BUS SUPERVISION DEPLOYMENT STRATEGIES FOR IMPROVED BUS SERVICE RELIABILITY

by

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Portland State University, 2004

Submitted to the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN TRANSPORTATION

at the

Massachusetts Institute of Technology

September, 2006

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Submitted to the Department of Civil and Environmental Engineering on August 11, 2006 in partial fulfillment of the requirements for the degree of Master of Science in Transportation

ABSTRACT

Bus service reliability has always been a top concern for transit agencies and their customers. Unfortunately, there are several factors detrimental to reliable bus service. Outside influences such as weather, traffic, and road construction can wreak havoc on even the best laid plans. Internally, poor planning, insufficient maintenance, and differing operator abilities can work to undermine bus service reliability.

To help counteract these problems, transit agencies typically deploy a team of supervisors who are responsible for monitoring, maintaining, and restoring reliable service. To do their job effectively, supervisors require high levels of operational information and a reliable communications system. These resources, however, can vary in their availability and may not be at ideal levels. This research proposes a framework to aid in the planning of bus supervision deployment given different levels of information, communications, and personnel.

The primary focus of the framework is the deployment of post, mobile, and control center supervisors given an agency’s current level of information and communication resources. The application of the framework begins with a service reliability and supervision resource assessment. Based on these assessments, a system level personnel deployment strategy is developed and then evaluated.

Two case studies – the Chicago Transit Authority (CTA) Route 20 and the Massachusetts Bay Transportation Authority (MBTA) Silver Line – are presented as applications of the proposed framework. Findings suggest that personnel deployment at both agencies is suboptimal: both agencies deploy too many post supervisors given current resource levels, and for the CTA, too few mobile supervisors. Findings also suggest that putting increased information and communication resources in place should lead agencies to have post supervisors only at the busiest most critical locations, mobile supervisors for incident response and reallocate many field-based supervisors to the control center for headway and schedule management.

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Acknowledgments

To my advisors Nigel Wilson and John Attanucci. Thank you for your unwavering confidence in my writing and my research abilities, and for pushing me to surpass my own expectations time and time again. You helped to create an MIT experience that was exceptionally rewarding and equally challenging – an unforgettable experience (in a good way!) that I will take with me throughout my career.

To Fred Salvucci, Mikel Murga, and Ken Kruckemeyer who could always be counted on to provide great conversation and advice on any transportation topic.

To Ginny Siggia, thank you for all of your help in staying organized, and for all those goodies that mysteriously appeared in 1-235.

To the Chicago Transit Authority for sponsoring my graduate studies and providing the basis for this research. To Angela Moore for allowing me to have an incredible experience as a summer intern at the CTA. Getting up at 4 in the morning to meet the great Eugene Thurmond (to whom I also owe gratitude for teaching me the finer points of bus supervision) and witness a morning pull-out is an experience that cannot be duplicated anywhere else. To Angela, Jason Lee, and Wai-Sinn Chan for letting me control Route 20 for one whole week. Incredible opportunity. To CTA President Frank Kruesi, and Vice Presidents Michael Schiffer and William Mooney for supporting my work on bus service reliability and believing that we can make bus service better. The City of Chicago is in good hands.

To David Barker and David Carney at the Massachusetts Bay Transportation Authority for providing data and working with me on the Washington Street Silver Line. Thank you as well for allowing me to shadow the supervisors and dispatchers.

To my professor at Portland State University, Robert Bertini. Your encouragement and push to reach for the sky is one of the main reasons I was able to go to MIT. Thank you for all of your support, and for your dedication to your students.

To my friends who made the past two years one of the most memorable times in my life. Lou Malnati’s and the Occidental with Drew and Mike. Madison Square Garden and the Rose Garden with Owen. Super Mario Kart with Tara. Maverick Airlines with Edgar. Anna’s runs with Hanowski. Concerts, and coffee with Mary. Pizza and “green stuff” with Elaine. And of course, countless adventures with Jeff and Danielle.

Last and certainly not least, thank you to my friends and family back home in Portland. To my family – Mom, Dad, and Vanessa – who always told me I could overcome any obstacle and achieve my dreams. To my Dad, who has been driving buses for TriMet for 17 years and counting, for offering practical and sound advice from the operator view on all of this research.
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1 Introduction

This research reviews current bus service supervision practices and develops a framework for transit agencies to aid in bus supervision deployment planning. The framework suggests how transit agencies should deploy their bus supervisors in order to maximize bus service reliability. Taken into account are the number of supervisors available, the communications structure in place, and the amount of information available to the supervisors.

1.1 Motivation

For transit agencies that try and provide quality customer service, bus service reliability is one of their top priorities. Not only do customers want safe, fast, and affordable transit, they also want to be able to count on it time and time again. Wait times should be predictable, and travel times should be consistent. Any deviations and customers will expect to be informed.

Unfortunately, there are several factors detrimental to reliable bus service. Outside influences such as weather, traffic, and road construction can wreak havoc on even the best laid plans. Internally, poor planning, insufficient maintenance, and differing operator abilities can work to undermine bus service reliability.

To counteract these factors, transit agencies typically deploy field supervisors in conjunction with establishing a control center as part of a bus service management program. The supervisors and the control center are then empowered to make real-time operating decisions regarding the buses on the street. Field supervisors can assist operators with defective equipment for example, or provide them instruction in order to restore “normal” bus service.
1.1.1 Prior Research Knowledge

The topic of bus supervision and bus service reliability has been studied extensively prior to this thesis. Much of this research has been conducted in the areas of transit service reliability, operations control, and bus supervision. This research has shown that there are many causes of unreliability, both external and internal to the transit agency, and that service unreliability plays a large part in the transit user’s experience. Several operations control methods such as holding, and expressing vehicles have been explored, and their theoretical benefits to reliability are well documented. Regarding bus supervision, studies have been completed suggesting the benefits of centralized control and technology in improving the effectiveness of supervision on service reliability.

Until now, most of the prior research has been theoretical both in approach and in findings. Operations control strategies have been modeled to show that selectively holding buses to either schedule or headway can produce net benefits for passengers by lowering their expected waiting times. Bus supervision findings have claimed that centralized operations control combined with advanced information and communications technologies will improve bus service reliability. This thesis will attempt to go a step further by applying these operations control and supervision strategies to two bus routes at the Chicago Transit Authority (CTA) and the Massachusetts Bay Transportation Authority (MBTA) in order to find out how effective they can be, and to uncover both the potential and the limitations of bus supervision.

1.1.2 The Supervision Challenge

In the past, a lack of technology has hampered the efforts of bus supervisors in maintaining reliable bus service. Supervisors in the field and in the control center have typically not had access to real-time information on their bus network. Information such as bus locations, passenger loads, and incident locations would have to be ascertained manually, and this would lead to slow and ineffective responses to service reliability.
problems. Communication constraints further inhibited supervisory effectiveness by slowing the information sharing process and restricting available responses.

In addition to a lack of technology, supervisors are often given a myriad of tasks to complete. While these tasks, such as conducting onsite repairs, managing crew changes (reliefs), or providing customer service do contribute to restoring service reliability, they detract from the supervisor’s ability to maintain reliability through schedule adjustments and utilizing other operations control strategies.

1.1.3 Role of Technology

Recently, emerging technologies have been at the forefront of transit research. Automatic data collection in the form of vehicle location information (AVL) and passenger counting information (APC) has given researchers the ability to examine vehicle movement behavior and passenger travel behavior. In addition, new real-time AVL information systems and digital communications are giving bus supervisors the resources necessary to detect service reliability problems earlier and tackle them more effectively.

In this thesis, the emerging technologies serve dual roles in the evaluation of bus supervision. Information and communications technologies are used to maximize the potential of bus supervisors while automatically collected vehicle location and passenger information is used to evaluate the benefits of bus supervision on service reliability.

1.2 Objectives of the Research

Utilizing the emerging transit technologies, and building from the prior research, this research will propose a framework to aid in the planning of bus supervision for improved
bus service reliability. The framework will then be applied to the CTA Route 20 and the MBTA Silver Line.

By applying the framework, this thesis will examine the role of field supervisors and the control center with regard to service reliability. The tasks assigned to each party, the decision making process, and the personnel assignments will be explored. In addition, the question of personnel requirements will be addressed given a certain level of information and communications technology.

1.3 Methodology and Approach

In order to carefully examine bus service supervision, the researcher must have first hand knowledge and experience of practice. Towards this end, field observations and discussions with key personnel at the CTA, the MBTA, and TriMet (Portland, OR) were conducted. This led to a working knowledge of the daily operations of bus service supervision at each of these agencies.

The state of the practice at the CTA and MBTA is analyzed to find out how bus supervisors are deployed and why. The drawbacks and potential benefits of each strategy are outlined and lessons are drawn from each one. From these lessons, a framework is developed in order to improve deployment strategies and ultimately, bus service reliability.

This framework is then applied to two case studies involving the CTA’s Route 20 and to the MBTA’s Silver Line. These routes were chosen due to their technological innovations and research potential. At the CTA, a project is currently being piloted that will provide real-time AVL information at the control center, in effect giving a dispatcher real-time knowledge of bus locations and schedule adherence status for Route 20. At the MBTA, the Washington Street Silver Line bus route is already equipped with this technology but it is not officially being used for operations control. By selecting Route
20 and the Silver Line, the framework application will be able to evaluate the full potential of bus supervision given these optimal operating conditions.

Applying the framework is a five step process. First, field observations and automated data are collected on each route to learn about ridership characteristics, current levels of service reliability, and available resources. This information is then used to develop a supervision deployment strategy for the route in question. Once the strategy has been formulated, a model is used to predict the potential benefits and costs of the strategy to the agency and its customers. Finally, if the net benefits are positive, the supervision strategy is deployed to verify the model results or for the long run. Data is collected and analyzed once again to measure the actual benefits and costs. As part of this thesis research a one-week experiment of a different supervision strategy was conducted on CTA Route 20.

From the extensive field work and case study applications, conclusions will be drawn regarding the effectiveness of the proposed bus supervision strategies. General conclusions will also be drawn with regard to how differing resource levels govern the way a transit agency deploys its bus service supervision team in order to best improve bus service reliability.

1.4 Thesis Organization

The next chapter will set the stage for the rest of the thesis by introducing the general concepts underlying bus service reliability. This includes defining bus service management, supervision, operations, and planning as they relate to service reliability. The concept of service reliability itself will also be laid out so the reader can better understand the goals of this research. A literature review is presented to put this thesis’s research in the context of prior findings. This includes research into transit service reliability, operations control, bus supervision, and a documented case study in supervision at TriMet.
The proposed bus supervision evaluation framework is presented in chapter 3. The purpose of the framework is explained, and the steps in applying the framework are reviewed in detail. In addition, the expected outcomes of the framework application are described at the end of the chapter.

The fourth chapter presents the CTA case study. An overview of the current supervision situation is presented first. Following that, a description of Route 20 will be given, and then a summary of the field work and data analysis as part of the problem identification process. The proposed supervision strategy to counteract the identified problems will then be presented along with the simulation results. Finally, a field experiment involving the CTA’s own Real-Time Computer Aided Dispatch and Automatic Vehicle Location pilot project will be described. This pilot will operate as the CTA’s first foray into real time AVL control for its bus system and allows the research to test the capabilities of the pilot in aiding bus supervisors during the experiment.

The fifth chapter presents the MBTA case study and how the research approach has been applied to the Washington Street Silver Line. A quick overview of the Silver Line will first be presented, followed by a summary of the field work and data analysis as part of the problem identification process. The proposed supervision strategy to counteract the identified problems will then be presented along with the simulation results.

Key findings and conclusions from the case studies and state of the practice reviews will be summarized in the sixth chapter. This leads to recommendations for the CTA regarding their supervision strategies, and deployment in the immediate as well as the not too distant future. Finally, a summary of conclusions will be presented. Newly raised questions and those left unanswered will be posed pointing the way to future research in this area.
2 Background

This chapter will first provide a literature review of the prior research concerning operations control and bus supervision. This will serve to put this research in the context of what has already been examined and how the prior research sets up the research presented here.

This chapter will then define the concept of bus service reliability as it pertains to the research. Issues affecting reliability will be discussed and explored to give the reader a sense of the current situation facing bus operations. Bus service management, the operations division that deals specifically with maintaining and improving service reliability, will then be described in detail.

2.1 Literature Review

Many studies have been conducted in the field of transit service reliability, operations control strategies, and bus supervision. Presented in this literature review will be the key findings of the prior research and how this research will build upon them.

2.1.1 Transit Service Reliability

Abkowitz et al. (1978) conducted a comprehensive study of transit service reliability, focused on the impacts of reliability on transit agencies and their customers. It identified possible causes of unreliability, methods to measure reliability, and strategies that could be employed to improve reliability.
Impacts of Transit Reliability

In reviewing prior studies concerning the relationship between travel behavior and transit service reliability, the authors note how improvements in reliability can have positive effects on the utility of transit relative to other transportation modes. Reducing travel time and especially wait time variability through reliability improvements can increase the frequency of transit use and can also attract new riders.

From the transit agency perspective, Abkowitz et al. (1978) discusses how reliability improvements can reduce capital and operating costs. This is achieved by reducing travel time variability which in turn can reduce the need for excess resources assigned to a route. Revenue increases are also possible as a result of reliability improvements leading to increases in ridership.

Causes of Unreliability

According to the study, unreliability factors can be classified as either environmental or inherent. Later in this chapter Table 2-4 in section 2.2.3 summarizes most of these factors and then goes on to describe them in detail. In general, traffic and demand variability are noted to be significant causes of unreliability. Traffic signals and traffic flow patterns contribute to travel time variability while variations in demand can cause variable dwell times as well as total travel times.

The study goes on to state that initial deviations from the timetable, either at the terminal or mid-route will propagate downstream. These propagations tend to create unbalanced passenger loads and contribute to further unreliability downstream.

Measuring Unreliability

Abkowitz et al. (1978) reviewed prior research into measuring transit service unreliability and described several weaknesses with these measures. The authors found that many of
the measures did not capture unreliability from the perspective of the passenger. Measures were tied to schedule adherence so ineffective schedules could cause biased measures. Finally, data collection methods failed to account for time-of-day and seasonal variations in demand and in the operating environment.

After reviewing prior studies, the authors developed a set of measures that would address these weaknesses. These measures could help identify reliability problems and assist in selecting strategies that could improve reliability.

The measures suggested by the authors involve finding the mean, and coefficient of variation of the following service attributes:

- Travel time distribution
- Schedule adherence
- Headway distribution

Seasonality and time of day variations should be controlled for when making comparisons.

**Improving reliability**

Several methods are outlined in the study for improving service reliability. The methods were classified as priority, control, or operational strategies.

Priority strategies generally involve infrastructure changes such as a dedicated travel lane or signal priority. The authors cite prior studies that indicate that priority strategies can reduce mean travel times by mitigating the environmental influences on reliability.

Control strategies are employed in real-time to improve reliability. These strategies, which will be described in detail in section 2.3.1, typically involve holding or expressing buses in one fashion or another in order to restore service reliability. One of the major
components in utilizing control strategies is the need to monitor service. Service monitoring, including information, communication, and personnel requirements, is described in section 2.3.2

In addition to corrective control strategies, the study describes how operational strategies can improve reliability through prevention. Schedule improvements can reduce the risk of service unreliability by giving operators sufficient time to complete trips and begin their following trips on time. Likewise, improvements in fleet and labor management can reduce the risk of unreliability by lessening the chance of a run being held-in or a bus breaking down mid-trip.

Future research suggestions

The study by Abkowitz et al. (1978) suggests many points for future research. Relevant to this thesis are studies testing the suggested control strategies and evaluating their effects. This thesis will cover both of these areas in detail.

2.1.2 Analysis of Transit Service Reliability

With the advent of automatic data collection, the methods to analyze transit service reliability have become much more powerful. Large databases that archive automatic vehicle location (AVL) and automatic passenger counter (APC) data now allow research to tap into a wealth of data in analyzing transit service reliability. However, even with large amounts of data available, a process to utilize this data must be clearly defined to be able to conduct a meaningful analysis.

Cham (2006) developed a framework detailing the application of automatic data collection to the analysis of service reliability. This framework first outlines relevant metrics to measure the state of unreliability. Second, the framework uses these metrics to identify the causes of unreliability, and then finally, proposes possible corrections to improve service reliability. Cham applies this framework to the MBTA’s Silver Line.
Cham, after citing Abkowitz et al. (1978), identified three major measurements that can be used to capture service reliability conditions:

- Schedule adherence
- Headway adherence (regularity)
- Running time distribution

Due to the automatic data collection available on the MBTA Silver Line, Cham was able to apply these measures over a 3 week period in September, 2004. The main finding was that the Silver Line suffered large headway variations leading to bus bunching and headway gaps in turn leading to excess waiting time for passengers. Variable running times throughout the day, especially along portions of the route where buses did not have preferential lanes, were shown to be partially responsible for uneven headways. The main cause of unreliability however was found to be at the terminals where departure headways were quite irregular. Cham’s analysis demonstrated a clear correlation between terminal departures and downstream performance. Those trips that left the terminal with the scheduled headway had a much greater chance of keeping that headway downstream than trips that left either bunched or gapped.

With her analysis showing irregular terminal departures and running time variability as the main causes of unreliability, Cham concludes that a combination of improved terminal supervision, conditional signal priority, and a higher level of priority on the right of way would help to improve service reliability on the Silver Line.

By using the large amount of automatically collected data available, Cham was able to develop a framework that measured service unreliability, identified probable causes of unreliability, and suggested changes that could improve reliability. This thesis will build on Cham’s work by extending this framework and applying it to the CTA’s Route 20, and then examining the effectiveness of supervision in improving reliability for both Route 20 and the Silver Line.
2.1.3 Operations Control

Much research has been conducted on the topic of operations control strategies. As described in the previous section, operations control strategies are a set of corrective actions that are utilized in real time in order to restore and maintain service reliability.

**Holding**

Turnquist (1981) examines vehicle holding strategies that can improve transit service reliability. In this study, schedule-based holding for low frequency routes and headway-based holding for high frequency routes are treated as two different cases. Turnquist notes that on low frequency routes, schedule adherence is very important because most passengers attempt to arrive at their bus stops shortly before the scheduled arrival of the bus. On high frequency routes, passengers generally arrive randomly without regard to the schedule and therefore headway regularity is most important.

With regard to headway-based holding, Turnquist cites Welding (1957) for the following widely used average waiting time equation:

\[
E(W) = \frac{h}{2} [1 + \text{cov}^2(h)]
\]

(2.1)

where \( E(W) \) is the expected wait time, \( h \) is the expected headway, and \( \text{cov}(h) \) is the coefficient of variation of headway. By regulating headways through holding, the variability of headways can be reduced leading to lower average waiting times.

Two types of headway-based holding are identified by Turnquist (1981): Single-headway holding and "Prefol" holding. The single-headway strategy requires only the knowledge of the headway of the vehicle to be held. If the headway is short, the vehicle is held to a minimum headway at the control point. Turnquist notes that this strategy is most
effective when headways are strongly correlated. In other words, single-headway holding works best when bus bunching exists with short headways followed by large headways. By holding the second bus, the bunch will be broken up and the following long headway will be reduced, thus reducing headway variability more than if the bus bunch consisted of three (or more) buses.

The Prefol strategy is thus named because it holds buses to split headway differences between the preceding headway and the following headway for each vehicle. Note that this strategy requires information on the following headway of a bus, information that traditionally has not been readily available. Turnquist (1981) notes that the Prefol strategy is more effective in regulating headways than the single-headway strategy but loses its advantage as headways become more strongly correlated.

Control Point Location

In another study, Turnquist and Blume (1980) discuss the importance of the control point location for headway-based holding. They also discuss the implications of holding when headways are perfectly correlated and when they are statistically independent of each other.

Turnquist and Blume state that "it is wise to control a route at a point where relatively few people are on the vehicle and relatively many are waiting to board at subsequent stops" in order to maximize total benefits. This means that for most routes, the control point should be as close to the departure terminal as possible. Headway variation will be lowest just past the control point but will tend to increase further downstream.

With regard to headway correlation, Turnquist and Blume show that holding to a minimum headway is more beneficial if short headways are always followed by long headways, than if headways are independent of each other. When headways are independent, this single-headway holding strategy becomes less effective because a short headway does not necessarily imply a large following headway. This conclusion has
strong implications for this research. Now that transit agencies such as the CTA are starting to have real-time vehicle location information, selective holding strategies can be employed where only those vehicles with long following headways are held. Real-time vehicle location information allows the Prefol strategy described earlier to be utilized. The case studies in chapters 4 and 5 of this thesis will describe the use and benefits of this strategy in detail.

2.1.4 Bus Supervision

Levinson (1991) completed a comprehensive synthesis of bus supervision practices at 20 U.S. and Canadian transit systems. This synthesis surveyed existing supervisory practices, identified impediments to transit service reliability and bus supervision, and suggests ways to overcome these impediments. Key factors that contribute to reliable bus service are identified. Levinson also goes on to describe the role of technology in bus supervision and control.

Key Factors for Reliable Bus Service

Levinson (1991) identifies four main factors that contribute to reliable bus service:

- Realistic routes and schedules
- Adequate maintenance
- Sound personnel policy
- Effective supervision

Schedules must be realistic if operators are to be able to adhere to them. Schedules that are too fast or too slow will result in poor adherence and possibly bus bunching and uneven passenger loads. Route structures must also be realistic for operators to adhere to the schedule. Routes that are too long or heavily congested will compromise schedule adherence.
Maintenance of vehicles and other equipment is important in order to maximize the mean distance between failures. It is also important to be able to maximize the number of buses that can be deployed on any given day. As will be discussed in section 2.2, poor maintenance can lead to runs being held-in and buses breaking down on the street causing severe service reliability problems.

As Levinson notes, sound personnel policies are important to keep absenteeism down and morale high among operators, supervisors, and other transit personnel. By encouraging team building efforts and promoting a “people serving people” concept, transit agencies will be in a better position to provide reliable bus service.

Once realistic schedules and routes are in place, maintenance is taken care of, and personnel policies are fine tuned, supervision will have a greater chance of being effective in keeping bus service reliable. Levinson finds that for supervisors to be most effective, “prompt and informed decisions must be made when emergencies or service problems occur. A fast exchange of information is essential to reduce response times. Communication and information technology provide the means for this rapid communication” (Levinson, 1991).

Impediments to Supervision

In the survey of transit systems, Levinson (1991) identified several impediments to supervision as reported by the transit agencies. Most often cited as a problem was the lack of financial resources. More specifically, the lack of resources led to maintenance problems, and absenteeism, complicating the task for supervisors in the field. Some transit systems reported that too many of their routes were either too long or poorly scheduled, leading to reliability problems and the inability to supervise these routes effectively.

Poor equipment maintenance was reported to take an extra toll on reliability. Not only did equipment such as fare boxes, mirrors, or the vehicle itself break down, but
supervisors had to take care of these problems in the field, diverting them from their primary task of maintaining service reliability.

Financial resource constraints affected the supervision staff as well. Inadequate communications was cited as inhibiting supervisors from responding in a timely manner and taking appropriate actions. The inability to have information on the entire route or network in real-time also hampered supervision efforts. Finally, several transit agencies cited a lack of personnel as an impediment to service reliability.

**Technology and Management as Methods to Improve Supervision**

The Southern California Rapid Transit District (SCRTD) (now known as LAMTA) as surveyed by Levinson (1991) cites several methods that could improve supervision:

- Schedule fast travel times and give operators more recovery time.
- Break long lines (routes) into segments to avoid accumulating headway problems.
- Minimize diversion of supervisors to other activities. Supervisors should focus on establishing detours, adjusting schedules, and replacing breakdowns.
- Improve management and “team building” to reduce absenteeism and excessive overtime due to “no shows”.

These suggestions address the main factors influencing reliability by reducing maintenance efforts by supervisors, improving personnel policies, and creating realistic schedules and routes.

In addition to improving on current practices, transit agencies are also looking to technology to help improve bus service reliability. Levinson (1991) cites automatic vehicle location (AVL) and automatic passenger counting (APC) systems that can be of aid to transit agencies and their supervisors.
The Ottawa-Carleton Regional Transit Commission (OC Transpo) experience with APC is documented by Levinson. After being installed in 1975, OC Transpo was able to utilize the new APC system to log and archive vehicle and passenger movements. This then gave OC Transpo the ability to produce reports on all of its APC equipped vehicles and analyze its routes looking for reliability, or other operational problems. Levinson states that APC systems are useful to support planning and for monitoring system performance. Recurring reliability problems can be identified and corrective actions can be taken to alleviate them.

With regard to AVL systems, Levinson examined the Toronto Transit Commission and their use of real-time AVL. Vehicles network wide communicated with inspectors at one of ten divisional control centers. The radio communications system allowed vehicles to be polled on their location about every 10 seconds. With this kind of monitoring, inspectors were able to correct scheduling and vehicle location problems by communicating directly with the operators via radio. The inspectors were also able to communicate with passengers to resolve fare disputes for example, or listen in on the vehicle to resolve emergencies. (This system however has since been retired due to its lack of effectiveness).

Summary

Levinson’s (1991) synthesis provided a comprehensive look at the practice of bus supervision, impediments facing supervisors and service reliability, and methods and technologies that can address these impediments. This thesis will build on Levinson’s work by examining how technology and management methods can improve service reliability at the CTA and MBTA but will also examine how deployment strategies of supervisory staff contribute to effective service management and improved reliability.
2.1.5 Communications and Information for Bus Supervision

Barker (2002) studied the Chicago Transit Authority’s communication and information sharing infrastructure. Barker focused on evaluating how communications constraints affect the availability of information to service managers and eventually bus service reliability.

Barker’s main findings demonstrated how the CTA’s current radio system lacks the capacity and structure to be able to effectively manage small delays before they become big ones. He notes that “a delay cannot be addressed until it becomes a significant problem” due to the fact that small delays are never reported over the air. Only when delays exceed 10 minutes do they become candidates for being broadcast but his study shows that this can take up to another 15 minutes to report over the air, rendering the information almost useless to supervisors. Barker goes on to note that the lack of radio capacity inhibits field supervisors from sharing their own knowledge of delays on the route with central control or their peers on the street, further limiting the amount of information supervisors have. The conclusion Barker draws is that often the best option that supervisors end up having is to do nothing when faced with a service gap. This lack of action has the benefit of having “the least appealing worst-case scenario”, which is the situation remaining as-is. Supervisors acting on a service gap with no information on what actions other supervisors may be taking or where other buses are, risk making the situation much worse. For example, if a supervisor expresses a bus expecting a follower close behind but the follower was short turned by a supervisor upstream, then collectively the situation is now far worse than either supervisor could have predicted (Barker, 2002).

2.1.6 Pre-planning for Service Disruptions

Moore (2002) conducted a study to develop a process to improve transit service management during disruptions. The study focused on the pre-planning necessary for service management to be able to respond effectively to disruptions.
Moore finds that pre-planning for disruptions gives transit agencies access to the ideal responses. Static information, such as the load profile or operations plan allows service managers the ability to pick out the best disruption response given a set of pre-defined options. Dynamic information such as the current loading conditions and bus locations further enhances the decision making process.

Communications and information gaps are shown in the study to be factors limiting service disruption response. Communication constraints were found to slow down the information sharing process, leading to slow responses to disruptions. This resulted in fewer service restoration options being available due to the delayed response, and greater negative passenger impacts.

2.1.7 Simulation for the Evaluation of Control Strategies

Much of the prior research has evaluated operation control strategies through the use of theoretical models, or experiments that have utilized manually collected data. Moses (2005) attempted to evaluate these strategies through the development and application of a simulation model. Inputs included automatic vehicle location (AVL) data and automatic passenger counter (APC) data. This simulation model, created in MATLAB, was designed to recreate observed operating conditions from the input data, and then predict the effects of various operations control strategies.

Unfortunately, Moses was unable to validate the model against real operating conditions. Simulated headway variances and travel time variances were statistically significantly different than the observed conditions at multiple timepoints. This was attributed to complex interactions between vehicle travel times, dwell times, and human behavior that have not yet been modeled successfully. The Ashland route characteristics – a long, high frequency route – were also cited as creating a “worst case” in terms of the difficulty of the simulator replicating actual conditions.
This thesis will attempt to use the simulation approach Moses described to evaluate the effectiveness of supervision and operations control. The simulator will focus on only one hour, and one direction of the route however in order to minimize the complexity Moses found to be difficult to model.

2.1.8 Operations Control and Bus Supervision: Tri-Met Case Study

Tri-Met, the transit provider in the Portland, Oregon metropolitan area has recently implemented an automated Bus Dispatching System (BDS). This system incorporates AVL and APC technology combined with real-time schedule adherence information that is communicated to the operator and dispatchers.

Strathman et al. (2001) conducted a study utilizing the BDS system in an attempt to improve reliability on a number of routes leaving downtown Portland during the PM peak hour. This study involved one dispatcher monitoring these routes during their inbound trip for schedule adherence. If the dispatcher anticipated that a run would be late on its outbound trip, a field supervisor was notified so that Turnquist’s (1982) “Prefol” holding strategy could be implemented. Other available operations control strategies included short turning and “switching” where the dispatcher would substitute a tripper run for a regular service bus, or vice versa, in order to maintain headway regularity.

The results of the study showed that headway variances declined 3.8% overall and 15.8% at the control point. Neither decline however was found to be statistically significant at the 0.05 level. Headway variance was found to be lowest at the control point and increased at every timepoint downstream. Most striking was that the effects of headway control at the terminal were concentrated at the first three timepoints.

Although the study’s effects on headways were mixed, passenger load variance was shown to decrease by 16%. The authors attribute this to the more regular departure headways and conclude that their analysis “indicates that small improvements in service
regularity can potentially generate more substantial improvements in passenger load maintenance.”

2.1.9 Summary of Literature Review

This literature review has shown that there has been a great deal of research into the topics of transit service reliability, operations control strategies, and bus supervision.

Abkowitz et al. (1978) documented several of the environmental and inherent causes of unreliability, methods to measure unreliability, and the impacts of reliability on traveler behavior.

Turnquist (1981) presented an analysis indicating the benefits of headway-based holding for high frequency routes on service reliability. An important conclusion that ties into this thesis relates to the “Prefol” strategy of holding buses to even out headways. This strategy requires information on the following headway – information that usually requires a real-time AVL system. The strategy however can be more effective than a single-headway holding strategy which only requires information on the preceding headway.

Turnquist and Blume (1980) demonstrated the effects of the control point location on the benefits of headway-based holding. The authors found that it is important to locate the control point as early as possible on the route. This way, many passengers who are waiting to board downstream will benefit while few passengers will be on board the held bus and inconvenienced.

Levinson (1991) surveyed several North American transit agencies about their supervision practices. The author finds that there are four main inherent factors that contribute to service reliability: realistic routes and schedules, adequate maintenance, sound personnel policies, and effective supervision. For supervisors to be effective, Levinson notes that they need an efficient communications system that allows a fast
exchange of information for timely and appropriate responses to service disruptions. Technologies such as real-time AVL and APC systems are cited as possible solutions.

This thesis will build from this prior research by attempting to define more effective bus supervision deployment strategies for the CTA given their evolving real-time AVL system and existing personnel and communications capabilities. The operations control strategies described by Turnquist and Blume will be applied in chapters 4 and 5 to examine their effectiveness on service reliability. Their supervisory resource requirements in terms of communications, information, and personnel will also be examined.

The next section will describe the key aspects of bus service reliability from planning to operations. The following section will then review the role of bus service management, the operations control toolbox, and the resources necessary for supervisors to be most effective.

2.2 Bus Service Reliability

At the core of bus service reliability is the notion of how customers and transit agencies perceive service delivery. Customers want to be able to count on transit service time and time again. They want predictable wait times as well as travel times that are consistent from day to day. Transit agencies also want the same thing for their customers. More reliable service means customers are being offered higher service quality, and agency resources are being utilized more effectively.

As long as service delivery perceptions fall in line with expectations, transit agencies and their customers can agree that bus service is reliable. If service expectations are not being met, then service could be classified as being unreliable. Headways may be uneven – leading to unpredictable waiting times – or travel times may be inconsistent. When
trying to maximize the benefits of public transportation, it is clear that making service reliability an underlying goal is in the best interest of transit agencies and their customers.

To help identify shortcomings in service reliability, transit agencies need to define their own internal metrics that will reflect service conditions. These metrics can then be used to highlight the most pressing improvements needed, such as correcting late terminal departures or decreasing operator absenteeism, as well as the methods that can be used to address them.

In order to achieve reliable bus service, transit agencies must first begin planning for it well in advance of their buses actually operating on the streets. This process, as shown in Figure 2-1, requires a coordinated effort from many departments within a transit agency. Service planners and schedulers need to develop operating plans with realistic frequencies and running times that meet their customer’s expectations. Resource planners, service planners, and garages will have to communicate effectively so that enough buses are in the fleet to meet service demands. At the garage level, fleet maintenance is essential to keeping the fleet operable and street ready. Garages have the added responsibility of making sure that there are enough operators to fill the service demands prescribed by the planners. Should all of these requirements be met, bus service will be in an ideal position to achieve maximum reliability on the street. Bus supervisors can then focus on real-time issues such as traffic, weather, and accidents to maintain service reliability.

Unfortunately, bus operations departments in the real world do not have the luxury of being perfectly set up to run reliable service. Budget realities limit the resources available to planners and garage managers meaning that they must prioritize resource allocation to gain the maximum service reliability benefits. In the following subsections, the planning process as it pertains to operations, as well as the activities that take place at the bus garages will be described to paint a clearer picture of these limitations and how they affect bus service reliability.
2.2.1 Planning for Service Reliability

To lay the groundwork for reliable service delivery, transit agencies can set their service standards (expectations) to reflect what their customers expect. These standards then serve as goals and objectives during the operations planning process.
For example, the MBTA 2004 Service Delivery Policy outlines a minimum frequency standard for all of its bus routes as shown in Table 2-1.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Weekday Time Periods</th>
<th>Minimum Frequency*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bus</strong> Local/Community Rts.</td>
<td>AM &amp; PM Peak</td>
<td>30-minute headway</td>
</tr>
<tr>
<td></td>
<td>All Other Periods</td>
<td>60-minute headway</td>
</tr>
<tr>
<td></td>
<td>(Mid-day policy objective of 30-minute headway in high density areas)</td>
<td></td>
</tr>
<tr>
<td>Saturday &amp; Sunday – all day</td>
<td></td>
<td>60-minute headway</td>
</tr>
<tr>
<td><strong>Express/Commuter Rts.</strong></td>
<td>AM Peak</td>
<td>3 trips in the peak direction</td>
</tr>
<tr>
<td></td>
<td>PM Peak</td>
<td>3 trips in the peak direction</td>
</tr>
<tr>
<td><strong>Key Routes</strong></td>
<td>AM &amp; PM Peak</td>
<td>10-minute headway</td>
</tr>
<tr>
<td></td>
<td>Early AM &amp; Midday Bas/ School</td>
<td>15-minute headway</td>
</tr>
<tr>
<td></td>
<td>Evening &amp; Late Evening</td>
<td>20-minute headway</td>
</tr>
<tr>
<td></td>
<td>Saturday – all day</td>
<td>20-minute headway</td>
</tr>
<tr>
<td></td>
<td>Sunday – all day</td>
<td>20-minute headway</td>
</tr>
<tr>
<td><strong>Light Rail/Heavy Rail</strong></td>
<td>AM &amp; PM Peak Periods</td>
<td>10-minute headway</td>
</tr>
<tr>
<td></td>
<td>All Other Periods</td>
<td>15-minute headway</td>
</tr>
<tr>
<td></td>
<td>Saturday &amp; Sunday – all day</td>
<td>15-minute headway</td>
</tr>
</tbody>
</table>

The MBTA then goes further and establishes service standards for reliability as shown in Table 2-2.

<table>
<thead>
<tr>
<th>Trip Test</th>
<th>Beginning of Route</th>
<th>Mid-Route Time Point(s)*</th>
<th>End of Route</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scheduled Departure Trips</strong></td>
<td>Start 0 minutes early to 3 minutes late</td>
<td>Depart 0 minutes early to 7 minutes late</td>
<td>Arrive 3 minutes early to 5 minutes late</td>
</tr>
<tr>
<td>(Headways &lt;10 minutes):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Walk-up Trips</strong></td>
<td>Start within 25% of scheduled headway</td>
<td>Leave within 50% of scheduled headway</td>
<td>Running time</td>
</tr>
<tr>
<td>(Headways &lt;10 minutes):</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Route Test | For any given bus route to be in compliance with the Schedule Adherence Standard, 75% of all trips on must adhere to the above measures over the entire service day. |

*For Schedule Adherence, mid-route time points will be used only for routes on which the on-time performance data has been collected using CAD/AVL equipment.

The CTA has also established its own service standards for recommended frequency for all of its bus routes as shown in Table 2-3. These standards are set to provide enough capacity to serve the current demand. Although the CTA has no official service standard for reliability, policies and programs exist to discourage bus operators from running early and to help them recover from running late.
Once the service standards have been set, it is up to the planning and scheduling department to craft an operations plan that effectively utilizes agency resources to meet the goals and objectives within the service standards. Route characteristics such as expected running time, running time variability, and ridership are folded into the planning process to produce an operations plan for each route. From this, the actual cycle time,
including recovery time, is calculated and an appropriate number of buses and operators are assigned to the route in order to meet the service standards.

It is during the planning process that the transit agency is able to take its first shot at establishing reliable service. The operations plan that results must be robust enough to allow service to run reliably given real world operating conditions. Physical features of the road network (i.e. width and number of lanes), traffic conditions (i.e. variability, traffic lights), ridership patterns, and other factors must be properly taken into account when formulating the operations plan.

Some of the tools available to the planning department that can help improve service reliability include schedule adjustments (running times and recovery times), and adding extra service (spare buses and operators). Placing idle buses and operators on a route to serve as “gap buses” in the event of a service disruption is rarer and not only is it very expensive, but it may be impossible if the equipment spare ratios are too low. If operators are constantly running late and unable to make their time points, scheduled running times may be increased, or more recovery time added in order to increase service reliability. This too can be expensive if more buses and operators are necessary to maintain the minimum frequency requirements.

2.2.2 Service Reliability at the Garage Level

Once the operations plan has been approved, it will be up to the bus operations division to see the plan through.

Each bus route plan consists of several pieces of work that are assigned to bus garages. The schedule, number of hours, and amount of work all depend of the specific operations plan for the route. Operators at each garage then bid on the work in what is usually a quarterly, seniority-based “pick” cycle. These cycles allow operators to decide which route(s) they want to work, the hours they are on duty, and their days off. The pick is designed to ensure that all pieces of work get covered by an operator. The higher the
operator's seniority, the better chance they have of getting their preferred routes and work days. In general, full-time operators will have 40 (or more) hours of work, and part-time workers less.

Since each piece of work is covered by only one operator, the reliability of the operations plan is vulnerable to absenteeism. An operator calling in sick or unexpectedly missing work for any reason leaves this work open while they are absent. The garage will attempt to cover the missing operator's work by assigning it to an extra-board operator or by calling up another operator to work their regular day off. This is an example of another line of defense in maintaining service reliability on the street. If the work cannot be filled, other already assigned operators may be reassigned to cover it if it is deemed important, leaving "less important" work to be dropped. At the CTA, this is referred to as a "10-52, personnel shortage – run held in". Every run that is held in represents a missing bus to customers along the entire route and it will be up to the last line of defense – bus supervisors – to manage this problem in real-time and keep service as reliable as possible.

Operating reliable bus service depends not only on operator availability, but also on bus availability. A transit agency's maintenance effort must keep enough buses in operable condition to meet peak pull-out requirements every day. Critical items such as headlights, brakes, windshield wipers, doors, and wheelchair lifts must be in working order before buses are allowed to hit the streets. If any critical item fails, the bus is sidelined even before pulling out and must be replaced by a spare, if available, to be able to make its scheduled trips for the day. With budget limitations straining transit agency resources, maintenance continues to be hard pressed to check and repair the entire fleet every night. Problems may go unnoticed right up until the morning pull-out check forcing buses into the repair bay at the last minute.

It is clear that even if there are enough operators and buses to cover the day's work, service reliability problems can still arise before they begin their runs. A last minute wheelchair lift or door problem will force the operator to find a new bus, a move that will
potentially put him well behind schedule. If there are no more buses available due to maintenance deficiencies, then the run may even be held-in. Garages with only one or two pull out lanes are especially vulnerable to maintenance delays. Operators at the CTA are required to cycle their wheelchair lifts and perform other checks before leaving the garage. With literally hundreds of buses pulling out of the garage within a short amount of time in the peak periods, one defective bus can lead to long delays for the buses behind it. Other issues such as operators arriving late to work, or taking too much time to pull out will also be detrimental to service reliability.

Once the buses begin their scheduled operations on the street, the internal policies and processes described here interact with external factors to influence the reliability of on street bus service. The planning and scheduling department has done its part to set up the operations department with the frequencies, run times, and recovery times it thinks necessary to give the best possible chance of running reliable bus service (to the extent that the budget will allow). The garages have done their part to fill as much of the work as possible with the available resources. Now, service reliability will be at the mercy of the lingering effects of internal factors, external factors, and the effectiveness of the bus service management (BSM) staff.

2.2.3 Service reliability on the street

Several factors exist that can cause service to become unreliable. While many of these factors are external and beyond the transit agency’s control, BSM must still deal with them to provide the most reliable service possible. Internal causes of unreliability also exist and add to the work load of BSM. Table 2-4 lists some of the common causes of service unreliability.
Table 2-4 Causes of service unreliability

<table>
<thead>
<tr>
<th>External Factors</th>
<th>Internal Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Unusual traffic conditions</td>
<td>• Equipment failures (engine, wheelchair lift, fare box, etc...)</td>
</tr>
<tr>
<td>• Inclement weather</td>
<td>• Runs held-in at the garage</td>
</tr>
<tr>
<td>• Special events</td>
<td>• Late garage pull-outs</td>
</tr>
<tr>
<td>• Train crossings</td>
<td>• Late/missing on-street reliefs</td>
</tr>
<tr>
<td>• Unusually high passenger demand</td>
<td>• Early/late terminal departures</td>
</tr>
<tr>
<td>• Road closures</td>
<td>• Variable operator behavior (fast and slow operators)</td>
</tr>
<tr>
<td>• Construction</td>
<td></td>
</tr>
<tr>
<td>• Police activity</td>
<td></td>
</tr>
</tbody>
</table>

With regard to the external factors, many of these should be known in advance and, with enough preparation, service impacts can be mitigated. Special events such as a sporting event or concert tend to draw large crowds over short periods of time. The spike in ridership can easily overwhelm normal available capacity and disrupt the service of nearby transit lines. However, special events are usually scheduled well in advance and transit agencies can thus be well prepared. More capacity can be added to take care of the crowds (depending on agency resources) while supervisors can be assigned to the event to assist in dispatching the buses.

Construction projects, road closures, parades, and other similar events also require the attention of BSM. These types of events generally will require buses to be rerouted around the affected streets and to be given a modified schedule to compensate for the new routing. Communication with the city or local department of transportation is the key to preparing for these types of events. Once BSM knows a reroute will be necessary, the new route is drawn up and distributed to the operators via the garage. In addition, supervisors can be put in place in order to direct operators on the street.

Some environmental causes of service unreliability, however, are not so easy to plan for. Traffic conditions can change and bus accidents can occur without warning. Police activity may shut down a street or intersection requiring reroutes. Rail service may be
suspended for some reason and suddenly demand for buses will spike. All of these events have the potential to affect service and cause it to deviate from the operations plan in a matter of minutes. It is then the task of BSM to spring into action and restore normal service as quickly as possible. The actions BSM can take and the resources necessary to do so will be outlined in the next section.

Internal factors can also lead to service unreliability. Inferior capital equipment such as poorly designed vehicles and fare boxes have been known to cause maintenance and operational nightmares. The MBTA recently experienced this with their new Automatic Fare Collection system on the Washington Street Silver Line. Numerous design flaws with the fare boxes coupled with their increased operational complexity drove travel times and dwell times upward.

Vehicle maintenance issues can also contribute to service unreliability. If the maintenance department of a transit agency is not able to keep up with its work load, for example, due to funding problems, there may not be enough buses available to meet peak requirements and consequently runs will be held in. Poorly maintained vehicles that are on the street may become disabled ending their runs prematurely. Either way, every run that is not on the street represents a gap in service to BSM and ultimately to the customers on the street waiting for service.

Operator discipline plays a large role in the delivery of reliable bus service. Absenteeism, tardiness, and variable driving behavior are all detrimental to service quality. Excessive absenteeism will lead to runs being held-in when there are not enough operators to cover all runs. On-street reliefs, where an operator will relieve another of their duty and take over mid-route, may be compromised as well, and this will cause serious delays in service. Operators who pull out of the garage late risk starting their first trip late or missing it altogether. It will then be up to BSM to put them in place (deadhead back on schedule) and manage any gaps in service. Finally, differences in driving habits among operators can cause service to be less than ideal. Fast operators coupled with inexperienced or slow operators on the same route will inevitably produce
gaps and bunches. On high frequency routes, terminal departure discipline is key: prior research has shown that operators leaving bunched from a terminal have little chance to achieve the scheduled headway downstream while operators that leave with a large headway will only lose ground as they move along the route. While in the end it is up to the operators to control their own behavior, agency policies and management style strongly influence working conditions and morale.

2.3 Bus Service Management

The internal and external factors described in the previous subsection will continue to affect service reliability if left unchecked. Barker (2002) outlines the following common service disruptions:

- Bus early
- Bus delay (short headway route)
- Bus delay (long headway route)
- Crush load (one bus, not delayed)
- Mechanical problem (minor - bus movable)
- Mechanical problem (serious - bus movable without passengers)
- Mechanical problem (major - bus immobilized)
- Emergency / Security / Fare Dispute
- Accident
- Operator Misses Relief
- Blockage
- Bus Standing / Service Gap
- Unfilled Run
- Unplanned Bus Bridge
- Congestion / Weather / Route-wide Crowding
- Late Pull-Out
Ultimately, these disruptions can lead to:

- Excess passenger waiting times
- Excess passenger travel times
- Crowded vehicles
- Overtime pay for delayed operators

Fortunately, the factors causing service unreliability can be checked on the street. A team of supervisors, control center dispatchers, and maintenance vehicles that make up the bus service management team are deployed throughout the service area to help mitigate service disruptions and to keep service as reliable as possible. In *Theory and Practice in Service Management* (Froloff et al., 1994), bus service management (BSM) is broadly defined by the RATP (Paris, France) as the department responsible for overseeing transit operations and taking the necessary actions to bring these operations in line with the service quality objectives of the transit agency. In other words, BSM serves to manage bus operations in real-time to ensure that the service being delivered on the street resembles as closely as possible the prescribed operations plan. The more often this occurs, the more reliable the service.

The following subsections describe the tools and the resources necessary for BSM to do their job.

2.3.1 Operations Control Toolbox

Bus supervisors, in the control center or in the field, have a variety of tools available to them in the form of service restoration actions that can be employed to maintain, or restore, reliable service, including:

- Space back
- Express
- Move up
- Short turn
- Fill-in

**Space Back**

Spacing back is the process of slowing down, or holding back, one or more runs ahead of a service gap in order to divide the gap among multiple runs. Spacing back can be done at a terminal or mid-route. Spacing back is most effective when the buses that are being held are empty and when a large number of passengers are waiting to board immediately downstream. That way travel time delays for passengers already on board are minimized while the benefits of lower expected waiting times are conferred on those passengers waiting downstream. By the same token, spacing back is generally not beneficial if buses have already reached the main distribution zone (e.g. the central business district during the AM peak): buses will be full of passengers seeking to alight and will have very few passengers waiting to board downstream.

In order to space back, supervisors first need to know that a service gap exists. Once detected, the location of the service gap must be known so that, combined with the knowledge of the route’s load profile, supervisors can determine if spacing back will be beneficial as discussed in the previous paragraph. If deemed beneficial, supervisors will need to be able to communicate with the bus operators in front of the service gap in order to execute a space back. This can be done in person or wirelessly via radio or digital messaging.

In most transit agencies, supervisors are only aware of service gaps when the gap reaches them. If a hold-in or late pull-out is broadcast over the radio, supervisors should be able to act in front of the gap. However, a congested radio system may limit broadcasts to emergencies only or delay announcements until it is too late to act on them. This leaves supervisors in the dark about service gaps until they notice a missing, or late, run by which time it will be too late to act on as they are now behind the gap. Supervisors can
however radio ahead to another supervisor on the route to take action, as long as there is sufficient communications capacity to do so.

Express

Expressing buses is the process of having a bus allow passengers to alight only or go “out of service” for a short period of time before returning to local service. This service restoration action is meant to close a service gap from behind by affording the expressed bus a shorter travel time. The best time to express a bus is when there is a bus bunch behind a service gap. The first bus from the bunch is expressed into the gap while the second bus remains in local service.

The main advantage of expressing buses is that supervisors can work service gaps from behind. This requires less information and communications than working in front of the gap since the supervisor already knows a gap exists when the bus to be expressed reaches his location.

Expressing buses however has several drawbacks. First, supervisors must be confident that there is a second bus close behind. If not, passengers who have already suffered waiting through the service gap will now have to watch an expressed bus pass them with no other bus in sight. This alone can cause transit agencies to shy away from allowing buses to be expressed. Second, there is no guarantee that an expressed bus can effectively catch up and successfully fill a service gap. Traffic conditions and other factors can make this infeasible. Finally, capacity issues may arise: the bus following the expressed bus will now have to pick up effectively twice as many people as normal and may not have enough capacity to do so.
Move Up

Moving up is the process of having buses depart a terminal earlier than scheduled. This action is meant to divide a service gap among at least two runs when it is known that the preceding run is missing or severely delayed.

For example, buses are scheduled to depart a terminal every 10 minutes beginning at 0700. If it is known that the 0710 run is missing, then moving up runs can divide the service gap.

<table>
<thead>
<tr>
<th>Departure times without moving up</th>
<th>Departure times after moving up</th>
</tr>
</thead>
<tbody>
<tr>
<td>0700</td>
<td>0700</td>
</tr>
<tr>
<td>0720 (Twice the normal headway)</td>
<td>0714 (+6 minutes)</td>
</tr>
<tr>
<td>0730</td>
<td>0727 (+3 minutes)</td>
</tr>
<tr>
<td>0740</td>
<td>0740</td>
</tr>
<tr>
<td>0750</td>
<td>0750</td>
</tr>
</tbody>
</table>

As shown in Table 2-5, the 0720 run now has twice the normal preceding headway and most likely twice the number of passengers to pick up at the terminal and downstream. Besides capacity issues, the increased dwell time due to picking up more passengers will likely cause this run to fall behind downstream and eventually bunch up with the 0730 run.

Using the move up action can mitigate this problem by dividing the service gap over the three following runs. The 0720 run is moved up by six minutes to 0714, and then the 0730 run by three minutes to 0727. This creates one 14-minute headway and two 13-minute headways.

Moving up buses at the terminal requires, above all, the ability to communicate with the operators turning at the terminal. It also requires that the runs to be moved up be at the
terminal before they need to depart. Information about where the following runs are (in this example, the 0720 and 0730 runs) is very helpful but not required in order to optimally space the terminal. Not knowing if these runs will actually be able to turn at the terminal when desired (0714 and 0727 respectively) could lead to suboptimal spacing or even a worse situation than if nothing was done. If the 0730 run was missing too, blindly moving up the 0720 by 6 minutes will lead to a 14 minute gap and a 26 minute gap, as opposed to two 20 minute gaps.

**Short Turn and Fill In**

Short turning and filling in are two ways to reallocate service in order to fill a gap. Short turning involves turning a bus around before it reaches its terminal and having it begin a new trip immediately on the same route but now in the opposite direction. Filling in involves pulling a bus from another nearby route – usually one that intersects or shares a trunk portion – and reassigning it to the route being filled.

Both of these actions can quickly fill a gap but at a great cost to the route/direction where the bus is coming from. Once a bus is chosen to be short turned or interlined, passengers on the reassigned bus must alight and wait for the next bus. Even if there are no passengers on board, reassigning a bus will create a new service gap on the affected route/direction which will then have to be managed.

Given these tradeoffs, short turning and filling in from another route are actions to be used only during the most serious situations. Even when warranted, steps must be taken to ensure that the negative effects on the displaced passengers are minimized. This means making sure that there is enough capacity left on the donor route and that any gaps created by pulling a bus are not too great for downstream passengers.
Resource Needs

Spacing back, expressing, moving up, short turning, and filling in are all very powerful tools for service restoration. Each one can be used independently or in combination to address different kinds of service problems and to maintain service reliability. Each one also requires differing amounts of resources to be effective. Table 2-6 summarizes these properties.

As will be described in the next section, the more robust the information and communications, the more informed choices supervisors can make among service restoration options. In addition, time is of the essence when responding to delays and service gaps since delays get worse over time without intervention, leading to larger service gaps and higher unreliability (Barker, 2002). The faster that bus service management can detect and respond to service gaps, the more reliable bus service will become.
<table>
<thead>
<tr>
<th>Table 2-6 Service restoration resource needs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Action</strong></td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td><strong>Space Back</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Express</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Move Up</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Short Turn</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fill In</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
2.3.2 Resource Needs and Availability

Different types of resources are required for Bus Service Management to maintain and restore bus service reliability effectively. These resources fall into three categories: Information, Communication, and Personnel.

Information

Information is arguably the most important resource to have for a bus supervision team. As shown in Figure 2-2, historical information gives the team the ability to plan ahead and develop strategies for service maintenance and restoration. The team can use the information—be it archived AVL/APC data or supervisor reports—to identify the most common disruptions and to pinpoint the probable causes. A strategy to counter these disruptions can then be developed and implemented. Elements of this strategy could include standard operating procedures that outline which service restoration actions to take, the service problems that will trigger these actions, and where supervisors should be deployed in order to execute these actions. Historical information can then be utilized to analyze the effectiveness of this strategy.
While archived information can help in developing supervision strategies, it is the availability and level of real-time information that determines how effective these strategies will be. When more is known about a route or a network, a greater number of tools becomes available to bus supervision and the use of these tools becomes more effective as shown in Table 2-6.

In its most basic form, real-time information comes from the eyes and ears of the supervisors on the street, personnel in the garage, and from the operators driving the buses. Information relevant to service reliability such as the location of buses, schedule adherence, headways, missing runs, and major incidents is scattered throughout the agency at any given time. Operators know their own location, garage personnel know...
which runs have been held in, and field supervisors are aware of headways as buses pass their location. However, the key for successful bus supervision is to get all of this information in one place and delivered to the people who can act on it in a timely matter – preferably in real-time.

More advanced real-time information systems serve to collect all of this data automatically, and then report it in an easy to read format (such as a dynamically updated map) in a central location. This central location can be in the control center, or it can be on a personal digital assistant (PDA) or laptop in the hands of field supervisors. By using such advanced systems, transit agencies can empower their control center and field supervisors with the information necessary to make better decisions regarding service reliability.

**Communications**

As information starts to become available automatically in real-time, a transit agency’s communication structure will start (or continue) to become the bottleneck in implementing service restoration actions. A reliable, efficient communications system with sufficient capacity will allow for the information sharing necessary to execute appropriate service restoration actions in the field and provide reliable bus service.

Communications does not have to be thought of as only voice communications over radios, or telephones. With the advent of real-time AVL information systems, wireless data transmissions are becoming just as important. Where, in the current system, bus delays, bus locations, and other pieces of relevant information are communicated by voice radio, real-time AVL systems broadcast this information digitally over a wireless network. Even with a digital wireless network, communications capacity and reliability will still be important issues in ensuring that relevant information is transmitted reliably and in a timely manner to the people who can act on it.
**Personnel**

Personnel refer to the field, mobile, and control center supervisors who utilize the information and communications infrastructure to make decisions regarding service restoration and maintenance. These are the people on the front line of bus supervision who monitor service (gathering information), execute service restoration actions as they see fit, and communicate these actions and their observations to their peers in the field and in the control center. Their ability to make the best service restoration decisions depends largely on how much real-time information they have in addition to their experience and training. Their ability to execute these decisions depends on how well they are able to communicate with their peers and with the bus operators. Their ability to be effective in maintaining and restoring service reliability depends on the strategy planning beforehand (service restoration tools and responsibilities given to them, their location, and their knowledge of the route).

Supervisory personnel fall into three main categories: post supervisors, mobile supervisors, and the control center staff. Each type of supervisor has different capabilities in terms of monitoring service on the street and the ability to respond to certain situations.

**Post Supervisors**

Post supervisors are supervisors who man posts located within a transit agency's bus network. Post locations are usually bus terminals or major intersections where the supervisor is able to monitor multiple bus routes passing his location. In the most basic form, a post supervisor is armed with a supervisor’s guide detailing each run passing his location with a run number and arrival time, and a radio to communicate with other supervisors and possibly also with bus operators. By comparing their observations with the supervisor guide, supervisors can quickly determine if a bus is running late or if headways are uneven. They can then choose to act on this information or pass it on to their peers depending on the situation – assuming there is enough communications capacity to do so in a timely manner.
In general, post supervisors are given full discretion in managing their posts meaning that they are able to employ all of the service restoration actions described earlier. Traditionally, the major constraints on the effectiveness of post supervisors are a lack of automatic real-time information and serious capacity constraints on communications. The only information available to them is the information they collect with their eyes and ears, and any information they hear broadcast over the radio (severe delays, accidents, runs held-in, etc.). Communications constraints are typically severe as described earlier in this section, limiting their ability to make sound service restoration decisions, and frequently resulting in the “do-nothing” option being the only one feasible.

Without an automatic real-time information system, the post supervisor only knows where buses are as they pass his location, giving him, at best, historical data on headways and schedule adherence. As discussed earlier, this severely limits his ability to make service restoration decisions. A strong communications network however can partially compensate for a lack of automatic real-time information. If there is enough communications capacity, supervisors can radio to one another their observations at their posts, such as headways, schedule adherence, or any service restoration actions they have taken. Supervisors standing at a post will then have virtually up to the minute information on route conditions at posts upstream and downstream of their location and this will aid in the decision making process.

In addition to service monitoring and service restoration, post supervisors often have to take on other tasks. Repairing defective equipment is a large part of their responsibility as they are usually the first line of defense in taking care of minor problems such as fare box defects, broken mirrors, and the like. Post supervisors also represent the transit agency in the field and often assist customers. Other duties include setting up emergency reroutes, enforcing terminal and right-of-way space, and managing on-street reliefs.
Mobile Supervisors

Mobile supervisors are typically assigned to patrol a small portion of the bus network in a vehicle. Their primary responsibility is to respond to incidents and emergencies as assigned by the control center. While not on assignment, mobile supervisors can monitor and restore service just as a post supervisor would.

When responding to an incident, mobile supervisors become the transit agency's primary incident commander. They are responsible for ensuring the safety of both the operator and the passengers, and making sure that passengers are able to board the next bus to continue on their way. Mobile supervisors must also be able to interface with police and fire authorities as necessary. If a tow or a mobile repair truck is needed at the scene, mobile supervisors will work with the control center on dispatching one.

Control Center

Control Center supervisors are usually referred to as dispatchers and are primarily responsible for coordinating incident and delay responses between operators and field supervisors. Typically, operators will report delays or incidents to the control center so that they can receive assistance or instructions to recover. The dispatchers at the control center can then relay the delay or incident information to field supervisors so that they can respond as instructed.

Being the central nerve system of the supervision team, the control center works best when the dispatchers have accurate and timely information on the entire operations picture, and sufficient communications capacity to be able to coordinate responses among field staff.

2.4 Summary

This chapter has presented a literature review on service reliability, operations control, and bus supervision. Following the literature review, a description of service reliability was given from multiple perspectives. Finally, a detailed description of bus supervision
practice was given, including operations control capabilities and resource needs. The next chapter will present a framework to analyze bus supervision and its effectiveness with respect to bus service reliability.
3 Framework for Analyzing Bus Supervision

This chapter will focus on the development of a framework to analyze service reliability and specifically the contribution of bus supervision towards improving reliability.

3.1 Framework Introduction

The prior research presented in chapter 2 has shown several ways to analyze bus service reliability. It has also shown the theoretical benefits that could be achieved through operations control. Finally, the prior research has covered how bus supervision could be a partial solution to the reliability problem but that there are several impediments to supervisors achieving their full potential, including communications constraints, information sharing problems, and task assignment issues.

To organize this complex topic, a framework for analyzing and improving the effectiveness of bus supervision is proposed. The goal of the framework will be to formalize the process through which bus supervision is assessed and deployed based on available resources. The framework will also aim to aid in resource planning by identifying the most effective deployment strategies. The steps in the proposed framework are:

1) Assessment
2) Development of Strategies
3) Evaluation of Strategies

By applying this framework to the CTA and the MBTA, this research will be able to draw conclusions regarding effective bus supervision deployment strategies to improve bus service reliability.
3.2 Assessment

There are two types of assessment proposed. The first is an assessment of the available supervision resources and its deployment, and the second is the assessment of the bus service reliability problem.

3.2.1 Supervision Resource Assessment

In order to fully understand the capabilities, strengths, and weaknesses of bus supervision, the current level of supervisory resources must first be assessed. As discussed previously, these resources fall under the general categories of information, communications, and personnel. By taking inventory of these resources, a “resource state” can be determined. This resource state will affect the potential effectiveness of bus supervision and its deployment, and can point the way towards worthwhile upgrades. Table 3-1 suggests possible resource levels at a transit agency.

<table>
<thead>
<tr>
<th>Level</th>
<th>Information</th>
<th>Communications</th>
<th>Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No real-time or archived bus location, passenger count, or maintenance information whatsoever.</td>
<td>Dispatchers, supervisors, and operators can only communicate face-to-face.</td>
<td>Few or no dispatchers, supervisors, and support staff.</td>
</tr>
<tr>
<td>1</td>
<td>No real-time information. Archived information based on manual collection.</td>
<td>Radio communication between dispatchers, supervisors, and operators.</td>
<td>Dispatchers and supervisors available for incident response.</td>
</tr>
<tr>
<td>2</td>
<td>No real-time information. Archived information collected automatically.</td>
<td>Radio and text communication between dispatchers, supervisors, and operators.</td>
<td>Dispatchers and supervisors available for incident response AND headway/schedule control.</td>
</tr>
<tr>
<td>3</td>
<td>Automatically collected real-time and archived bus location, passenger count, and maintenance information.</td>
<td>Digital voice and data communications between dispatchers, supervisors, operators, and equipment.</td>
<td>Support staff available for data analysis, supervision strategy development, and implementation.</td>
</tr>
</tbody>
</table>

Four possible resource levels are defined for each category. Level 0 indicates a complete lack of investment in a particular category, severely limiting supervision effectiveness.
In this state, supervisors (if any) do not know where buses are in real-time, or the profile of bus routes in the network, and cannot effectively communicate with operators or one another. This lack of information and communications makes it very hard for a transit agency to conduct even basic incident response, let alone headway or schedule control. Furthermore, the lack of archived information on bus schedules and passenger behavior hinders planners and schedulers in their quest to improve service.

On the other end of the spectrum, a resource level of 3 in each category reflects an advanced stage of investment allowing for, the most effective supervisory function. In this state, supervisors are well equipped with the information and communications infrastructure they need in order to effectively respond to incidents and maintain reliable service. In addition, there is sufficient personnel to handle both functions as well as analyze archived information.

As supervision resources are built up at a transit agency, levels are not necessarily similar across all three categories. Information could be at a “2”, communications at a “1”, and personnel at a “3”. This is important for an agency to know in order for them to identify current resource bottlenecks and possible over-investment. In this example, the hypothetical transit agency with this type of resource state could be over-invested in personnel. The lack of real-time information and digital communications leaves the staff without the resources necessary to maintain reliable service through operations control. On the flip-side of the coin, the same transit agency could be said to be under-invested in information and communications and upgrading these resources would improve bus supervision and service reliability.

3.2.2 Service Reliability Assessment

When attempting to solve any problem, the problem must first be understood before a solution can be developed. This principle holds true for bus service reliability. After conducting an assessment of supervision resources, transit agencies need next to conduct an assessment on their current bus service reliability.
As defined in Chapter 2, bus service reliability is measured through on-time performance (low frequency routes), or headway regularity (high frequency routes). The amount and quality of archived data available will greatly affect the quality of the service reliability assessment. An agency with a fully equipped fleet featuring AVL and APC systems will potentially have a much clearer picture of the reliability problem than an agency relying on manual data collection.

Assessing service reliability is done at two levels: the route level, and the system or network level.

**System Level Assessment**

At the system level, transit agencies can look for unreliability trends that are affecting most, if not all their network. By identifying these trends, a supervision deployment strategy can be developed to counter them and improve reliability. Similarly, in-house procedures such as scheduling or labor policies can be adjusted to counter internal unreliability trends.

When conducting a system level reliability assessment, transit agencies should look for trends that can be addressed with system level strategies. For example, a system-level strategy would be to redeploy personnel or to upgrade resources. Utilizing archived AVL and APC data, several system-wide reliability measures can be tracked including:

- Terminal departure and arrival performance
- Overall on-time performance
- Overall headway consistency
- Missing or "held-in" runs
- Maintenance delays
- Garage pull-out performance
Once these measures have been tabulated, it can be helpful to sort them by time of day (morning peak, afternoon, etc.) and by geographical region. As shown by the example in Table 3-2, this can lead to the development of targeted solutions, such as scheduling improvements for on-time performance, new labor policies for held-in runs, or specific supervision deployments by geographical region and/or time for a host of unreliability problems. Developing supervision deployment strategies based on an unreliability analysis (and available resources) will be further discussed in the next subsection.

<table>
<thead>
<tr>
<th>System-Wide Unreliability Trend</th>
<th>Possible Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late terminal departures or headway variability</td>
<td>Assign supervisors to terminals. Increase recovery times. Give operators schedule/headway information in-vehicle and encourage operators to depart on-time.</td>
</tr>
<tr>
<td>at terminals</td>
<td></td>
</tr>
<tr>
<td>Highly variable travel times</td>
<td>Increase terminal departure performance. Control mid-route through supervision. Adjust running time schedule. Add signal priority and exclusive lanes.</td>
</tr>
<tr>
<td>Frequent &quot;hold-ins&quot;</td>
<td>Address relevant labor and maintenance issues. Assign supervisors at terminals to restore service.</td>
</tr>
</tbody>
</table>

Route Level Assessment

Cham (2006) developed a comprehensive process for route level assessment. The process involves creating a set of measures to characterize the degree of service unreliability, identifying the causes of unreliability, and then selecting appropriate strategies to improve service unreliability (supervisory or otherwise). The next few paragraphs will summarize Cham’s approach to the first two parts of route level reliability assessment. Discussion of selecting appropriate strategies will follow.

a) Characterizing Service Unreliability

To characterize the level of service unreliability, a large amount of data on the route in question must be analyzed. The most important data sources are those that track vehicle and passenger activity. AVL and APC data sources are best since they record detailed
vehicle movements such as stop arrival time, and dwell time which then lead to headway and schedule adherence measures. APC's can also record passenger boarding and alighting counts leading to a picture of bus load variation along the entire route.

Using the AVL and APC data on a specific route, the state of service unreliability can now be characterized. For high frequency routes, the headway adherence at terminals and at mid-route stops can be measured, whereas for low frequency routes, schedule adherence is more important.

The analysis of the AVL and APC data can finally be used to generate performance reports summarizing the service reliability. This can be a report on the percent of trips during a specific time period that adhere to the schedule, or adhere to the headway. Excess passenger waiting times can also be calculated to quantify the effects of unreliability on passenger travel experience.

b) Identifying Causes of Unreliability

With the level of unreliability assessed, the next step is to identify likely causes so that solutions, supervisory or otherwise, can be developed. Cham describes two main causes of unreliability: deviations at terminals, and deviations at other points.

Deviations at terminals were cited as important because this is where service reliability should be at its best. Terminals serve as the “restart” point where prior deviations should be prevented from carrying over to the next trip. Poor terminal performance tends to propagate along the route, making reliability here paramount if the route is going to operate reliably overall.

Several causes of unreliability at terminals were cited by Cham including:

- Lack of available recovery time.
- Adequate recovery time but poor schedule adherence or headway adherence due to operator behavior or lack of supervision.
Deviations at other points along the route will also cause service to become unreliable – again meaning that either buses go off schedule, or their headways become too short or too long. These deviations can occur because of poor terminal departure performance (with the performance propagating down the route), or other factors including irregular passenger demand, inadequate scheduling, operator behavior, or externalities such as traffic and weather conditions.

Some measures that can help identify mid-route deviations are running time and dwell time distributions. If trips have good terminal departure performance but have a widely distributed running time, inadequate scheduling, operator behavior, or other externalities may be to blame. If dwell times are inconsistent from trip to trip, irregular passenger demand may be leading to differing travel times and thus unreliability.

3.3 Development of Strategies

Before supervision is considered, every effort must be made to eliminate internal causes of unreliability. Schedules need to be set so that running time variability is low, and most trips have sufficient recovery time at the terminals. Labor policies need to be defined in such a way that absenteeism is minimized and good operator behavior is encouraged. By doing so, supervisors will not have to fix problems created by the transit agency itself and can focus instead on maintaining reliable service given the myriad of external factors they face (such as accidents, traffic, weather, and passenger demand).

Once the supervisory resources are known, and the system and route level unreliability characteristics and causes identified, a set of supervision strategies can be developed. These strategies will be defined to make the best use of the limited personnel given constraints on information and communication.
In general, supervision deployment, including personnel and responsibilities, can be distributed among the control center, mobile supervisors, and post supervisors. The most effective type of deployment strategy will depend primarily on the supervision resource state.

3.3.1 Distribution of Responsibilities

As mentioned previously, supervisors have many responsibilities. For this study however, supervision responsibilities that are related to service reliability can be broken up into four main tasks:

- Incident detection – initial discovery that an accident, breakdown, or similar “standing vehicle” event has occurred.
- Incident response – coordination of, and response to the incident.
- Service disruption detection – initial discovery of unreliable service through events such as a long headway, late bus, or missing service.
- Service restoration – coordination of, and execution of operation control strategies to restore reliable service.

Depending on the state of information and communication resources as shown in Table 3-1, each task will be the joint or individual responsibility of the control center, mobile supervisors, and post supervisors.

a) *Incident detection and response*

Incident detection and response always begins in the field with the operator who generally reports a problem to his/her supervisor or the control center, however, as information and communication capabilities increase, these tasks will increasingly fall within the realm of the control center as shown in Table 3-3.
Table 3-3 Effects of resource changes on incident detection and response

<table>
<thead>
<tr>
<th>Information State</th>
<th>Communications State 0</th>
<th>Communications State 1</th>
<th>Communications State 2</th>
<th>Communications State 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
</tbody>
</table>

A - Incident detection and response by field supervisors only.
B - Control center receives incident reports from the field and coordinates response.
C - Control center automatically detects incidents and coordinates response.

In the most primitive resource state, field supervisors will be the only ones capable of responding to incidents. Operators lacking any effective communications will be unable to alert control center dispatchers or field supervisors, and will have to rely on passing a post supervisor for assistance, or having a mobile supervisor see them if they are unable to move (or using a personal cell phone to contact someone).

In all other resource states except for full information and communications, bus operators will have a radio available and can notify the control center immediately after an incident occurs. This represents a shift of incident detection responsibility from the field supervisors to the control center. Of course, the bus operator is still the primary incident detector and any delays in reporting the incident (the operator may attempt to first repair the vehicle on their own, for example) can negatively affect service reliability. Once the control center is aware of an incident, dispatchers can coordinate a response as necessary between field supervisors, the operator, and local authorities.

If real-time AVL information is available, and communications are advanced enough, incident detection can become automatic as individual buses stream their “health” information into the control center. Dispatchers would then be immediately notified of the incident location and perhaps the type of incident as well, further improving response times. This type of incident detection represents a complete shift of responsibility into the control center.
It should be noted that across all resources states, it will be the task of the field supervisors to actually respond to an incident. This will be the case whether they detect an incident, or if the control center detects it and coordinates a response.

b) Service disruption detection and service restoration
Service disruptions can occur in two forms, depending on the bus route frequency. If the route has a low frequency, a service disruption is defined as a bus becoming excessively late or early relative to its schedule. For high frequency routes, a service disruption is defined as a headway that is excessively long or short.

Without real-time information or effective communications, field supervisors and operators will be primarily responsible for detecting service disruptions and for restoring service. For low frequency routes, this means that operators will bear the greatest responsibility for keeping their bus on time. If this becomes a problem due to traffic, maintenance, or other circumstances, then field supervisors will become responsible for assisting the operator in returning to schedule. For high frequency routes, neither the operator nor the supervisor will have the information necessary to detect service disruptions, let alone restore service. Headway gap detection requires that the supervisor or operator know the position of consecutive buses, knowledge that is not possible without real-time AVL information. This means that full headway management on high-frequency routes will not be possible until advanced information and communication resources are in place.

For transit agencies with reliable communications, some service disruption detection responsibilities will move into the control center, but the vast majority will remain in the field as before. Service disruptions resulting from hold-ins, incidents, or excessive delays can be reported into the control center from operators or other personnel. This information can then be broadcast to supervisors to give them a chance to act on it before the situation deteriorates further, as opposed to waiting for the problem to reach them first. Even with a dependable communications system, service disruption response still depends heavily on the operator and supervisor reporting hold-ins, incidents, and delays.
in timely manner. Service disruption detection and service restoration are still quite inefficient at this resource state, especially for high frequency routes.

Once real-time AVL information becomes available, complete schedule and headway management becomes possible, and this task will move into the control center. Dispatchers will have the ability to instantly see if service disruptions are forming in low or high frequency routes, and will be able to contact operators with the appropriate service restoration instructions. As information processing technology and communications become stronger, automatic service monitoring may become possible. This will allow dispatchers to focus on the service disruptions and to quickly communicate via text messages to field supervisors and operators. Service restoration instructions can also be communicated to operators through the use of “ring-off” departure bells at terminals, or in-vehicle messages.

3.3.2 Distribution of Personnel

The number and deployment of mobile, post, and control center supervisors will depend greatly on the level of information and communication resources. As discussed in the previous section, different supervision personnel will be able to take on more responsibility as resources increase, while others will see their responsibilities level off or even be reduced. These changes in task assignment will affect the way that supervisors are deployed to take advantage of the increased resource.

a) Low resource state

At the most primitive of resources states, all supervision tasks are done in the field. Establishing a control center at this stage would not be prudent since dispatchers would not have any information on service conditions nor the means to communicate any instruction.

A “low resource state” may not be a reflection of the actual resources available, but may be a temporary state when communications go down, or when communications capacity
is insufficient. Since capacity issues usually arise when most incidents occur – the peak hour period – the “low resource state” could still be considered appropriate.

Without an effective communications system, all incidents and service disruptions will have to be detected and responded to by field personnel. This will require a large number of supervisors just to cover the network to look for incidents and service disruptions. Obviously this is a poor use of an expensive personnel resource and every effort should be made to upgrade communication resources before any more supervisors are hired.

b) Medium resource state

If there are at least reliable radio communications available between operators and supervisors, establishing an effective control center is clearly appropriate. This increase in resources allows incident response to shift into the control center and will require that enough personnel be present to effectively handle all incident calls in a timely manner. In addition, more dispatchers may be needed to handle service disruption calls coming in from the field or the garages.

As the control center takes primary responsibility for incident detection, fewer field supervisors will be necessary for incident and service disruption detection. However, there still needs to be a sufficient number of mobile supervisors to quickly respond as directed by the control center. If there are too few mobile supervisors, the number of incidents may outstrip the ability of supervisors to respond creating additional service delays. Mobile supervisors also may not be able to cover large geographic areas in a timely fashion if their numbers are too low. Additional tasks such as service restoration, or on-street relief management, may also require additional mobile supervisors.

Post supervisors will not be needed nearly as much as mobile supervisors. Being stationary, they are not well suited for incident response, and without real-time AVL information, they are unable to effectively monitor and restore service. Post supervisors can, however, contribute to service reliability in other ways but their numbers will depend on the priority a transit agency puts on those contributions.
Being on foot, post supervisors are able to interact easily with customers and operators, lending support and assistance whenever it is needed. If they are positioned in the right locations, such as a busy terminal, post supervisors can help keep terminal departures on time and perform minor repairs on buses to keep them on the street (e.g. fixing defective fareboxes, swapping for working buses, repairing loose mirrors). They can also perform some service restoration if the control center is able to give them delay information in a timely manner.

If transit agencies value service reliability highly, then post supervisors should concentrate first and foremost on keeping terminal departures on time. Without real-time AVL information or timely delay information over the radio, this will be the best that post supervisors can do to ensure reliable service. Supervisors can then focus on maintenance issues that keep buses on the street, as this task will contribute to reliability. Mid-route locations do not offer any of these opportunities unique to post supervisors and should only be considered for reasons other than service reliability.

c) High resource state
Moving to the highest resource states will serve two purposes. The first will be to improve service reliability by giving supervisors, dispatchers, and operators the tools that they need, and the second will be to lower total personnel requirements by improving the effectiveness of individual supervisors.

With real-time AVL information and full communications capabilities, control center responsibilities increase as well as the personnel needs. More dispatchers will be needed to monitor the real-time information stream for service disruptions and to communicate to operators and field supervisors any required service restoration instructions. The task of service monitoring and restoration is not trivial and will require additional staff beyond that already required for incident response.
Since the control center is now able to coordinate incident response and service restoration, fewer mobile supervisors will be needed than before. Their primary task of incident response will still exist, but auxiliary assignments such as service monitoring and restoration will now be handled by the control center.

Even fewer post supervisors will be needed in this advanced resource state. The control center will be responsible for monitoring and restoring service, reducing post supervisors roles. Terminal departure control as well as other operational control will be conducted centrally. Transit agencies can still utilize post supervisors though at major terminals or other places where they can offer customer assistance, perform maintenance, or provide a presence that the control center cannot (and may need to, for enforcement purposes for example).

If technological advances are sufficient, overall personnel requirements can be reduced even further. Automatic information processing can be introduced into the control center, relieving dispatchers of the task of service monitoring. This will allow them to focus instead on exception based reports such as long headways or buses that are off schedule. Automatic communications may also be introduced, giving operators in-vehicle instructions based on their current headway and schedule status. Instructions can also be delivered through terminal departure cues such as lights or bells, alerting operators of the appropriate departure time based on current conditions. These types of systems can have the overall effect of reducing personnel needs by automating tasks previously carried out by dispatchers and supervisors.

3.4 Evaluation of Strategies

After reviewing the possible supervision deployment strategies, it is important to conduct an evaluation to determine which supervision strategy best fits the available resources and state of reliability. This section will cover the system and route level evaluations.
3.4.1 System Evaluation

In evaluating a supervision deployment strategy, a transit agency must ask itself:

- Are the right tasks being assigned to address the principle causes of service unreliability?
- If not, are resource investments necessary to carry out these tasks? If so, which resources and how much investment is needed?
- Are supervision personnel overwhelmed with their tasks or mostly idle due to a lack of work?

By answering these questions, transit agencies can further fine tune their deployment strategies, personnel numbers, and resource investments. These questions are discussed below.

**Task Assignment**

For a supervision deployment strategy to be successful, it must be able to address the principle causes of service unreliability. If incidents have been determined to cause most unreliability problems, then incident response should show improvement in the new strategy. This may mean faster response times to incidents and the resulting delay.

Deployment strategies that have not addressed the principle causes of unreliability will need to be adjusted so that they do. This may mean shifts in personnel to mobile supervisors to improve incident response time and to dispatchers to handle the calls.

**Resource Investments**

If the task required to address unreliability is currently infeasible due to resource constraints, then plans for investing in improved information or communications systems may be necessary. This situation can come about, for example, if terminal departure performance is poor and no real-time AVL information is available. The task of managing headways would be impossible since neither the field supervisors nor the
control center know what the headways are in the first place. An investment in real-time AVL information would enable supervisors to carry out this task, provided communications capabilities are sufficient.

**Personnel**

With tasks and personnel being redeployed to the field or to the control center, transit agencies will have to monitor the work load to make sure that there are enough, but not too many personnel assigned to the right place. This problem can come up right after a major resource investment when new tasks become available and when personnel may have been redeployed.

For example, after a real-time AVL information system comes online along with improved communications, control center dispatchers may initially be overwhelmed with their new responsibility of monitoring and managing service unless their numbers are increased. Meanwhile, post supervisors who used to be responsible for monitoring service will see their roles and their numbers drastically reduced.

Constant evaluation of task assignment, personnel assignment, resources, and service reliability will be required over the long run to ensure that the supervision deployment strategy still meets the needs of the transit agency.

3.4.2 Route Level Service Reliability Metrics

Several metrics are available to use when measuring the service reliability benefits of a bus supervision strategy. These include AVL-provided data measurements such as:

- On-time performance
- Headway consistency
- Terminal departure performance
- Travel time consistency
With a new supervision strategy, benefits can be measured by an increase in on-time performance, more consistent headways at terminals and at mid-route timepoints, as well as improvements in travel time consistency. If reliable APC data is available, improvements can be noted through more consistent bus loads and fewer overcrowding situations.

At the route level, AVL data measurements can translate directly into headway consistency at each timepoint, as well as expected and excess passenger waiting times as calculated by equation 2.1. A beneficial supervision strategy will result in more consistent headways for high frequency routes which in turn will mean lower excess passenger waiting times.

Another route level measure is the headway ratio distribution at each timepoint. This ratio is a measure of the actual observed headway to the scheduled headway for that particular trip. A headway ratio of 1.0 would indicate a trip operating at its scheduled headway. Any beneficial supervision strategy will result in a tighter headway ratio distribution. This means more trips than before will have a ratio of 1.0 and fewer trips will have headway ratios at the shoulders of the distribution.

3.4.3 Modeling

A simulation model can be used to evaluate the effects of a supervision strategy on service reliability. By utilizing archived AVL data, a Monte Carlo simulation can be created to simulate “before and after” scenarios for the proposed supervision strategy.

In a Monte Carlo simulation, the archived AVL data is used to create a simulation of the bus route in question. Once the simulation is verified to reflect reality, the supervision strategy can be programmed in to evaluate its effects on the reliability metrics described above. Data collected for the simulation should span 3-4 weeks so as to capture the full range of operating conditions.
3.4.4 Experimentation

If the model shows that the proposed supervision strategy could be beneficial, a live, on-street experimentation can be carried out to verify the model results and better to ascertain the actual effects of supervision on service reliability.

Data from the experiment should be automatically collected through an AVL system to obtain the most accurate results. This includes both the experiment period and a “base” comparison period. The experiment should be run for at least a week to smooth out any daily variations, and holidays or school vacation days should be avoided. Finally, a similar week, perhaps immediately before or after the experiment week, should be used as a “base week” for comparison.

Once the data has been collected during the experiment and base periods, the metrics described earlier can be used to determine if there has been an improvement in service reliability during the experimental period.
4 Chicago Transit Authority Case Study

This chapter applies the framework described in chapter 3 to the Chicago Transit Authority. Section 4.1 assesses the current resources available for bus supervisors at the CTA. Section 4.2 and 4.3 propose system level strategies for supervision given the current and expected future levels of resources respectively. Section 4.4 presents an assessment of reliability on one CTA bus route, Route 20, and the final four sections of the chapter describe an experiment to restructure supervision on Route 20 and interpret the results.

4.1 Resource Assessment

This section will present an overview of the supervision practices and resources at the CTA. A general description of the staffing level and deployment plan will be given first. This will then be followed by a more detailed description of the duties and responsibilities of each type of supervisor.

4.1.1 General Overview

In 2005, the CTA had a total of 143 field supervisors in its bus supervision staff. About 71 (49%) supervisors are deployed in the field during any weekday AM or PM peak hour. Of these 71 supervisors, 28 (39%) are mobile, and 43 are post supervisors on foot (61%). The field supervisors are supported by five dispatchers in a control center.

As shown in Figure 4-1, the CTA service area is divided into 4 regions – North, West, Central, and South. Each region is led by a Transportation Manager who is responsible for his or her staff of mobile and post supervisors. The two digit numbers are the call signs of patrol areas assigned to mobile supervisors while the dots indicate the locations of post supervisors.
Figure 4-1 CTA service management regions and supervision locations
Two-way radios are used by field supervisors to communicate with each other and with the control center. The primary bus supervisor radio channel carries all general and targeted announcements from the control center while the secondary channel is used if an extended conversation is necessary. Supervisors can only communicate with operators in-person while the control center can communicate with operators by radio.

4.1.2 Control Center Operations

The main function of the control center is to coordinate the response of the field supervisors to incidents in the field. These “incidents” can include emergencies, accidents, maintenance issues, or other major delays. The control center’s response will depend on the type of incident but often involves sending a mobile supervisor to the scene and/or alerting post supervisors who will be passed by the reporting vehicle.

On the bus side, the control center is staffed by five dispatchers during the peak shift periods. Four (4) of the dispatchers are referred to as “garage dispatchers” or “monitors” who are responsible for communicating with operators based in one of their two assigned garages. The other dispatcher, referred to as the “C1” controller, manages the bus supervisor channel radio traffic, relays information to supervisors, assigns reported service problems to specific supervisors, and records information provided by supervisors in the Orbital Computer-Aided Dispatch (CAD) system.

Incidents are reported by operators over CTA’s CAD system, Orbital Bus Emergency Communications System (BECSS). This system gives operators a menu of canned text messages to send to the control center to alert them of their problem and the option of a “request to talk” if voice communications becomes necessary. A silent alarm is also available to operators who need to contact the control center discreetly. These text messages go into the event queue of the garage dispatcher responsible for the operator. If necessary, the garage dispatcher will open a voice channel with the operator to collect more information such as location, incident severity, and the exact nature of the incident. Once a response is formulated, the garage dispatcher will forward this event to the C1
controller. The C1 controller then announces the event over the radio, assigning a specific supervisor and providing information as needed.

Incidents can also come into the control center through other means such as by telephone. Garage clerks will call their garage dispatcher to report held-in or delayed runs. Runs held-in are broadcast on the bus supervisor channel so that field supervisors can take action to space their street if affected. Late pull-outs are put back on schedule by the garage or told to see a supervisor to be "put in place". The C1 controller will then notify the affected supervisors. In-service operators will also call control if the on-board CAD mobile data terminal (MDT) is not transmitting properly.

Overall, the control center has little problem processing all of the incidents. Event queues can sometimes build up during the peak hours, but rarely are any events left open. The major limitation faced by dispatchers is a lack of reliable communications capacity, which directly affects their ability to disseminate information in a timely manner. The lack of real-time AVL information also hampers their ability to quickly locate and detect incidents and delays.

4.1.3 Mobile Supervisors

Mobile supervisors are primarily responsible for fulfilling assignments in their service area as assigned by the C1 controller. They are equipped with a sport utility vehicle and a two-way radio for communicating with the control center and other field supervisors.

Given their mobility, mobile supervisors are typically the first to respond to reports of standing buses and accidents. According to the CTA they "can often address problems with transmissions, generator lights, fare boxes...to prevent a tow". When being dispatched to an accident, mobile supervisors become the initial incident commanders and can act as the CTA's representative to authorities. Mobile supervisors are also able to ensure that customers are served and can provide support to the operator.
When not responding to an incident, mobile supervisors will stand at a timepoint of their choice to check service. They have a supervisor’s guide, a complete schedule for each route, and can verify the schedule adherence and spacing of runs passing their location. If a bus is running early, the supervisor can hold it or if a bus is running late, the supervisor can express or short turn it to get it back on schedule.

A breakdown of the time spent on a sample duty for a mobile supervisor is shown in Table 4-1. This data was gathered during the author’s ride-along with a mobile supervisor in July 2005.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time (Minutes)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silent Alarm (10-88)</td>
<td>10</td>
<td>4%</td>
</tr>
<tr>
<td>Fuel Stop</td>
<td>20</td>
<td>8%</td>
</tr>
<tr>
<td>Relief Management</td>
<td>30</td>
<td>13%</td>
</tr>
<tr>
<td>Standing Bus</td>
<td>30</td>
<td>13%</td>
</tr>
<tr>
<td>Service Check</td>
<td>30</td>
<td>13%</td>
</tr>
<tr>
<td>Terminal Check</td>
<td>30</td>
<td>13%</td>
</tr>
<tr>
<td>Driving to Scene</td>
<td>30</td>
<td>13%</td>
</tr>
<tr>
<td>Right-of-Way Dispute</td>
<td>60</td>
<td>25%</td>
</tr>
</tbody>
</table>

One of the biggest hurdles mobile supervisors currently face is a lack of real-time information. This prevents them from being able to quickly locate moving buses that need their help such as those with broken fareboxes or silent alarms. It also prevents them from being able to manage existing service when responding to an incident or when performing a service check.

4.1.4 Post Supervisors

Post supervisors are mainly responsible for monitoring service at their location and restoring service when they detect a problem or under instructions from the control center. They are equipped with a two-way radio for communications and a supervisor’s guide detailing the schedule of runs passing their location.
In addition to monitoring service, post supervisor duties involve trouble-shooting defective equipment, enforcing operational and safety procedures, and mentoring and supporting operators. Being on foot, post supervisors are also recognizable CTA representatives who assist customers as necessary.

As shown in Table 4-2, post supervisors spend most of their time monitoring service. This task involves noting what time each bus passes as well as the number of passengers on board and the bus identification number. If a bus is running early, the supervisor can hold it or if a bus is running late, the supervisor can express or short turn it to get it back on schedule.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time (Minutes)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relief Management</td>
<td>20</td>
<td>8%</td>
</tr>
<tr>
<td>Administrative</td>
<td>20</td>
<td>8%</td>
</tr>
<tr>
<td>Service Restoration</td>
<td>30</td>
<td>13%</td>
</tr>
<tr>
<td>Defective Bus Repair</td>
<td>60</td>
<td>25%</td>
</tr>
<tr>
<td>Service Check</td>
<td>110</td>
<td>46%</td>
</tr>
</tbody>
</table>

During the course of monitoring service, post supervisors often assist operators with equipment defects. Upon receiving a report of a broken farebox for example, the garage dispatcher will tell the operator to see a post supervisor stationed along their route. The C1 controller will then notify the supervisor of the problem and the identification number of the affected bus. Additionally, operators know where post supervisor are located and will report equipment problems directly to the supervisor instead of notifying the control center. When the bus arrives, the post supervisor will try to fix the problem to prevent service from being pulled off the street.

Another key responsibility of post supervisors is to manage any on-street crew changes or reliefs at their location. This involves making sure that the relief operator is at the relief point on time, and that the operator to be relieved will arrive on time to the relief point.
If anything is amiss, the supervisor can take one of two actions according to the CTA Bus Service Supervisor Workshop (2001) in order to keep service on the street:

- Have relief operator pull out a new bus, or take a bus that is to be pulled in if the operator to be relieved is running too late
- Have the operator to be relieved operate extra trips if the relief operator fails to arrive

One of the major limitations on post supervision is the lack of real-time information on bus locations, headways, and schedule adherence. Post supervisors only know the service history at their location as they have observed it and cannot anticipate conditions beyond their visual range.

Communications constraints also pose a limitation on their abilities. As described in Chapter 2, Barker's (2002) analysis of the CTA's radio system shows how a lack of communications capacity delays the sharing of information. This is especially true concerning lower priority messages such as hold-ins, delayed departures from garages and reported service delays.

4.1.5 Information Resources

Referring to Table 3-1, the CTA information resource is classified at level 2. No real-time information is available but archived information is available through AVL and APC systems.

Since real-time information is not in place, field supervisors and control center dispatchers are only aware of the operational situation by radio broadcasts and their own visual observations. As described in the previous subsections, this severely limits their ability to maintain and restore reliable service. These limitations will have implications on personnel deployment and task assignments and this will be discussed in detail in the next section.
Archived automatic data collection, however, is in place and this greatly enhances the CTA's ability to analyze their bus network for service reliability problems. The entire bus fleet is equipped with an AVL system allowing transportation managers to discover trends leading to unreliable service such as chronically late terminal departures. Problem routes can also be identified which can assist in guiding supervision efforts. APC systems are deployed on a subset of the fleet and can be used to sample load profiles and other ridership data on specific routes. This information can be useful in determining where supervisors can be most effective.

4.1.6 Communication Resource

Although the CTA supervision force is equipped with a radio communications system, reliability and capacity issues keep many needed transmissions off the air. In addition, the radio system does not provide field supervisors the capability to contact bus operators directly, and vice versa, relegating their communications to intermittent face-to-face encounters on the street. These inefficiencies indicate that the CTA communication resource is classified between level 0 and level 1.

The relative lack of communications resource represents the biggest bottleneck in the CTA supervision force. Not only does it restrict the coordination of service restoration techniques, but it also limits information sharing among field supervisors and the control center. With post supervisors scattered throughout the network, observations of late or held-in buses happen frequently, but supervisors are unable to share this information with their colleagues downstream who might otherwise have been able to act and restore service due to congested radio traffic. Supervisors are also unable to directly communicate with operators which means that they must wait for the operator to arrive before instructions are given. The result is that service maintenance and restoration is a task largely left undone by CTA supervision.
4.2 Strategy Development – Current Resource Level

After completing an assessment it’s of supervisory resources, the CTA needs to decide how to deploy its personnel to make the best use of its supervision staff. In other words, the CTA needs to examine how it should allocate personnel among control center staff, mobile supervisors, and post supervisors, given the current levels of information and communications. Furthermore, the location of post supervisors needs to be prioritized, and responsibilities distributed among all three positions.

4.2.1 Control Center

Given the lack of automated real-time information in the control center, as well as the limited communications system, it does not make sense to add more personnel unless the present staff is overwhelmed, which does not currently seem to be the case. Adding more garage dispatchers may increase the rate at which events are processed and decrease the event queue, but the limited radio system and the availability of field supervisors to respond will continue to limit the effectiveness of the control center in incident response and delay management.

In terms of responsibilities, the CTA will have to determine the priority of the major tasks at the control center that compete for radio air time: delay management and incident response. Clearly, incident response is currently the number one priority as it takes nearly the entire control center time during the peak hours as noted by Barker (2002). This means that delay/hold-in announcements are often late and, as a result, ineffective. A possible way to improve this situation is to move delay management into the field where it can be acted on more effectively.

Managing delays in the field will still be quite limited due to the resource constraints, but there is room for improvement. Clerks and transportation managers at the garages need to take more responsibility of monitoring bus pull-outs and reporting any discrepancies to
field supervisors immediately. This may be able to provide the rest of the supervision force with timely information regarding delayed pull-outs and hold-ins.

4.2.2 Mobile Supervisors

With the current resource level at the CTA, mobile supervisors are perhaps the most important part of the CTA supervisory staff. Being in the field, they are able to visually gather intelligence on the state of operations in real-time, something the control center is unable to do. Furthermore, they can respond to incidents and delays that are out of reach for post supervisors. Considering their versatility, it would behoove the CTA to convert most of the existing post supervisors to mobile supervisors. They are able to do the tasks currently assigned to most post supervisors, but have the advantage of being mobile. The reallocation of post supervisors will be discussed later in this section.

By adding more mobile supervisors, the event queue for each supervisor will decrease as more supervisors are able to shoulder the same load. However, mobile supervisors do not appear to be overwhelmed at the moment, and their increased numbers will allow the CTA to give them more responsibility, such as taking full control of on-street reliefs, and participating in delay management. If the garages are able to provide timely delay reports, mobile supervisors would be able to respond to the route and re-space the street as needed. These additional responsibilities are discussed further below.

On-street reliefs
As described in section 4.1.4, on-street reliefs need to be managed by a supervisor if either the relief operator is a no-show or late, or if the operator to be relieved is running late. Since these reliefs happen on a regular schedule but not continuously, a mobile supervisor could go to a relief site during the “relief time window” to help ensure smooth reliefs. At other times, the supervisor can take on different tasks. By cycling between relief management and other tasks, the supervisor’s time is spent much more effectively than a post supervisor on relief duty who is unable to leave the post whether or not reliefs are taking place.
**Delay management**

Due to the lack of real-time AVL information at the control center, it is up to operators to report delays of 10 minutes or greater, and field supervisors to monitor service and communicate directly (face-to-face) with operators in order to restore and maintain reliable service. Service monitoring alone will not be able to detect minor service disruptions, but delays emanating from incidents and late pull-outs, if broadcast over the radio in a timely fashion, can be addressed.

Currently when an incident occurs, C1 broadcasts the route, run number, location and nature of the incident to all supervisors. A mobile supervisor is assigned to respond to the scene of the incident while post supervisors along the route take notice so they can monitor and restore service as necessary. However post supervisors are not always in a good position to restore service such as at a terminal or other posts where passenger loads are light: mobile supervisors are likely to be more effective. While one supervisor responds to the actual incident, another one can set up at the terminal to deal with the missing service. Figure 4-2 depicts this situation on a hypothetical bus route.

![Figure 4-2 Mobile supervisor incident response and service restoration](image)

Similarly, a mobile supervisor can respond to timely late pull-out and hold-in announcements by repositioning to the terminal or pull out point quickly to re-space the street and restore service.
To summarize, mobile supervisors are a versatile force and fill an important role given the CTA’s current levels of information and communications resources. Being in the field, they can gather more “operational intelligence” than the control center and act on it to keep service reliable. These supervisors can quickly move from point to point, taking care of occasional problems that do not require a full time supervisory presence – problems such as standing buses (typically due to a disturbance, accident, or equipment defect) on-street reliefs and occasional delay management.

4.2.3 Post Supervisors

From the description of the mobile supervisors, it may appear that the job of the post supervisor is largely redundant. Just about every task a post supervisor performs – service monitoring, service restoration, and relief management – can be done as well, or better, by a mobile supervisor, and they can do these tasks at multiple points over the course of a day. Furthermore, the state of supervisory resources at the CTA usually means that post supervisors are relegated to monitoring service since they do not have the information or communications necessary to maintain reliable service. If relief management duties are shifted to the mobile supervisors, this leaves even less for the post supervisors to do given their current deployment.

Post supervisors, however, do have a couple of advantages over their mobile counterparts. Being on foot and out on the street, post supervisors are much more accessible to the public and to the bus operators. This gives them the ability to provide customer service and to mentor operators. This can be valuable, especially in places where customers may need more assistance, such as at a transfer point, or when there are many new operators who may need guidance. Being on foot also requires post supervisors to stay in one area which may be effective at terminals that may require constant supervision. They can focus all of their attention on managing the routes passing through their location.
Should on-street relief management prove too problematic for mobile supervisors, than post supervisors will be needed to do this task. Under the current communications system, mobile supervisors may not find out about a relief problem for some time due to delays associated with operators reporting the missed relief to the control center, the control center notifying supervisors, and then mobile supervisors taking time to respond to the location or find a replacement bus. Post supervisors stationed at the relief point, however, will know of a problem immediately and can usually marshal buses and operators at their location who would normally be pulling-in or are on another route for relief substitution.

It should be recognized that post supervisors can be an effective part of the supervision force if they are given appropriate responsibilities, placed in the right locations, and supplied with the best information given the state of resources.

Location
The location of a post supervisor will determine how effective they can be in contributing towards reliable service. Some locations, such as major terminals, offer the best opportunities to restore service, and to see as many customers and operators as possible. Mid-route locations may not lend themselves to service restoration but may allow supervisors to monitor more routes than at terminals, and to also manage on-street reliefs and “fallbacks” or breaks if they occur often enough to warrant full-time supervision (if they do not occur as often, a mobile supervisor could be assigned).

Of the 43 peak period post supervisor positions, 10-20 of them should probably remain at the major terminals and transfer points, while the rest (23-33) are converted to mobile supervisors or control center dispatchers. This number may be on the conservative side and could even be reduced further considering the versatility of mobile supervisors versus the lack of a well-defined role for post supervisors due to the existing limited resources at the CTA.
Responsibilities

If the mobile supervisors are going to take on the management of on-street reliefs and other similar tasks, post supervisors could be concentrated at the major terminals to focus on customer service, assist in maintaining on-time terminal departures, and manage reliefs and delays.

4.3 Strategy Development – Future Resource Level

As the CTA looks to improve its level of communications and information, the supervision deployment strategy should evolve in order to take advantage of the resulting greater capabilities.

Currently, the CTA is piloting a project that would bring real-time AVL information on one route to the control center. Additionally, an improved computer aided dispatch (CAD) system is being tested that reports schedule adherence, pullout status, and allows direct text messaging between dispatchers and operators. These improvements in information and communications will clearly have implications for the way supervisors are deployed. This section will discuss these implications as they pertain to personnel deployment at the control center, and in the field.

4.3.1 Control Center

With the addition of real-time information and direct text communications between dispatchers and operators, the control center will have the information it needs to manage service beyond incident response as well as the communication means to act on it. The personnel requirements, however, will rise significantly as more dispatchers will be needed to monitor the real-time AVL information and communicate instructions to operators.
In the current pilot project, real-time AVL information is displayed graphically as shown in Figure 4-3. In order for a dispatcher to effectively monitor headways and schedule adherence, full attention must be paid to individual bus icons looking for signs of service unreliability such as long headways or late buses. These bus icons are color coded to indicate on-time, late, early, no-route, and off-route status. This effort can be quite consuming and would require a large number of dispatchers to monitor all 1700+ peak-hour buses. If a dispatcher is able to handle 50 buses, a reasonable number as determined from the experiment experience described in section 4.5, then 40 extra dispatchers would be required, a number that is unsustainable due to the physical space requirements and the desire to reduce overall personnel requirements.

If, however, the monitoring of the buses could be automated and the real-time AVL information system used to generate exception based flags, dispatchers would only have to be concerned with noting the exceptions and communicating the correct service restoration techniques to the operators affected. For example, exception flags indicating a long headway could trigger a “slow down and hold” text message from the control center to operators in front of the gap. Similarly, exception flags indicating early buses
could trigger a “slow down” text message to operators running ahead of schedule or too close to its leader. This could allow dispatchers to focus on perhaps 5 to 10 times as many buses each, if not more, reducing the number of additional dispatchers to as low as four.

Exception flags could also be used in the form of an automated dispatch system at terminals to indicate to operators – and customers – when the bus should be departing. Much like a ring-off bell used in some subway systems, this system should be able to improve on-time departures and improve headway consistency by adjusting the schedule based on current conditions.

In the mean time, excess post supervisors, as described below, can be shifted into the control center to take up roles as dispatchers.

4.3.2 Field Supervisors

As the control center assumes more control over headway and schedule management, fewer field supervisors will be needed to do this task. Real-time AVL information will allow service monitoring to be conducted centrally, and direct communications between the control center and operators will allow service restoration to be directed centrally. Incident response, however, will still require mobile supervisors.

The number of mobile supervisors will depend on the number of incidents that occur during a given time period and the desired response time. An increase in incidents and/or a decrease in desired response time would require more mobile supervisors. This number though will be lower in the advanced resource state than the current resource state as fewer supervisors are needed for delay management and service monitoring.

Post supervisors will be needed even less in the advanced resource state. Their two primary tasks – service monitoring and service restoration – are now housed in the control center. Instead, post supervisors can be placed at major terminals or transfer
points where the CTA feels constant supervision is necessary. This can be due to customer service issues, maintenance issues, relief management or other issues requiring a constant supervision presence. As more headway management personnel are needed in the control center, post supervisors who have field experience with managing service can be shifted to the control center to fill the now pressing need for dispatchers described earlier. However, once the service restoration actions and instructions are clearly defined and automatic information processing and communications are available in the CAD/AVL system, personnel requirements in the control center may be reduced or shifted again into developing, updating, and maintaining decision support tools.

4.3.3 Application and Evaluation of Future Resource Level

Since the CTA has just begun to increase the resource levels on one route (Route 20 Madison), the rest of the framework will be applied to this route to evaluate the effectiveness of this proposed system-wide supervision deployment strategy. The route level evaluation will consist of an experiment and model that simulates the future resource level described above by using current temporarily assigned personnel resources as a proxy for better information and communication. This simulation is not representative of a long-term strategy for the current resource level, but only a simulation of the expected future resource level. The next few sections will review a reliability assessment of the route, followed by a detailed supervision strategy development. The rest of the chapter will then detail the results of the evaluation and summarize this case study.
4.4 Route Level Reliability Assessment

This section presents the reliability assessment portion of the framework described in Chapter 3 to the CTA Route 20. While the previous section reviewed the CTA supervision state of the practice system-wide, this section will focus on the following:

- Description of Route 20 – route characteristics and demand profile
- The current state of Route 20 – AVL data analysis outlining the symptoms and probable causes of service unreliability

4.4.1 Description of Route 20 Madison

For this case study, all data and descriptions refer to the eastbound portion of Route 20 in the AM peak unless otherwise noted. The westbound portion of the route is addressed where relevant. Demand data is based on Schwarcz (2004) and refers to November 2003. Her study period (7:00 AM - 9:15 AM) coincides closely with the study period here (7:25 AM – 9:15 AM).

In the AM peak, Route 20 runs east-west along Madison Avenue from its western terminal at Austin to its eastern terminal at Columbus/Randolph in the Chicago Loop. Due to the one way streets downtown, Route 20 eastbound east of Halsted runs on Washington Street. Heading west, Route 20 runs on Madison Avenue from Michigan Avenue. Figure 4-4 shows the alignment and boarding and alighting counts for Route 20.
The CTA has established 8 timepoints along the route. It is at these points where headway and schedule adherence data is sampled for the analysis of the route. Table 4-3 summarizes the key timepoints analyzed in this thesis.

<table>
<thead>
<tr>
<th>Table 4-3 Key timepoint information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance from preceding timepoint (miles)</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Scheduled travel time from preceding timepoint (minutes)</strong></td>
</tr>
</tbody>
</table>
At the CTA, timepoints serve as mid-route checkpoints where operators are able to determine their schedule adherence. If they are ahead of schedule, operators are instructed to lose time so that they are back on time by the next timepoint.

Passenger demand for Route 20 is characterized by two peak load points – one just west of Kedzie, and the other at Halsted. The load profile which was measured over three AM peak periods from November 17-19, 2003 is shown in Figure 4-5. On the y-axis is the cumulative observed load and on the x-axis are the key timepoints from west to east.

![Figure 4-5 Route 20 demand profile](image)

Most of the drop in load at Kedzie can be attributed to two schools in the vicinity. Lower passenger activity between Kedzie and Ashland is a reflection of the relatively low densities in this area. Loads build up again between Ashland and Halsted along a new residential and mixed use corridor until the Metra commuter rail station when passengers begin to alight in the Loop.
4.4.2 Route 20 Reliability Analysis

This portion of the chapter will describe the current state of service reliability for Route 20. Schedule adherence at Austin and headway regularity along the route will be presented to demonstrate current service reliability conditions and to develop the basis for the proposed supervision strategy.

Eleven eastbound trips that are scheduled to depart Austin between 7:25 and 8:15 AM were chosen for this analysis. Their schedule and recovery time information is shown in Table 4-4. Six of them complete a full westbound trip prior to their studied eastbound trip while the other five pull directly out of the garage. Given their 60 minute travel time, they are scheduled to reach Columbus between 8:25 AM and 9:15 AM. Four weeks of AVL data from February-March 2006 is used for this analysis.

<table>
<thead>
<tr>
<th>Run</th>
<th>Schedule Departure Time from Austin</th>
<th>Scheduled Arrival Time at Columbus</th>
<th>Prior Westbound Trip</th>
<th>Recovery Time at Austin</th>
</tr>
</thead>
<tbody>
<tr>
<td>5058</td>
<td>725</td>
<td>825</td>
<td>Garage Pullout</td>
<td>3 minutes</td>
</tr>
<tr>
<td>5001</td>
<td>730</td>
<td>830</td>
<td>Full trip from the Loop</td>
<td>7.5 minutes</td>
</tr>
<tr>
<td>5073</td>
<td>735</td>
<td>835</td>
<td>Garage Pullout</td>
<td>3 minutes</td>
</tr>
<tr>
<td>5052</td>
<td>740</td>
<td>840</td>
<td>Full trip from the Loop</td>
<td>7.5 minutes</td>
</tr>
<tr>
<td>5055</td>
<td>745</td>
<td>845</td>
<td>Garage Pullout</td>
<td>3 minutes</td>
</tr>
<tr>
<td>5053</td>
<td>750</td>
<td>850</td>
<td>Full trip from the Loop</td>
<td>7.5 minutes</td>
</tr>
<tr>
<td>5009</td>
<td>755</td>
<td>855</td>
<td>Garage Pullout</td>
<td>3 minutes</td>
</tr>
<tr>
<td>5014</td>
<td>800</td>
<td>900</td>
<td>Full trip from the Loop</td>
<td>9.5 minutes</td>
</tr>
<tr>
<td>5071</td>
<td>805</td>
<td>905</td>
<td>Full trip from the Loop</td>
<td>7.5 minutes</td>
</tr>
<tr>
<td>5074</td>
<td>810</td>
<td>910</td>
<td>Full trip from the Loop</td>
<td>5.5 minutes</td>
</tr>
<tr>
<td>5010</td>
<td>815</td>
<td>915</td>
<td>Garage Pullout</td>
<td>3 minutes</td>
</tr>
</tbody>
</table>

Measures of Headway Regularity

Service reliability on Route 20 is best measured by headway regularity at the key timepoints since with scheduled 5 minute headways this is a high frequency route. For this type of route passengers tend not to use a timetable, and to them, headway regularity is much more important than schedule adherence when waiting for a bus.
Two metrics will be used in the discussion of headway regularity – the headway ratio distribution and the coefficient of variation for headway at each timepoint. The headway ratio is the observed headway divided by the scheduled headway. Headway ratios less than one indicate a headway that is less than scheduled, while headway ratios greater than one indicate a headway greater than scheduled. For example, if a bus has an 8 minute preceding headway, and its scheduled headway is 5 minutes, then its headway ratio would be 1.6. This analysis will present the distribution of headway ratios at each timepoint. With perfectly regular service all trips observed at each timepoint would have a headway ratio of 1.0. This ideal distribution would result in a mean headway ratio of 1.0, and a standard deviation of 0.

The coefficient of variation is defined as the standard deviation of headway divided by the mean scheduled headway. This value is measured at each timepoint and is positive with a higher value indicating a more dispersed distribution. Ideally, the coefficient of variation at each timepoint would be 0, indicating deterministic headways.

The Transit Capacity and Quality of Service Manual (TCRP Report 100) has established level of service grades based on the coefficient of variation of headways and the probability of bunched buses as shown in Table 4-5. As the coefficient of variation increases, the probability of bunched buses also increases, and the level of service deteriorates.

<table>
<thead>
<tr>
<th>Level of Service</th>
<th>Coefficient of Variation of Headway</th>
<th>Bunching Probability</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.00 - 0.21</td>
<td>&lt; 1%</td>
<td>Service provided like clockwork</td>
</tr>
<tr>
<td>B</td>
<td>0.22 - 0.30</td>
<td>≤ 10%</td>
<td>Vehicles slightly off headway</td>
</tr>
<tr>
<td>C</td>
<td>0.31 - 0.39</td>
<td>≤ 20%</td>
<td>Vehicles often off headway</td>
</tr>
<tr>
<td>D</td>
<td>0.40 - 0.52</td>
<td>≤ 33%</td>
<td>Irregular headways, with some bunching</td>
</tr>
<tr>
<td>E</td>
<td>0.53 - 0.74</td>
<td>≤ 50%</td>
<td>Frequent bunching</td>
</tr>
<tr>
<td>F</td>
<td>≥ 0.74</td>
<td>&gt; 50%</td>
<td>Most vehicles bunched</td>
</tr>
</tbody>
</table>

From the coefficient of variation, two more measures of service reliability – expected passenger waiting time and excess passenger waiting time – can be calculated (Welding,
The expected passenger waiting time is half the scheduled headway for perfectly regular high frequency routes where passengers are assumed to arrive randomly. This value increases as headway variability increases and is calculated as follows:

$$\bar{w} = \frac{\bar{h}}{2}[1 + \text{cov}^2(\bar{h})]$$

Excess passenger waiting time is the difference between the actual expected waiting time and the expected waiting time if headways were as scheduled (coefficient of variation = 0) and is calculated as follows:

$$EWT = \bar{w} - \frac{\bar{h}}{2}[1 + \text{cov}^2(\bar{h})]$$

where $\bar{w}$ is the actual expected passenger waiting time, $\bar{h}$ is the mean scheduled headway, and $\text{cov}(\bar{h})$ is the square of the coefficient of variation of the scheduled headway (Welding, 1957).

Analysis Results

The first step in examining headway regularity on Route 20 is to look at the schedule adherence of departures at the Austin terminal. As shown in Figure 4-6, just under half of the trips leave within one minute of their scheduled departure time while the rest are distributed between 2 to 6 minutes late. During this four-week period, no trips were observed to leave early.
The observed schedule deviations at Austin translate directly into headway variability. If all trips were to leave on time, or even if all trips were to leave 3 minutes late, then there would no variability in the headways at Austin. However, should some trips leave on time while other trips leave late (or early), then the departing headways will be irregular.

Figure 4-7 shows the headway variation at Austin (as well as at other timepoints downstream) in the form of a histogram of observed headway ratios. About 65% of the trips have an observed headway ratio between 0.8 and 1.2 and 10% of trips leave Austin either bunched (headway ratio less than or equal to 0.4) or with a large gap (headway ratio greater than or equal to 1.6). The primary reason for this headway variation at Austin can be traced to the fact that some trips leave on time while others leave late.

As buses travel along the route, service reliability progressively deteriorates. As shown in Figure 4-7, at each timepoint east of Austin fewer and fewer trips operate with headway ratios between 0.8 and 1.2 while more and more trips operate at headway ratios that indicate either bunching or large gaps.
Figure 4-7 Headway variation at Austin, Pulaski, Ashland, and Halsted
By the time service reaches Ashland, less than 40% of trips are operating at or near their scheduled headway while over 20% of trips could be considered bunched and another 15% are operating with large service gaps. This is important because Ashland is directly upstream of the second segment of heavy boardings as seen in Figure 4-2. A large number of passengers board Route 20 downstream of Ashland and will be subjected to the service unreliability being observed between Ashland and Halsted.

As headways become more erratic downstream from Austin, the coefficient of variation of these headways increases as shown in Figure 4-8, where the coefficient of variation at Austin is 0.36 and climbs to just over 0.6 at Ashland. By the time service reaches the Loop, the coefficient of variation is approaching 0.8. From the Transit Capacity and Quality of Service Manual level of service guide in Table 4-6, Route 20 starts off at Austin at the ‘C’ level and quickly reaches level of service ‘E’ by Kedzie.

As headway variability increases, so does excess passenger waiting time. If operating as scheduled, passengers wanting to board Route 20 are expected to wait 2.5 minutes on average – half the scheduled 5 minute headway. However, the variation in headways at each timepoint leads to increasing excess passenger waiting times as shown in Figure 4-9. The percentages next to the bars indicate the proportion of the excess passenger waiting
time compared to the scheduled passenger waiting time of 2.5 minutes. For example, passengers waiting for Route 20 at Ashland are spending 60% more time on average than they would if Route 20 were perfectly reliable.

The analysis so far has shown that Route 20 eastbound trips begin with a moderate degree of unreliability at Austin but service quickly deteriorates downstream. The variation in terminal departures at Austin will now be examined as a possible cause for unreliability throughout the route. Referring to the literature review in Chapter 2, Cham’s (2005) analysis of the MBTA’s Silver Line demonstrated how bunched and gapped terminal departures have little chance of achieving their scheduled headway in the middle of the route. This same phenomenon also holds true for route 20.

In order to find out what was actually occurring on Route 20, the headway for each trip at Austin and at another timepoint downstream were compared. The output becomes a chart showing the probability of a headway ratio downstream given an initial headway ratio at Austin.

Looking at Figure 4-10, trips that begin at Austin with a headway ratio of less than or equal to 0.4, or greater than 1.6 were virtually never able to achieve their scheduled
headway by Pulaski. As expected, trips that started on their scheduled headway at Austin had the highest probability of making their scheduled headway at Pulaski.

As noted earlier, service reliability deteriorates as buses traverse the route. In Figure 4-11, this trend is evident at Ashland, where no trip has more than a 50% probability of making its scheduled headway no matter the initial situation at Austin. It is worth noting that trips leaving Austin with a headway ratio of less than 0.4 have nearly a 60% probability of remaining bunched at Ashland while trips leaving Austin with a headway ratio of greater than 1.6 have a similar probability of remaining gapped.

Overall, it is those trips that are departing Austin with extreme headway ratios that have the least chance of achieving their scheduled headway downstream. Trips with more moderate initial headway ratios (greater than 0.4 and less than 1.6) stood the best chance of keeping their scheduled headway downstream.
This set of analysis clearly shows the importance of disciplined terminal departures on reliability downstream. It is imperative that operators begin their trips on their scheduled headways in order to have the best chance of maintaining headway regularity downstream.

Another possible cause of service unreliability on Route 20 is travel time variation. Figure 4-12 shows the mean observed and scheduled travel time between timepoints as well as the observed travel time plus and minus one standard deviation. Travel times are fairly consistent throughout the route and are nearly identical to the scheduled travel times. This leads to the conclusion that the schedule is not the primary cause of service unreliability. However there is enough variation to cause service reliability to deteriorate.
Summary

While variations in travel times may cause service reliability to degrade downstream, it is clear that the primary cause of service unreliability stems from the lack of uniformity in terminal departure headways. Right out of the terminal, Route 20 is shown to have a moderate degree of variability in headways that only gets worse downstream. The data then plainly shows how bunched and gapped terminal departures have virtually no chance of achieving their scheduled headway anytime downstream. It is those trips that start out on, or close to, their schedule headway that have the highest chance of maintaining reliable service throughout the route.

It is worth noting however that there is still a substantial buildup of travel time variability along the route. Fixing the terminal departure discipline at Austin will not fix the service reliability problems at Ashland, as Figure 4-9 illustrates.
4.5 Development of a Supervision Strategy

This section outlines the development of an experimental bus supervision strategy based upon the current resources available, and the reliability conditions of Route 20. The purpose of this experiment is not to find a strategy that fits the current resources, but rather to simulate a future resource state and develop a strategy that could take advantage of real-time AVL information, and improved communications. The actual recommended deployment strategy will come about after an analysis of the experiment.

4.5.1 Goals of the Supervision Strategy

Part of any supervision strategy that is applied to Route 20 should aim to bring uniformity to terminal departure headways. This will not only benefit passengers waiting for a bus near Austin, but will also benefit all passengers waiting downstream as shown in the analysis. The strategy should also account for Route 20’s load profile (see Figure 4-4). A high number of boardings occur between Austin and Kedzie, and then again between Ashland and Halsted. While service reliability may be at its lowest between Halsted and Michigan, it would make no sense to take any action here because few passengers board within the Loop (short turning could be a beneficial action depending on the bus loads the severity of bus bunching but for this experiment, short turning will not be an option). It would make sense however to take action at Austin and at Ashland as these are the timepoints just upstream of the major boarding zones.

With this in mind, it is proposed that one post supervisor each be deployed at Austin, Pulaski, Kedzie, and Ashland. These post supervisors will simulate the effect of the control center having direct communications with the operator by relaying control center requests to the operator during the experiment. In the actual “high resource state” deployment, these post supervisors would not have a role as the task would be the complete responsibility of the control center. Since real-time AVL information is available to the control center dispatcher, it is proposed that the dispatcher monitor
service along the entire route and notify post supervisors of recommended actions. Table 4-6 summarizes the resources available for Route 20.

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel</td>
<td>Street supervisors at Pulaski, Kedzie, and Ashland. One mobile supervisor along the Madison corridor who is stationed at Austin. One dedicated dispatcher at the Central Control.</td>
</tr>
<tr>
<td>Information</td>
<td>Real-time AVL data at Central Control, supervisor guide. Knowledge of immediate surroundings (traffic, vehicle status, etc.) from street supervisors.</td>
</tr>
<tr>
<td>Communications</td>
<td>Cell phone communications between dispatcher and the supervisors. No direct contact with bus operators. Supervisors may contact each other. Supervisors may contact operators only in person.</td>
</tr>
</tbody>
</table>

Placing a supervisor at Austin will give the dispatcher the ability to re-space the terminal if any large delays arise. The supervisor will also be able to enforce the scheduled departure headway under normal operating conditions. At Pulaski, the supervisor will serve to help the dispatcher verify the real-time AVL information by being the eyes and ears on the street, rather than performing operations control due to the load profile of Route 20. The Pulaski supervisor is in a position to verify the pull-outs where the other supervisors are not. At Kedzie, the supervisor will serve as the first control point prior to the Ashland-Halsted boarding zone. Relatively few passengers are on board the buses at Kedzie, so this makes it a good control point. The Ashland supervisor represents the last control point prior to the second major boarding zone. This supervisor will be responsible for holding buses as instructed by the dispatcher to promote even headways.

Ordinarily, not all of these resources are available for Route 20. For the purposes of this research and experiment, extra resources have been added. These resources will only be in place for the experiment, and not for the long run. In practice, there is no dedicated dispatcher for a single route at the CTA, nor is there a street supervisor at Austin or Kedzie. The additional resources exist to ensure that the maximum potential of the new real-time AVL system can be explored and automation techniques can be documented.
As concluded in the prior analysis, Austin and Ashland are the key timepoints for the proposed supervision strategy. It is at these points where headway regularity will be promoted through bus supervision actions.

4.5.2 Responsibilities of the Control Center Dispatcher

With real-time AVL data available only at the control center, the decision making powers regarding the route must lie here. The dispatcher’s primary responsibility will be to monitor vehicle locations on Route 20 during the study period in order to detect service gaps and bus bunching. If any conditions are detected that may lead to unreliable service, the dispatcher will decide on what action, if any, should be taken and will call the appropriate supervisor to execute the action.

The only operations control strategies available for the experiment are:

- Holding
- Running slow or “dragging the street”
- Move up runs at Austin

Expressing was taken off the table because the CTA did not want to irritate any passengers who would be passed up by the expressed run. Short turning was an available option but would be used only in the most extreme circumstances due to the inconvenience costs to passengers onboard the short turned bus and the amount of time and effort it takes to short turn a bus.

4.5.3 Austin Supervisor Responsibilities

The Austin supervisor’s main objective is to maintain the scheduled headway for buses beginning their eastbound trips. At times, this may mean spacing back or moving up buses to compensate for any westbound trips that may be late arriving at the terminal.
Without the real-time ALV information, the Austin supervisor will be able to properly space bunched buses but will not be able to detect incoming service gaps. As covered in chapter 2, post supervisors are only able to detect a service gap when they notice a bus is late arriving at their location. By the time this happens, the buses in front of the gap will have left the terminal and the supervisor will be unable to hold them and split the gap. However, real-time AVL information is available to the dispatcher at the control center. If the dispatcher notices a missing or delayed westbound run, he will be responsible for contacting the Austin supervisor and advising her on how to space her terminal. The overarching objective will be to break up bus bunches at the terminal and spread large service gaps (headway ratios greater than 1.2) across multiple runs when possible. Figure 4-13 shows a flowchart depicting the process for the control center-Austin supervisor relationship.

The appropriate actions will be either to hold runs in front of a gap, executing Turnquist’s (1982) “Prefol” strategy, or to move up runs already at the terminal to fill a gap from behind. Expressing buses or deadheading to fill a gap were options that were taken off the table due to their perceived cost to downstream passengers being passed up.
Figure 4-13 Decision flow chart for Austin

4.5.4 Pulaski Supervisor Responsibilities

The Pulaski supervisor is in a unique position – one that is able to meet operators pulling directly out of the Chicago Avenue garage but unable to perform any beneficial operation control moves due to the Route 20 load profile. According to the historic data, eastbound buses passing Pulaski will be quite full while relatively few people will be waiting to board immediately downstream (see Figure 4-4).
However, the ability to meet operators pulling out of the garage will be of great aid to the experiment. Five of the eleven eastbound trips included in the experiment, as shown in Table 4-4, pull directly out of the garage. Figure 4-14 shows their pull-out route beginning at the Chicago Avenue garage, heading south on Pulaski and then finally heading westbound on Madison before making their first eastbound trip from the Austin terminal. If the real-time AVL system is showing a run missing, a call to the Pulaski supervisor can confirm this. Another call can then be made to the Austin supervisor to space the terminal if necessary.

4.5.5 Kedzie Supervisor Responsibilities

The Kedzie supervisor will act as the first mid-route control point. Normally, a mid-route post supervisor has no information on service gaps upstream of their position as described in Chapter 3. During the experiment however, the dispatcher will be able to monitor runs coming into Kedzie for signs of a gap forming. If a run has a following headway of 7 minutes or more and a preceding headway of 5 minutes or less, the dispatcher will instruct the Kedzie supervisor to have the run “drag the street” until Ashland to lose about 2 minutes along the way. If 2 minutes is not enough to split the
gap, the dispatcher would instruct Kedzie to hold the bus 1-2 minutes maximum in addition. Holding a bus mid-route even at the lowest load point is an action of last resort because passengers on board may get irritated. Dragging the street is seen as less irritating since the bus is moving – albeit catching a couple of extra red lights. Again, expressing is not considered due to the costs to passengers being passed up.

4.5.6 Ashland Supervisor Responsibilities

The Ashland supervisor will represent the last chance to restore even headways before the major boarding zone between Ashland and Halsted. If the dispatcher was unable to effectively close a service gap at Kedzie, the Ashland supervisor will be instructed to hold runs in front of gaps to split the gap. In order to minimize the costs to on board passengers, holds will be no longer than 2 minutes.

4.5.7 Summary and Expectations of Proposed Supervision Strategy

The proposed strategy encompasses the three major aspects of supervision – information, personnel, and communications – to determine how effective supervision can be in improving service reliability.

1) Real-time information will be used by one dedicated dispatcher at the control center who is responsible for monitoring service on Route 20. Headways of 7 minutes or greater are considered service gaps and are dealt with as described above.

2) Four post supervisors are deployed along Route 20. Their primary responsibility is to execute operations control strategies as directed by the dispatcher. These supervisors will also help corroborate the real-time information by being the dispatcher’s eyes and ears on the street.
3) Communications between the dispatcher and the four post supervisors will be handled through cellular phone. This represents a dedicated channel to each supervisor and between supervisors providing virtually unlimited communications capacity between all parties.

In essence, the real-time information at the control center combined with extensive communications gives supervisors access to all the information they need to maintain and restore service reliability. Furthermore, all decision making is done centrally by the dispatcher, making the execution of operations control even easier for the post supervisor. This should lead to much more reliable service on Route 20 as measured by the headway variation of the eleven eastbound runs in Table 4-4.

4.6 Evaluation – Model Results

As described at the end of section 4.5, the headway variation along Route 20 eastbound is expected to decrease dramatically due to the headway control at Austin, Kedzie, and Ashland. In order to test this hypothesis, a model was constructed to simulate the effects of:

1) Enforcing terminal departure headways of at least 4 minutes (Single-headway strategy). Note that this is less than the scheduled headway so that buses would not stack up at Austin and cause excessively late buses. Timetables were still in use during the experiment and care was taken not to cause undue schedule disruptions.

2) Holding buses at Austin to split large headways (Prefol strategy).

3) Holding buses at Ashland to split large headways (Prefol strategy).
The next two subsections will detail the model’s inputs and assumptions, and the results of the model with regard to predicted headway variation at each timepoint after implementing the proposed supervision strategy.

4.6.1 Model Inputs

A Monte Carlo simulation was created in Microsoft Excel to predict the effects of the experiment’s supervision strategy. Four (4) weeks of archived AVL data from February and March 2006 was used to extract timepoint-to-timepoint travel time distributions and Austin departure times for the 11 trips considered in the experiment. The simulator then recreated the 11 trips based on this distribution to create “one day” of data. Thirty (30) simulated “days” were run through the simulation model to find the baseline headway distribution at each timepoint and the headway distribution after implementing the supervision strategy.

In order to validate the model, the simulated headway distribution at each timepoint was compared to the actual headway distribution using an F-test two sample for variances test. The input to the model included timepoint-to-timepoint travel times, so it is not necessarily true that the headway distribution will be the same. However, the F-test showed that the standard deviation of the distributions was found to be not significantly different at each timepoint except for Michigan at the 0.05 level. In other words, the model successfully recreated the observed reliability conditions.

The proposed supervision strategy was then simulated to generate new headway distributions. To simulate the supervision strategy, the following logic was added to the model:

- If a run could depart Austin with less than a 4 minute headway in the baseline scenario, hold it until its preceding headway is 4 minutes.
• If a run’s following headway is greater than 5 minutes at Austin or at Ashland in the baseline scenario, hold to split the gap between the run’s leader and the run’s follower – the “Prefol” strategy described in Chapter 2.

One of the major assumptions behind the model is that timepoint-to-timepoint travel times remain unchanged from the baseline scenario to the supervision scenario. In other words, it is assumed that a run that was simulated to take 8 minutes to travel from Austin to Cicero in the baseline scenario would still take 8 minutes in the supervision scenario whether or not it was held at Austin. This assumption was made because no relationship could be established between headways and travel times at any point in the route.

4.6.2 Model Results

As expected, the model predicted a drop in headway variation at the two control points, Austin and Ashland. As shown in Figure 4-15, the initial drop is quite dramatic but headway variability increases at timepoints downstream as travel time and dwell time variability begin to take their toll on reliability.

![Figure 4-15 Forecast headway variation with the proposed supervision strategy](image)
This drop in headway variation leads directly to a drop in excess passenger wait times as shown in Figure 4-16. Again, the effects of the supervision strategy are concentrated at the first few timepoints following the control point, a result that is consistent with the experiment described in the literature review involving Tri-Met and their BDS system (Strathman et al., 2001).

At first glance, excess passenger wait times of less than one minute in the baseline scenario seem small. Even smaller are the excess passenger wait time savings produced by the supervision strategy, which are on the order of 0.2 to 0.6 minutes. To be meaningful however, these results should be looked at in terms of a percentage of the expected scheduled waiting time. Table 4-7 summarizes the excess passenger wait times as a percentage of the expected scheduled wait time. The baseline scenario results are presented alongside the supervision scenario results which are in parentheses.

<table>
<thead>
<tr>
<th>Timepoint</th>
<th>Austin</th>
<th>Cicero</th>
<th>Pulaski</th>
<th>Kedzie</th>
<th>Ashland</th>
<th>Halsted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduled Wait Time</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Simulated Wait Time</td>
<td>(2.68)</td>
<td>(2.9)</td>
<td>(3.06)</td>
<td>(3.2)</td>
<td>(2.71)</td>
<td>(2.94)</td>
</tr>
<tr>
<td>Simulated Excess Wait Time</td>
<td>(0.18)</td>
<td>(0.4)</td>
<td>(0.56)</td>
<td>(0.7)</td>
<td>(0.21)</td>
<td>(0.44)</td>
</tr>
<tr>
<td>Percentage of Scheduled Expected Wait Time</td>
<td>12.5%</td>
<td>20.3%</td>
<td>25.1%</td>
<td>29.1%</td>
<td>34.9%</td>
<td>38.2%</td>
</tr>
</tbody>
</table>

Table 4-7 Excess wait time as a percentage of scheduled wait time

Figure 4-16 Forecast excess passenger wait time for the proposed supervision strategy
The scheduled expected wait time in Table 4-7 is calculated using equation 4.1 where the mean headway is 5 minutes and the coefficient of variation is zero. By reducing the coefficient of variation at each timepoint, the proposed supervision strategy is expected to reduce excess wait times from 12.5% of the scheduled wait time to 7.1% at Austin. At Ashland, the effect is even more pronounced with the supervision strategy expected to reduce excess wait times from 34.9% of the scheduled wait time to only 8.3%.

Another way to look at the results is by examining the resources necessary to produce the expected wait times at each timepoint. To achieve 5 minute headways on Route 20, the CTA must deploy 24 buses for the estimated 120 minute cycle time during the AM peak. According to the model, this deployment gives passengers an expected wait time of 3.4 minutes at Ashland as shown in Table 4-7. Again, this expected wait time factors in a coefficient of headway variation equal to 0.6 as shown in Figure 4-16. If the CTA were able to achieve an 0.3 coefficient of headway variation at Ashland with the proposed supervision strategy, a deployment of only 19 vehicles producing headways of 6.3 minutes would be necessary to give passengers the same expected wait time of 3.4 minutes at Ashland as shown in Table 4-8.

<table>
<thead>
<tr>
<th>Cycle (min)</th>
<th>Vehicles</th>
<th>Headway</th>
<th>Coefficient of Variation</th>
<th>Expected Passenger Waiting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Scenario</td>
<td>120</td>
<td>24</td>
<td>5</td>
<td>0.61</td>
</tr>
<tr>
<td>Supervision Scenario</td>
<td>120</td>
<td>19</td>
<td>6.3</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Of course, this analysis must be taken with a grain of salt. Improving reliability along a route should not just be looked at as a way to cut costs, but also as a way to improve the transit experience and hence customer satisfaction and eventually ridership. In addition, capacity constraints must also be taken into account. Reducing the number of vehicles on a route may compromise the capacity needed during the AM peak hour. With those caveats in place, this analysis is still quite powerful in demonstrating the benefits of improved service reliability, whether from the passenger or transit provider point of view.
4.6.3 Modeling Summary

The Monte Carlo simulation presented in this section demonstrated that executing both a single-headway hold strategy and the Prefol hold strategy at Austin and Ashland has the potential to reduce headway variation and improve reliability. This is achieved by breaking up bus bunches at both timepoints and by filling in large headway gaps by holding buses to split the gap. The benefits of holding however are shown to be confined to the control point and timepoints immediately downstream. This is a reflection of the fact that traffic conditions and dwell time variability will continue to erode service reliability despite intensive supervision efforts.

Without real-time AVL information and dedicated communications, the Prefol holding strategy would not be possible due to the information requirements described in Chapter 2.

4.7 Evaluation – Experiment Results

This section will review the results of the experiment carried out on Route 20 for four weekdays (Tues-Fri) during the week of April 25-28, 2006. The experiment involved implementing the proposed supervision strategy described in section 4.5, and then analyzing data from the CTA BLIS database to evaluate the impacts on service reliability.

During the experiment, numerous runs were held at Austin, Kedzie, and Ashland in order to break up bus bunches when there was a following headway in excess of 6 minutes. These holds did not exceed 1-2 minutes. In addition, there were four runs that were either excessively late pulling out of the garage, or held in altogether. In order to compensate, the preceding runs of the late or held-in runs were held in accordance to the Prefol strategy, and the following runs were moved up whenever possible.
As expected, the coefficient of variation of the headways decreased at each timepoint when compared to the previous week (April 18-21) as shown in Figure 4-17. The drop in headway variation at Austin was not as large as predicted in the model, but its effects reached much farther downstream than predicted.

The decrease in headway variation ultimately led to a decrease in excess passenger waiting times as shown in Figure 4-18. Again, the effects of the Austin control point are not as pronounced at Austin but linger for the entire route. At Ashland, the effect of the control point was not a reduction in excess waiting time, but likely the prevention of a spike in headway variation at Halsted which occurred the previous week.
As with the model results, the reductions in headway variation and excess passenger wait times are not as meaningful until looked at as a percentage of the scheduled expected waiting time. At the Austin control point, excess wait times declined from 22.8% of the scheduled wait time during the previous week to 14.1% during the experiment week as shown in Table 4-9. The difference in expected waiting times between the previous week and the experiment week grows larger at timepoints downstream, indicating that the effect of the Austin control point, combined with some control at Kedzie and Ashland, greatly reduced excess passenger waiting times throughout the eastbound portion of Route 20.

<table>
<thead>
<tr>
<th></th>
<th>Austin</th>
<th>Cicero</th>
<th>Pulaski</th>
<th>Kedzie</th>
<th>Ashland</th>
<th>Halsted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduled</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Expected Wait Time</td>
<td>3.07 (2.85)</td>
<td>3.44 (3.29)</td>
<td>3.74 (3.24)</td>
<td>3.96 (3.34)</td>
<td>3.88 (3.5)</td>
<td>4.43 (3.66)</td>
</tr>
<tr>
<td>Excess Wait Time</td>
<td>0.57 (0.35)</td>
<td>0.94 (0.79)</td>
<td>1.24 (0.74)</td>
<td>1.46 (0.84)</td>
<td>1.38 (1)</td>
<td>1.93 (1.16)</td>
</tr>
<tr>
<td>Percentage of Scheduled Expected Wait Time</td>
<td>22.8% (14.1%)</td>
<td>37.7% (31.7%)</td>
<td>49.8% (29.7%)</td>
<td>58.4% (33.5%)</td>
<td>55.3% (40.1%)</td>
<td>77.3% (46.4%)</td>
</tr>
</tbody>
</table>
As noted in Chapter 2, in the Tri-Met BDS experiment the effects of terminal control lasted for only a short period of time before the prior level of unreliability returned. In the case of this experiment, it appears that this is not the case. Headway variation and excess passenger wait times decrease slightly at Austin but do not rebound much at all compared to the results from the baseline week. One possible explanation is that at Austin, the extreme headways were drastically cut back (headways less than 2 minutes or greater than 8 minutes) but the variation around the mean did not decline as shown in Figure 4-19. Bus bunches were reduced by about half, and large headway gaps were reduced by about five fold. However, headways in the range of 4-6 minutes did not see a large increase. This was due to the fact that the real-time AVL system gave advanced warning to the supervision team of large incoming headways, and supervisors acted on them, and also that supervisors at the Austin terminal were enforcing the scheduled headway.

By cutting down on the large headways and bus bunches leaving Austin, more runs had a higher chance of achieving their scheduled headway downstream as discussed in section 4.2.2. This led directly to more runs with headways between 4-6 minutes downstream and fewer bunched or gapped runs as shown in Figures 4-20 and 4-21.
4.8 Case Study Summary

In applying the framework presented in Chapter 3, this case study has developed recommendations for supervision personnel deployment based on current and future resource levels. Utilizing the CTA’s Real-Time Network pilot project as a simulation of
future resources, an experiment was conducted to evaluate the proposed supervision strategy. This section presents a summary of the experiment followed by the implications of the results towards the redeployment of supervision resources at the CTA.

4.8.1 Experiment Summary

This experiment has shown that terminal control through a post supervisor can have a positive effect on service reliability by enforcing the scheduled departure headway. Knowing the schedule adherence and location of incoming runs, the terminal supervisor was able to go a step further and employ the Prefol strategy. The end result was that many fewer runs departed Austin bunched or with large headways and more runs were able to maintain their scheduled headway downstream compared to the baseline week. This in turn produced lower expected waiting times for the bulk of the passengers boarding between Austin and Kedzie, and again between Ashland and Halsted.

The experiment also revealed the potential impacts of real-time AVL information on service reliability as well as task and personnel assignment (more on personnel in the following subsection). With the control center dispatcher fully informed on vehicle location and headways, more effective operational control decisions could be made and passed on to the operators via the post supervisors.

The supervision strategy did have two shortcomings with regard to reliability. The first is that despite having full communications, information, and personnel capability at Austin and Ashland, supervision was unable to reduce headway variability to zero at these timepoints. This can be attributed to several factors including:

- The central dispatcher being unable to focus solely on Austin or Ashland operations. This led to some long headways going undetected until it was too late to act.
- Missing real-time data. Some runs did not show up on the real-time AVL system and subsequently could not be tracked.
Inherent variations in tracking time. It is unrealistic to expect a supervisor to be able to have each bus leave Austin exactly 5 minutes apart. There are numerous distractions, including noise, weather, and other tasks that will inevitably cause departure variations.

At Ashland, there were additional issues that had to be considered. Holding buses longer than 1 or 2 minutes was unrealistic due to the inconvenience it caused passengers already on board. Although these buses were at the lowest load point on the route, they were still typically carrying 15-20 people each. Additionally, if a run's preceding plus following headway exceeded 10 minutes, then it would be impossible to achieve the scheduled 5 minute headway.

4.8.2 Supervision Deployment

As stated earlier, the experiment in no way represented an actual deployment recommendation due to the unsustainable amount of resources used to achieve a high level of communications and operator compliance. It did, however, shed light on the potential of improved information and communications on increasing service reliability through the shifting of supervision responsibilities and personnel deployment.

By bringing real-time AVL information into the control center, the dispatcher has full knowledge of vehicle location, headway, and schedule information and thus is in a better position to manage service than field supervisors. With improved communications, the dispatcher can directly instruct operators in an effort to restore and maintain service and improve reliability, reducing the need for field personnel. This was simulated in the experiment through the use of cellular phones and post supervisors relaying instructions to the operators.

Once real-time AVL information becomes available on more routes, the CTA will need to upgrade its communications upgrade to take advantage of the information upgrade. Control center dispatchers monitoring service without improved communications will not
be able to communicate their instructions with operators quickly, and the real-time information will not be taken advantage of. In addition, the improved communications will reduce the number of post supervisors as the control center takes on the dual role of monitoring service and restoring/maintaining service. Some of these post supervisors can then be moved into the control center to assume dispatcher positions.

As the control center begins to fully assume the tasks of service monitoring and service restoration, post supervisors will no longer be needed to duplicate these tasks. Instead, one approach could be to reduce their numbers to 10 or even less, depending on the priority the CTA places on their customer service, and terminal management (mentoring operators, performing minor repairs) capabilities. Fewer will be needed if only the biggest terminals are to be staffed such as 95th/Dan Ryan, Jefferson Park, or locations within the Loop and more may be needed if there is a need for stationary personnel elsewhere.

Mobile supervisor numbers can also be reduced as they too will no longer have to participate in service monitoring or restoration. They will still be responsible for incident response at the direction of the control center, managing on-street reliefs as they occur throughout the day, and for performing safety checks on operators as required.

For this strategy to become fully scalable to the entire CTA network, exception based reporting through automatic information processing will be needed at the control center. More specifically, headway and schedule adherence monitoring needs to be automated to give dispatchers only the information they need concerning unreliable service conditions. Monitoring over 1,700 peak hour buses will require a number of dispatchers unless this task can be automated. Dispatchers can then focus on the exceptions that require their attention and can instruct those operators as required. The additional dispatchers required to respond to the new real-time AVL information can come from the reallocated number of field positions.
5 MBTA Case Study

This chapter presents the partial application of the framework described in chapter 3 to the MBTA Washington Street Silver Line. The first part of the chapter will introduce the Silver Line, assess the current state of reliability (section 5.1), and the supervision resources available (section 5.2). The later part of the chapter will propose changes to the way supervisors are deployed (section 5.3), and then analyze the potential improvements to service reliability that should result.

5.1 Reliability Assessment

As discussed in the literature review, Cham (2006) completed a thorough reliability analysis of the Washington Street Silver Line. This section summarizes Cham’s findings for the PM peak period, which was generally found to be most problematic in terms of running time variability, and headway variation.

5.1.1 Description of the Silver Line

The MBTA’s Washington Street Silver Line is a bus rapid transit line running between downtown Boston and Dudley Square to the southeast. As shown in Figure 5-1, there are 12 stops in each direction providing transfer opportunities to the MBTA’s rail rapid transit lines as well as numerous other bus routes along the route. Buses run on non-protected exclusive bus lanes through most of Washington Street and in mixed traffic through downtown.
The two terminals are at Dudley Square and at Temple Street in downtown. Dudley Square functions as the main terminal with room for multiple Silver Line buses to layover. The Temple Street terminal is more a turn around stop, and can hold only two buses due to the physical layout of the street. Due to this configuration, recovery times at Temple are less than 4 minutes while at Dudley they can be up to 11 minutes.

During the AM peak, most of the Silver Line passengers are heading inbound toward Temple Street, while in the PM peak, the reverse is true as shown in Figure 5-2 (Cham, 2006).
Headways range from 5-6 minutes during the peak periods to 12-15 minutes as shown in Table 5-1 (Cham, 2006).

Table 5-1 Silver Line Schedule

<table>
<thead>
<tr>
<th></th>
<th>Rush Hour Service</th>
<th>Midday Service</th>
<th>Evening Service</th>
<th>Late Night Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dudley Square</td>
<td>5 mins</td>
<td>8 mins</td>
<td>10 mins</td>
<td>12 mins</td>
</tr>
<tr>
<td>Temple Place</td>
<td>5 mins</td>
<td>8 mins</td>
<td>10 mins</td>
<td>12 mins</td>
</tr>
</tbody>
</table>

5.1.2 Data Analysis

Archived AVL data on the Silver Line was used from May, 2005 to analyze running times, schedule adherence, and headway variation along the route.
The AVL data is aggregated at the timepoint level, which for the Silver Line is simply the individual bus stop, and includes the time a specific vehicle arrives and departs a timepoint, the vehicle ID number, trip ID number, and other data that makes it possible to track vehicle movements along the route.

5.1.3 Running Time Analysis

PM peak running times along the Silver Line generally fall within the schedule except for the inbound trips running from E. Berkeley to Temple. Nearly all of these trips took longer than scheduled to traverse this section of the route. The variability of running times of all PM peak trips was noted to be high with standard deviations of running times calculated in excess of 20% of the mean running time, as shown in Tables 5-2 and 5-3 (Cham, 2006).

<table>
<thead>
<tr>
<th>Table 5-2 Inbound Running Time Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running Time (min)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Dudley-E. Berkeley</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>E. Berkeley-Temple</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Inbound</td>
</tr>
<tr>
<td>Scheduled</td>
</tr>
<tr>
<td>Actual</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5-3 Outbound Running Time Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running Time (min)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Temple-E. Berkeley</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>E. Berkeley-Dudley</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Outbound</td>
</tr>
<tr>
<td>Scheduled</td>
</tr>
<tr>
<td>Actual</td>
</tr>
</tbody>
</table>

Cham notes that the main problem with running time is that it is unpredictable and inconsistent. Travel time variability also leads to headway adherence problems propagating along the route.
5.1.4 Headway Adherence

Similar to Route 20, the Silver Line was found to have the highest headway adherence at its terminals, with running time and dwell time variability contributing to headway adherence breaking down mid-route. Figure 5-3 clearly demonstrates this, with over 30% of trips departing the terminals with their scheduled headway but fewer than 20% of trips maintain this headway mid-route (Cham, 2006).

The main cause of unreliable headways was determined to be poor terminal discipline: sufficient recovery time was available at the Dudley terminal, yet only 35% of trips left with their scheduled headway. Of the trips leaving Dudley with their scheduled headway, 47% were found to be operating on schedule at East Berkeley. Of the trips leaving Dudley with shorter or longer headways, no more than 21% were found to be operating on schedule. As in the Route 20 case, this highlights the need for good terminal departure discipline if service is to be reliable downstream.
5.2 Resource Assessment

The Silver Line, unlike the rest of the MBTA bus network, is rich with supervision resources. Two post supervisors are stationed along the route, one at Temple, and the other at Dudley. A dedicated dispatcher is also assigned to the route and has access to real-time AVL information from his post at the control center. The two post supervisors and the dispatcher can communicate via a two-way radio.

This level of resources is unique to the Silver Line since it serves as the flagship BRT route for the MBTA. Scaling them up to the level where the entire network could be covered, or maintaining this level of personnel for the Silver Line alone is not a viable option. Instead, a better personnel deployment strategy is required to 1) take advantage of the available resources on the Silver Line, and 2) allow for personnel reductions as technology advances.

The post supervisor stationed at Temple Street is focused solely on Silver Line operations. Observations of the supervisor's activities were taken in December, 2005. Most of the time, this supervisor could be considered idle, only taking notes on departure times and occasionally answering customer questions. Every so often however, the supervisor would have to move private vehicles out of the way on the narrow street so buses could get through. The fact that this supervisor is dedicated to the Silver Line, and has few tasks taking his time makes Temple Street a prime location for operations control.

The other post supervisor is stationed at Dudley Square but must split time between the Silver Line and the rest of the bus routes that serve the terminal. Observations of the supervisor's activities were also taken in December, 2005. Unlike the Temple Street supervisor, the Dudley post was quite busy handling customer questions, operator concerns, and keeping order at the terminal. The terminal is very busy, with hundreds of passengers passing through during the PM peak. With such a large volume of other tasks
to handle, operations control at Dudley is not as feasible for this supervisor when compared to the Temple supervisor.

At the control center, a dedicated Silver Line dispatcher watches over the route using real-time AVL information. The location and schedule adherences of all buses are known to the dispatcher but as of January 2006, none of this information is used for operations control.

5.3 Development of the Supervision Strategy

Cham's (2006) analysis of the Washington Street Silver Line found that the route was experiencing poor departure headway ratios at the terminals, leading to worse reliability conditions downstream. One possible solution to this problem would be to have supervisors at each terminal enforce the scheduled headway by holding buses to their headway. Buses could also be held longer to split large headway gaps as Turnquist (1981) suggests with the Prefol strategy.

This type of holding strategy, as discussed in the prior chapters, is proactive and would require a supervisor to have real-time information on bus locations as well as the ability to communicate any instructions to the operators. The feasibility of executing this strategy on the Silver Line will be discussed in the next subsection covering supervision resources for the route.

5.3.1 Proposed Supervision Strategy

a) Existing Resources

From Cham's (2006) analysis presented in section 5.1, terminal departure discipline was found to be the most important element in promoting reliable bus service along the route. Therefore, for any supervision strategy to be successful at improving reliability, terminal
departures must be the focus. Good departure discipline will not only benefit passengers waiting at the terminal, but will also benefit those waiting downstream by providing more consistent headways throughout the route.

From that finding, it is proposed that the supervisor already in place at Temple take a more active role in regulating headways with the help of the control center dispatcher. When large inbound headway gaps are observed to be coming into Temple, the dispatcher should alert the Temple supervisor to hold the preceding bus long enough to split the gap. This strategy should prevent most large headway gaps without having to hold too many buses at Temple where the physical capacity is limited. By preventing buses from leaving Temple with large headways, service reliability will be improved and excess passenger waiting times will be reduced. In addition, this strategy has the added benefit of adding no new resources to the Silver Line, instead, the existing resources will be used more productively.

b) Future Resources
With relatively minimal investment, the MBTA Silver Line supervision force could cut their field personnel requirements and concentrate headway management at the control center. Under the proposed strategy for existing resources, the primary role of the Temple post supervisor is to enforce terminal departure headways under the instruction of the control center dispatcher. Through text messaging or radio contact, the dispatcher can communicate directly with the operator and eliminate the need for the post supervisor.

Upgrades can also be made at the control center. Automatic information processing would give the dispatcher the ability to handle more routes (equipped with real-time AVL) by providing exception based reports. Communication systems could also be upgraded to allow for terminal “ring-off” bells that would alert operators of the appropriate departure time based on the changing conditions, further reducing the need for field personnel.
5.4 Evaluation – Model Results

As suggested in section 3.4, a model will be used to evaluate the effectiveness of the proposed supervision strategies. This model will assume the same effectiveness for both strategies, the advantage of the higher resource version being less personnel requirements. Due to time constraints and other obstacles, in this case an experiment was not feasible and the model serves as the primary evaluation tool for the MBTA case study.

5.4.1 Data

In order to model the effects of the proposed supervision strategy, AVL data from November 28 to December 2, 2005 was analyzed. Scheduled and actual arrival and departure times from the Temple terminal were used to create a deterministic model that could predict the effects of the proposed supervision strategy. The model focused on the PM peak hours of 1500-1700, where there were 21 departures from Temple outbound each day, for a weekly total of 105 departures. Table 5-4 presents an example of the data from Thursday, December 1, 2005.

To simulate the proposed supervision strategy, the model looked at all actual departures from the study period. For all headways greater than the scheduled 6 minutes, the model held the bus in front of the gap to split the gap as following the Prefol strategy. For example, trip number 3 from Table 5-4 is before an 18 minute gap. The model would recognize this and hold the bus for 7 minutes until its new actual departure time is 3:21 PM, giving it a 10 minute preceding headway and an 11 minute following headway. Physical characteristics at Temple limit the terminal to a maximum of only two buses and so the model did not hold a bus long enough to exceed this limit.
Table 5-4 Temple PM peak departure AVL data for 12/01/05

<table>
<thead>
<tr>
<th>Trip Number</th>
<th>Scheduled</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3:05 PM</td>
<td>3:10 PM</td>
</tr>
<tr>
<td>2</td>
<td>3:10 PM</td>
<td>3:11 PM</td>
</tr>
<tr>
<td>3</td>
<td>3:16 PM</td>
<td>3:14 PM</td>
</tr>
<tr>
<td>4</td>
<td>3:21 PM</td>
<td>3:32 PM</td>
</tr>
<tr>
<td>5</td>
<td>3:27 PM</td>
<td>3:32 PM</td>
</tr>
<tr>
<td>6</td>
<td>3:32 PM</td>
<td>3:41 PM</td>
</tr>
<tr>
<td>7</td>
<td>3:38 PM</td>
<td>3:44 PM</td>
</tr>
<tr>
<td>8</td>
<td>3:43 PM</td>
<td>3:46 PM</td>
</tr>
<tr>
<td>9</td>
<td>3:49 PM</td>
<td>3:55 PM</td>
</tr>
<tr>
<td>10</td>
<td>3:54 PM</td>
<td>3:58 PM</td>
</tr>
<tr>
<td>11</td>
<td>4:00 PM</td>
<td>4:01 PM</td>
</tr>
<tr>
<td>12</td>
<td>4:05 PM</td>
<td>4:06 PM</td>
</tr>
<tr>
<td>13</td>
<td>4:11 PM</td>
<td>4:20 PM</td>
</tr>
<tr>
<td>14</td>
<td>4:17 PM</td>
<td>4:24 PM</td>
</tr>
<tr>
<td>15</td>
<td>4:22 PM</td>
<td>4:25 PM</td>
</tr>
<tr>
<td>16</td>
<td>4:27 PM</td>
<td>4:27 PM</td>
</tr>
<tr>
<td>17</td>
<td>4:32 PM</td>
<td>4:32 PM</td>
</tr>
<tr>
<td>18</td>
<td>4:37 PM</td>
<td>4:37 PM</td>
</tr>
<tr>
<td>19</td>
<td>4:42 PM</td>
<td>4:47 PM</td>
</tr>
<tr>
<td>20</td>
<td>4:47 PM</td>
<td>4:50 PM</td>
</tr>
<tr>
<td>21</td>
<td>4:52 PM</td>
<td>4:57 PM</td>
</tr>
</tbody>
</table>

5.4.2 Results

As shown in Table 5-5, the model forecasts that more trips will operate at close to the scheduled headway ratio when the proposed supervision strategy is in place than was observed without the strategy, with fewer trips being bunched (headway ratio \( \leq 0.4 \)) or gapped (headway ratio \( > 1.6 \)).
Similar to the Chicago Transit Authority case study, a more consistent headway ratio leads to less excess passenger wait time as shown in Table 5-6. During the study period, the AVL data reflected a headway coefficient of variation of 0.4, leading to excess passenger wait times of 1.2 minutes. This represented on average 44.6% of the scheduled expected wait time. With the proposed supervision strategy, the headway coefficient of variation falls to 0.4, leading to an average excess passenger wait time of 0.6 minutes, or only 21.2% of the scheduled expected waiting time. In other words, the use of the proposed supervision strategy is forecast to halve excess passenger wait times.

<table>
<thead>
<tr>
<th>Headway Ratio at Temple</th>
<th>Observed Scenario</th>
<th>Supervision Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;= 0.4</td>
<td>10.0%</td>
<td>20.0%</td>
</tr>
<tr>
<td>0.4 to 0.8</td>
<td>20.0%</td>
<td>30.0%</td>
</tr>
<tr>
<td>0.8 to 1.2</td>
<td>30.0%</td>
<td>40.0%</td>
</tr>
<tr>
<td>1.2 to 1.6</td>
<td>20.0%</td>
<td>10.0%</td>
</tr>
<tr>
<td>&gt; 1.6</td>
<td>10.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Table 5-5 Forecast headway ratio with proposed supervision strategy

<table>
<thead>
<tr>
<th>Headway Ratio at Temple</th>
<th>Observed Scenario</th>
<th>Supervision Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;= 0.4</td>
<td>10.0%</td>
<td>20.0%</td>
</tr>
<tr>
<td>0.4 to 0.8</td>
<td>20.0%</td>
<td>30.0%</td>
</tr>
<tr>
<td>0.8 to 1.2</td>
<td>30.0%</td>
<td>40.0%</td>
</tr>
<tr>
<td>1.2 to 1.6</td>
<td>20.0%</td>
<td>10.0%</td>
</tr>
<tr>
<td>&gt; 1.6</td>
<td>10.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Table 5-6 Forecast excess passenger wait time with proposed supervision strategy

<table>
<thead>
<tr>
<th></th>
<th>Scheduled</th>
<th>Observed Scenario</th>
<th>Supervision Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Headway (min)</td>
<td>5.3</td>
<td>5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.5</td>
<td>3.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>0.1</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Expected Wait Time</td>
<td>2.7</td>
<td>3.9</td>
<td>3.3</td>
</tr>
<tr>
<td>Excess Wait Time</td>
<td>1.2</td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>% of Schedule</td>
<td></td>
<td>44.6%</td>
<td>21.2%</td>
</tr>
</tbody>
</table>
5.5 Summary of Case Study

This case study has shown the application of the framework presented in Chapter 3 to the MBTA's Silver Line. By conducting a thorough assessment of the state of reliability and the state of supervisory resources, unreliability causes can be quickly identified and a supervision strategy developed. Using existing supervisory resources more effectively, more consistent departure headways can be achieved at the Temple terminal during the PM peak period. As a result, the average excess passenger waiting time is cut in half as the headway coefficient of variation is reduced.

The lowering of the terminal departure headway variation through supervision will not only benefit passengers waiting at Temple, but should also benefit those waiting downstream. The effect of terminal departure performance on downstream reliability is well documented on Route 20 and the Dudley terminal of the Silver Line as mentioned in sections 4.5 and 5.1 respectively. As terminal departure headways become more consistent at Temple, so should the headways downstream.

The case study has also shown that not only can current supervisory resources be used more effectively, but personnel requirements can be reduced through minimal upgrades in communications and shifts in responsibilities. If the dispatcher is given direct communications with the operator, than the post supervisor position at Temple can be eliminated as headway management moves into the control center. Furthermore, information processing upgrades could allow the dispatcher to manage more routes.
6 Conclusions and Key Findings

This chapter begins with an assessment of the supervision evaluation framework, and then summarizes the key findings from its application to the CTA and the MBTA case studies. Newly raised questions and those left unanswered will be posed pointing the way to future research in this area.

6.1 Framework Assessment

The framework developed and applied in this thesis serves as a tool for transit agencies to use in order to maximize the contributions of their bus supervision force. The steps in the framework were designed to take a system-level approach in assessing supervision resources and service reliability before developing a deployment strategy that reflected this assessment. Once a strategy was developed, evaluation methods at both the system and route level were employed to fine tune it.

Assessing the three major supervision resources – information, communications, and personnel – is necessary to know the potential strengths and weaknesses of the supervision force. These resources will act as constraints on the personnel deployment strategy but will also point the way towards future investments that can have the most impact on deployment and service reliability.

By assessing the state of service reliability, transit agencies will be able to prioritize the most important tasks for supervisors (e.g. incident management, terminal departures) and assign them accordingly. While information and communication constraints will restrict the feasibility of some tasks, a reliability assessment will highlight the most pressing supervision needs and can steer future resource investments accordingly.
After taking inventory of the supervision resources and service reliability problems, a supervision deployment strategy can be developed. This strategy will primarily aim to allocate personnel among the control center, mobile, and post supervisor positions given the current information and communications resources. The allocation serves to take advantage of the inherent strengths in the current resource state while minimizing deployment in areas of weakness. For example, after applying the framework to the CTA, a recommendation of fewer post supervisors and more control center staff emerged as tasks shifted to the control center.

When a supervision deployment strategy has been formed, an evaluation will be necessary to verify if the changes have been beneficial, and to determine what changes can be made to further improve the strategy. At the system level, this means making sure that the right number of personnel are assigned to the right places. Mobile, post, and control center personnel should not be overwhelmed with a large queue of tasks, nor should they be so numerous that there is not enough work to go around. System level reliability indicators should show improvements, and if they do not, the priority of tasks may need adjustments or future resource investments should be looked into. An evaluation at the route level will involve looking for improvements in service reliability and making sure that the causes of unreliability (e.g. terminal departures) have been addressed.

### 6.2 Key Findings

Several findings have come about from this research, both in terms of bus supervision deployment, and service reliability. The following subsections will describe the most important findings.
6.2.1 Resource State and Personnel Deployment

The principle feature of the proposed framework is that as information and communication systems evolve, personnel deployment strategies need to change in order to take advantage of the increase in resources. By repositioning limited personnel resources, changes in information and communications can be harnessed to improve service reliability and possibly reduce personnel requirements at the same time.

The framework has shown that in a very limited resource state, personnel requirements are extremely high since all tasks will have to be done manually. This includes service monitoring, and incident detection and response. Certain tasks such as service restoration prove to be very difficult when resources are so low and this prevents supervisors from significantly improving service reliability.

As resource investments increase, information collection and sharing improves and more tasks are able to be completed. A reliable communications system allows for an effective control center to be established, and for the reallocation of post supervisor positions to mobile positions and developer/analyst positions who can assist in maintaining and developing new decision support tools. In the field, mobile supervisors are able to work with the control center to respond to incidents as well as restore service when delay announcements are made in a timely fashion. Fewer post supervisors are needed as mobile supervisors are able to respond more quickly with improved incident, delay and equipment defect detection and communications. They can continue to contribute in key locations with heavy service levels that require constant supervision.

With advanced real-time vehicle location information, decision support tools and digital communications, the control center will be able to take on most responsibilities, reducing overall personnel requirements even further. Mobile supervisors will still be needed to respond to incidents, but fewer will be required as headway management moves to the control center. Post supervisors will manage the busiest location where they can quickly respond to operator and equipment needs.
6.2.2 CTA Recommendations

In its current resource state, it is recommended that the CTA shift most post supervisors to mobile supervisors. Post supervisors have the best idea of how a route passing them is performing, but are unable to effectively manage headways due to a lack of real-time vehicle information and communications, nor are they able to quickly respond to incidents. Without real-time vehicle location information, supervisors must guess the future state of service delays and instruct operators in advance of the desired service restoration action. Mobile supervisors can respond to incidents as well as delay announcement, but only once C1 announces the delay.

To improve the delay announcement process, the CTA should work with each garage to improve the detection and announcement of hold-ins and delayed pull-outs as soon as possible so that the street can be re-spaced effectively. Currently, garages are too slow to report these delays to the control center, and the control center is too busy with incidents to be able to broadcast the delays when they are received.

The biggest resource problems are a lack of real-time AVL information, and a lack of communications capacity. This may change in the future with projects such as the Real-Time Network pilot project described in Chapter 4. As these resources increase, a personnel deployment shift will be necessary to take advantage of them. Further technological improvements (primarily in the development of exception-based reporting and automatic terminal departure alerts) should be pursued to improve service.

As real-time AVL information comes online, the control center will be able to take care of service monitoring and restoration as well as its previous incident response task. This will require more dispatchers to monitor service as well as communicate with field supervisors the service restoration instructions. Once the system is developed, field personnel requirements should shift from post supervisors to mobile supervisors as
control will be able to deploy supervisors more quickly for incident response and service restoration, and fewer post supervisors will be needed for service monitoring.

If improved communications also comes online, then the control center will be able to take full responsibility for service management and incident response, reducing the need for field supervisors while increasing the need for system support and service management-oriented technically comfortable personnel. Field personnel who are no longer tasked with service management can be reassigned to assist in maintaining and developing decision support tools and response standards, drawing on their extensive experience from being in the field.

6.2.3 Terminal Departures

The case studies on Route 20 and the Silver Line have shown how bus service reliability is able to dramatically improve once bus bunching and headway gaps are managed from the terminals. The effects of the terminal discipline are felt downstream as more buses are able to maintain the scheduled headway after leaving the terminal with the scheduled headway.

It is not cost-effective to place a supervisor at each terminal in order to enforce the scheduled headway and to space the terminal when delays arise. Therefore, it is recommended that the real-time AVL project at the CTA continue its development towards automatic headway monitoring and exception based reporting to control center staff. If any delays are present in the route or network, the automated service management system needs to be able to give instructions directly to operators so that they can adjust their departure times and headways as needed.

A culture of schedule and headway adherence must also be promoted at the operator and supervisory level for service reliability to improve substantially. Bus operators already know their schedule but there is still variability in schedule adherence despite this information. Providing headway information without instilling a culture of headway

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adherence will not help solve the reliability problem. Operators need to know that schedule and headway adherence is important and that they need to make every effort possible to be compliant. Transit agencies could foster this culture in a variety of ways, including strict discipline for non-compliance, or rewards for adhering to schedule/headway. The data is readily available now in the form of archived AVL data, and should be used more intensively as a performance reporting tool.

6.2.4 Headway Degradation

Even with good terminal departure performance, service reliability will degrade along a bus route as shown in the case studies. Traffic variability, signal lights, and dwell time variations will continue to take their toll on service reliability despite the best supervision efforts. To help combat this effect and preserve the efforts made at the terminal, conditional signal priority should be aggressively pursued in combination with far-side bus stops. This investment can help lower overall travel times as well as travel time variability. Smart card use should be promoted to minimize dwell time variability. With these steps in place, bus supervision will be in a better position to promote bus service reliability.

As technology continues to advance, operators should be given their headway information directly in vehicle. This way they can continuously adjust their speed and spacing in order to maintain the scheduled headway.

6.2.5 Power of Technology

The case studies in this thesis have shown the potential impacts of real-time AVL information and improved communications on bus supervision and bus service reliability. Having access to real-time AVL information, supervisors are able to respond more quickly, execute operations control strategies more effectively and are able to spend less time manually monitoring service. Through improved communications, dispatchers are
able to monitor service, while calling on field supervisors to execute operations control strategies and respond to incidents.

6.2.6 Move towards Automation

As information and communications technology continues to evolve, a move towards automation should take place. Real-time AVL information needs to be automatically processed to give dispatchers actionable exception based reported information, such as the locations of bus bunching, headways gaps, and incidents. This way, service management improves and the personnel requirements to monitor service may be reduced. In addition, headway and schedule adherence information should be automatically communicated directly to operators in real-time. This will place terminal spacing and headway maintenance tasks in the hands of operators and should free up field supervisors to perform tasks that require personnel, such as repairs, incident response, and customer service.

With automatic information processing and sharing in place, standardized responses will need to be developed in tandem so that dispatchers, supervisors, and operators will know what is expected of them in any given situation. These responses should be developed from the experience of field supervisors so that they provide optimal results and are practical to implement.

6.3 Future Research

Much of this thesis focused on the development and application of a framework that could be used to analyze service reliability and supervision in order to develop improved supervision deployment strategies. Future work could be completed in applying this framework to other routes or perhaps other agencies to get feedback on its applicability.
While the proposed framework offered suggestions on evaluating different supervision deployment strategies, more work should be done in the development of evaluation tools. These tools could be used to measure supervisor work load, productivity, and effectiveness as well as overall service reliability changes. As communication, information, and personnel resources change, a set of tools are needed to evaluate the current supervision strategy and to help guide the development of new strategies.

Further research could also be done on operator reaction to new technologies such as schedule/headway feedback and text messaging. If the technological improvements suggested here are to help reduce personnel requirements, positive operator response to these improvements needs to be documented.

With regard to supervision evaluation, the Monte Carlo simulation used on Route 20 could be further developed into a tool capable of simulating other routes with similar precision. The development of such a tool would give transit agencies the ability to simulate changes to scheduling, travel times, or other changes as well as supervision before actual implementation.
References


