the impacts of specific prior service changes and each general type of service change at improving route-level and overall performance, as described in Section 5.1.3.

5.3.5 Ongoing and Periodic Service Review Processes

The MBTA's Service Delivery Policy outlines the agency's ongoing and biennial service planning processes (see Section 3.2.4). This section provides specific steps that the MBTA should take to improve these processes to systematically measure route, corridor, and system performance in order to identify and resolve problems.

Ongoing Service Review Process

The MBTA's current ongoing bus service planning process involves analyses of performance on routes where problems have been identified through feedback from operations and planning staff, as well as comments from actors outside of the MBTA (customers, regional agencies, etc.). Reviews of performance for *every* route are conducted through the agency's biennial service planning process, but such analyses are done infrequently and are not as detailed as the performance analyses recommended in Table 5-4. Once the MBTA has invested in additional data processing and analysis resources, the agency should implement the ongoing service review process described in Section 5.1.4. As new resources and analytical tools are developed and become available, the agency can increase the frequency in which it completes a cycle of systematically evaluating the performance of every route, eventually performing the process at least semi-annually. Improving the ongoing service review process in this way will allow planners to more quickly and effectively respond to problems at the route level.

Periodic Service Review Process

During the MBTA's current biennial service planning process, planners perform analyses of each route to identify problems. Once the MBTA has the information technology and staff resources required to implement the recommended ongoing service review process, the MBTA should replace its current biennial service planning process with the recommended periodic service review process, as described in Section 5.1.4. This process, which should be conducted annually in conjunction with the agency's budget process, will enable planners to address problems that require major service changes identified during the ongoing service review process as well as identify new problems at the corridor or subarea levels.

The MBTA's new periodic service review process should have a particular focus on evaluating bus corridors and subareas to identify problems that affect more than one route. Specifically, periodic service reviews could include the analysis of corridors where multiple routes travel on the same roadway for a considerable distance, effectively providing very frequent service for customers that board and alight in such corridors. Examples of this phenomenon in the MBTA's bus network include the Longwood Avenue to Ruggles Station corridor (served by routes CT2, CT3, 8, 19, and 47) and the Warren Street to Ruggles Station corridor (served by routes 14, 19, 23, 25, 28, and 44). The MBTA should make a list of these trunk service corridors and evaluate the set of routes in at least one corridor per periodic service review. This process should result in a set of recommended service changes that improve the collective service quality of the bus routes in a corridor without adversely affecting the performance of the branch segments of these routes.

5.3.6 Customer Information

In 2009, the MBTA began providing monthly performance reports developed specifically for customers on its website. The report, know as the MBTA ScoreCard, presents performance in terms of ridership, on-time performance, infrastructure, dropped trips, vehicle reliability, safety, and customer feedback (MBTA, 2010c). Though the document was developed as a resource for customers, the ScoreCard provides performance summaries that reflect the agency's perspective of performance. For example, the ScoreCard displays the number and percent of bus trips that were not operated ("dropped trips") by route for the most recent month, which is intended to represent service reliability. Instead, the agency could report the scheduled, average, and total excess wait time by route to better reflect service reliability as experienced by customers. Once the MBTA has a sufficient fleet of APC-enabled buses to measure performance from the customer perspective, the ScoreCard should be modified to include the customer-centric performance metrics recommended in Chapter Four, including average passenger-experienced load, percent of overcrowded buses, and excess wait time. Additionally, the ScoreCard should be a prominent component of the agency's website and the MBTA should encourage customer feedback regarding route performance and the presentation of this data.

5.3.7 Summary

The MBTA has some of the critical elements necessary to evaluate service performance using automatically collected data. However, the agency needs to make significant investments in information technology, staff, and operating resources in order to fully realize the benefits of its automated data systems. The MBTA-specific recommendations outlined in this section will enable the MBTA to implement the recommended service planning process, as outlined in Section 5.1. With a significant investment in resources, the MBTA can become a model agency in terms of its use of automatically collected data to better identify and resolve performance problems.

6 Summary and Conclusions

This thesis concludes with a summary of the research, including a review of the research objectives and conclusions with respect to the benefits that automated data systems provide for the measurement of service performance and identification and resolution of performance problems. It also discusses potential areas for expanding this research to further improve the service planning process and bus transit performance.

6.1 Research Summary

Over the last decade, transit agencies have been changing their data collection methods from manual to automatic with the adoption of AVL, APC, and AFC technologies. These systems are capable of producing large volumes of highly detailed data about transit service performance and can improve the service planning process by allowing performance measurement more from the perspective of customers. Due to the precision of automatically collected data, agencies can identify performance problems more accurately than with manually collected data, often leading to more effective solutions. Additionally, information technology systems can be developed to automate the processing and analysis of data, potentially freeing up staff time for more in-depth planning analyses and other important tasks.

While most large transit agencies currently have some automated data systems, many agencies are still using the performance metrics and service planning processes that were used when data was collected manually. These metrics and processes are inherently limited by the shortcomings of manually collected data, particularly by the small data samples and the low frequency of data collection. By retaining the performance metrics and planning processes used under the manual data collection paradigm, these transit agencies do not realize the full benefits of the automated data systems in which they have invested.

This thesis argued that transit agencies can improve their service planning processes by incorporating the full benefits of automatically collected data. It included a set of recommended performance metrics which allow agencies to more precisely measure performance in the categories of bus loading, reliability, and passenger demand. This research then used Bauer's (1981) recommended short range transit planning process, which was developed when transit agencies relied on manually collected data, as a framework for the recommended service planning process under the automatic data collection paradigm. This thesis recommended enhancements to Bauer's process based on the features of automatically collected data and advanced analytical tools. Along with general recommendations to improve the service planning process using automatically collected data, this thesis made specific recommendations for the Chicago Transit Authority (CTA) and the Massachusetts Bay Transportation Authority (MBTA) based on each agency's current and potential future resources and constraints.

6.2 Conclusions

There are several overarching conclusions from this research. They are based on both the ongoing body of research on the topic of transit performance measurement and the empirical analyses performed in the context of the CTA and the MBTA. These conclusions are:

1. **Automatically collected data can be used to measure performance more from the customer perspective and can better identify the frequency of poor performance.** This thesis recommended several performance metrics that use automatically collected data to measure performance from the perspective of customers, including average passenger-experienced load and excess wait time. These metrics also take into account the impacts that significant crowding or unreliable service have on customers, which are sometimes diluted in traditional performance metrics. By considering the customer perspective of performance, transit agencies can address problems that have the greatest impacts on customers in order to achieve the agencies' goals in providing service.
2. **Large and highly detailed data sets from automated data systems allow agencies to more acutely identify performance problems.** This thesis demonstrated that data generated by automated data systems can be used to measure bus transit performance at fine levels of detail. For example, bus loads can be measured over many days at each stop and by half hour using AVL and APC data for a particular route, providing reliable distributions of operating conditions for any time period. These detailed analyses allow planners to identify and resolve acute performance problems that might have gone unnoticed with less detailed analysis.
3. **Route information remains a critical component of the service planning process.** While automated data systems provide large sets of data capable of supporting detailed analysis, this data still needs to be analyzed in context in order to properly identify, diagnose, and resolve problems. For example, data may indicate unreliable bus arrivals at a particular intersection; contextual information about customer transfer behavior, roadway geometry, and adjacent trip generators helps planners determine the factors that may be causing the problem in order to develop an effective solution. Therefore, contextual route information remains a critical component of the service planning process.

4. **Efficiencies in automated data collection and processing allow planners to conduct systematic service evaluation processes.** In addition to being collected automatically, data can also be processed automatically. Agencies can develop software to automate the data processing and analysis components of the service planning process. For example, agencies can develop analytical tools to apply the successful headway performance metric to AVL data to summarize reliability performance by route and time period. By automatically performing functions that previously required significant staff time, automated data systems allow transit agencies to systematically evaluate the performance of all routes on an ongoing basis.
5. **Automated data systems can reduce data collection costs but may require investments in planning staff resources.** Automated data systems eliminate the need to collect transit performance data manually using full-time or temporary data collection staff, resulting in cost savings. However, a staff of skilled planners remains the driving force behind the service planning process under the automated data collection paradigm. Once data is collected, planners must use data analyses, in addition to route information and their professional judgment, to make decisions regarding the implementation of service changes to improve bus performance. The development of analytical tools that process and summarize data also requires significant resources to develop and maintain. Therefore, although ancillary data collection staff can be reduced, service planning and data resource staffing levels should be maintained, if not increased, with the introduction of the advanced data processing and analysis techniques allowed by automated data systems.

6.3 Future Research

There are several opportunities for research to extend this work that can be useful in allowing transit agencies to realize more benefits from automated data systems. Some of these research topics focus on transit service planning in general, while others focus on applying the results of current research in differing contexts. This section identifies these potential research opportunities.

- **Apply the recommended service planning process to various transit agencies with differing resource levels and constraints.** The general recommendations for improving the bus transit service planning process are intended to be applicable to all large transit agencies. However, as shown in Sections 5.2 and 5.3, varying resource levels and constraints among agencies require alternative strategies. Researchers could apply the improved process to specific transit agencies to determine the effectiveness of the proposed ongoing and periodic service review processes in agencies with differing resource levels and constraints.

- **Develop new performance metrics which take further advantage of the benefits of automatically collected data, including network- and origin-destination-based analyses.** The performance metrics recommended in Chapter Four were drawn from the large body of prior research on transit performance measurement. Researchers should continue to develop new metrics that measure performance from the perspective of customers, consider the full distribution of values (including instances of very poor performance), and provide insight into acute performance problems. In particular, additional research should be conducted regarding the use of AFC data, in conjunction with AVL data, to measure performance at the network and origin-destination levels, as described more fully in Section 4.4.
- **Investigate new methods of processing data to further streamline the route review/problem identification processes.** This thesis recommended the use of software to process and analyze data automatically in order to supply the data analyses recommended for inclusion in route profiles. Additional research could yield new data processing methods which further aid service planners in the analysis of service performance at the route, corridor, and system levels.
- **Research the effectiveness of service change types at resolving specific problems.** Section 5.1.3 of this thesis recommended that transit agencies review the performance of routes that received particular types of service changes in order to determine how effective each service change type is at addressing particular problems. This analysis could also be conducted in a separate study and across several large agencies to determine the most effective, transferable resolutions to transit performance problems in a larger context.

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