IMPROVING SERVICE RESTORATION USING AUTOMATIC VEHICLE LOCATION

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College of Engineering
Department of Civil and Environmental Engineering
University of Wisconsin, Madison

Authors: Zhong-Ren Peng(1), Eric Lynde(2), Wei-Ya Chen(1);
(1) Department of Urban and Regional Planning,
College of Design, Construction and Planning,
University of Florida,
Gainesville, FL 32611-5706

(2) Center for Advanced Spatial Information Research
School of Architecture and Urban Planning
University of Wisconsin – Milwaukee
Milwaukee, WI 53211

Principal Investigator: Zhong-Ren Peng;
Professor, Department of Urban and Regional Planning, College of Design, Construction and Planning, University of Florida

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16. Abstract

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ABSTRACT

This study investigates important issues in transit service reliability, namely large service gaps and bus bunching. Using automatic vehicle location (AVL) data from the Route 20 – Madison bus route of the Chicago Transit Authority (CTA), the primary focus is on identifying and establishing conditions that indicate a large service gap is imminent. In addition, the spatial and temporal patterns of large service gaps along the route are illustrated, along with the degree to which large gaps and bunching propagate down the route. Recommendations for improving the service restoration approach at the CTA are also presented based on the AVL data analyses, field observations at the CTA, and interviews with key members of large transit agencies across the United States. Among the recommendations is the implementation of a flag system, which notifies control center personnel that a large service gap is likely to occur so that preventive action can be taken.

EXECUTIVE SUMMARY

A critical issue in transit service is service reliability, which is undermined in particular by large service gaps and bus bunching. Restoring service after these problems arise is important, and preventing them can be even more important. The approach taken in this report is to determine the following:

- Where and when does a large service gap occur?
- How severe is the large gap and does it propagate down the route?
- Are there patterns for these large gaps that appear on trips?
- How can the probability of a large gap occurring be detected?
- If detection is possible, how can large gaps be prevented?
- What other strategies or technologies can be recommended to deal with service reliability issues?

Automatic Vehicle Location (AVL) data from the Chicago Transit Authority's (CTA) Automated Voice Annunciation System (AVAS) were obtained for the Route 20 – Madison bus route for a one-week period, July 9-15, 2007. These data, along with HASTUS schedule data and field observations, were utilized to perform analysis to provide answers to the above questions.

The major findings include:

- The spatial distribution of large service gaps on the route 20 shows that the percentage of trips with large gaps rises continuously between the beginning and end of the route, both eastbound and westbound. The temporal pattern is not as clear, but the afternoon peak period tends to have the highest occurrence of gap trips.
- A large gap at one time point tends to lead to a large gap at the following time point, but the effect is diminished at the next time point. Thus, the propagation of each large gap is only definitive at the immediately following time point and not at time points beyond that. Bus bunching does not appear to propagate from one time point to the next.
- The difference in travel time between two consecutive buses can be used to predict whether or not a large gap is imminent. We have identified conditions or thresholds for different situations in the report. For example, in the morning peak period, when a bus is 2.5 minutes quicker than its scheduled travel time, and its follower is 1 minute slower, a large gap is very likely to result.

Based on the above analysis results and the current practices of major transit agencies across the country, the following actions are recommended:

- Implement a flag system that notifies control center personnel of conditions that will lead to large gaps in service.
- Enhance wireless communications between control center personnel, supervisors, and bus operators so that requested actions can be sent quickly and easily.

- Pursue queue jumping and traffic signal priority technologies to improve an operator's ability to get on time and stay on time.
- Implement headway-holding strategies at terminals and mid-route control points to close large gaps which occur.

Future research in this area should focus on evaluation and implementation of the described aspects of a successful service restoration policy.

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1 INTRODUCTION

The Issues

Reliable service is essential for transit agencies to attract and maintain passengers, and to keep customers satisfied. Unfortunately, there are many factors detrimental to reliable transit service, such as weather, traffic, road construction, poor scheduling, insufficient maintenance, and personal issues of operators. These factors often lead to unreliable services like bus bunching, schedule deviation, and large headway gaps. Service restoration is the process of restoring service to its scheduled time and/or headway by using different techniques.

Traditionally, service restoration is handled by deploying a team of supervisors in the field to monitor, maintain, and restore bus services. But, as well documented in the literature, these field supervisors have not had real-time information about what is going on beyond their visual observations, and there has been poor communication between bus operators, field supervisors and dispatchers in the control center (Pangilinan, 2006). For example, the field supervisor has had access to real-time information on bus operations downstream. This lack of information and poor communication has prevented field supervisors from doing their job of maintaining and restoring reliable services.

Some service restoration techniques have also been proposed to restore services, such as schedule-based holding for low frequency routes and headway-based holding for high frequency routes (Turnquist, 1981). However, due to a lack of real-time information, some strategies are very difficult to implement.

In our case study, on Route 20 at the CTA (not being introduced here yet) typical techniques include switchback, express, put follower ahead, and tradeoff defective bus with a pull-in. Other techniques used sparingly or not at all on the Route 20 may include schedule-based holding, headway-based holding, and fill-in.

The deployment of transit technologies like AVL and APC has provided us an opportunity to address the problems with service reliability, because they provide bus location information in real time. The question is how to best use the information to improve the current service restoration approaches, while also trying to prevent service disruptions from causing major problems in bus operations.

Research Objectives

The purposes of this research project are to address transit service reliability issues at the Chicago Transit Authority (CTA), to identify conditions on bus routes that lead to service unreliability such as large gaps between buses, and to make recommendations on when to use what service restoration strategies and techniques under what conditions. The goal is to reduce service interruptions and improve bus service reliability by making better use of transit technologies like Automatic Vehicle Location (AVL) and wireless communications, while potentially adding new strategies and technologies for these purposes.

This study seeks to first develop a baseline for current practice in CTA in terms of service reliability issues, like large gaps between buses and bus bunching; next, to identify conditions leading to large service gaps by analyzing archived data generated by the AVL system; and finally, to explore new approaches on using AVL systems to improve current techniques.

Four major questions are to be addressed in this research:

1) How serious is the problem of bus trips with large gaps due to unreliable services? Do the service gaps propagate throughout the bus route?
2) What are the main identifiable conditions that tend to lead to large service gaps?
3) How can the CTA identify these conditions in real-time so that proper service restoration actions can be taken?
4) What other suggestions can be made to the CTA to help improve the organization's service restoration approach?

Research Approaches

To answer the above questions, the following tasks have been done:

1) Conduct a thorough literature search and talk with other large transit agencies about available ways to deal with service reliability issues.
2) Analyze AVL data to describe and assess the status of service reliability, particularly service gaps and bus bunching. The major goals of the analysis include:
    a. To identify the relationship of service gaps and bunching between different time points.
    b. To identify different categories of service gap among different time points throughout the route.
    c. To identify conditions that may lead to large service gaps.
3) Identify ways to improve current techniques of service restoration and formulate new approaches to facilitate field supervisors and operators to better deal with service interruptions and restore services.

In order to perform the tasks and answer the questions of this research, the CTA's Route 20 – Madison bus route is used as a case study (see Appendix A for route map). This case study uses AVL (AVAS) data and schedule (HASTUS) data, collected for a one-week period, July 9-15, 2007. The database is used for several analyses described in this introduction, and includes both data sources joined together. Important fields from the database include event time and scheduled arrival time, used to calculate actual and scheduled headways, as well as bus ID, trip ID, run ID, and time point ID, used to identify individual trips and the locations of buses on those trips.

The following approaches and tasks are adopted to address the various research questions and problems posed above.

1. State of Practice Search

We have conducted a thorough literature search in bus operation and management, and service restoration to find out the state of the practice of current techniques used in transit service restoration. In addition, we have worked with CTA staff (field supervisors, operators, and dispatchers) to investigate different techniques being currently used. Furthermore, we have contacted other transit agencies in the United States to investigate different service restoration techniques being used, the pros and cons of each, as well as their use of new technologies for the purpose of service restoration.

2. Determining the Conditions which Lead to Large Service Gaps

The most important task of this research is to determine the conditions which tend to create large service gaps on CTA buses. The effects of large gaps are recorded in the AVL data along with the behavior of buses as they traverse the Route 20. Thus, we have performed several analyses using the AVL data, which help to identify the previously discussed conditions:

1) Gap and bunching regression analysis has been used to determine whether or not large gaps or bunching propagates down the route, causing further disruption to service.
2) Gap trip pattern analysis identifies different patterns of gap propagation down the Route 20.
3) A gap reason analysis is used to try to find conditions in the data which tend to lead to large gaps, so that the CTA can take a preventive approach to service restoration.

3. Making Recommendations for Service Restorations

Based on our understanding of the presence of large gaps and their effect on service, along with the responses from other large transit agencies across the country, we can make some recommendations to improve upon current techniques of service restoration at the CTA.

Based on the data analysis results described above, we have developed a set of recommended improvements to be explored by the CTA. These recommendations involve enhancing the use of current technologies, while adding some new technologies and techniques to the CTA service restoration toolbox.

With the deployment of advanced technologies like AVL, APC and computer-aided dispatching, transit operation and management is clearly moving toward automation. The recommended improvements, as described in this project, will certainly aid the automation process. With real-time information and communication, the dispatchers at the control center can take over the tasks of monitoring bus service and convey service interruption and related information to bus operators in a timelier manner. Lastly, it has fundamental implications that reshape transit service planning and operation management, improving upon current methods while adding new ones.

2 LITERATURE REVIEW

2.1 Introduction

The basis of this research was established in literature previously published that has tried to improve transit service in many ways. The relevant text is found in several distinct topics. The first topic involves service reliability. Because service can be severely disrupted in many ways, such as weather, traffic congestion, or maintenance problems, transit agencies must implement techniques to restore the interrupted service. The use of these techniques is the second topic to be reviewed, because knowing the best strategy to use given a specific situation is extremely important. The third review topic is how to best use the AVL data to identify and improve service reliability. Overall, the literature review serves as a strong foundation for the research presented in this paper.

2.2. Importance of Service Reliability

One of the most important focuses of a transit agency is the reliability of its service. The earliest literature reviewed for the purposes of this paper came from Welding (1957). He asserted that the more regular a service is maintained the lower the average waiting time will be for potential passengers. The opposite is also true, as lower average waiting time leads to a more reliable service. In order to address that, Welding noted that increasing the running time or recovery time allowed for buses on a given route will make service more regular but it becomes impractical due to, among other things, the increased costs that are incurred. Thus, the forewarning of potential service irregularity and the immediate action to correct the problem are a service manager’s best and most practical measure. This is the underlying principle of the research presented in this paper.

Another important aspect of service is the relationship between average waiting time and headway. In some cases, the arrival of passengers to a stop will be random but many times it is not random at all. Turnquist (1978) attacks models that assume the average waiting time for a passenger is equal to one-half the headway, creating a model based on waiting time that includes non-random arrival and service regularity. The implication of the model is that the impact of service improvements can be determined more accurately with the inclusion of non-random passenger arrivals.

2.3 Use of Service Restoration Techniques

Turnquist and Blume (1980) placed control strategies into two groups; planning, which involve changes of a consistent nature, and real-time, which require immediate action to remedy a problem. Their focus on headway control, a way of improving service reliability by holding buses at a control point, allowed the discernment of situations where holding definitely helps, likely will not help, and where more analysis should be done to determine if it will help. These situations are denoted by combinations of proportion of passengers delayed and the headway coefficient of variation.

The major functions of control strategies are to prevent bus bunching and to ensure that buses arrive at transfer points as scheduled (Turnquist, 1981). Turnquist, looking at four distinct categories of control strategies – vehicle-holding, reducing the number of stops made by each bus, signal preemption, and the provision of an exclusive right-of-way – established that bus service frequency is the most important factor in choosing the best strategy. In addition, implementing these strategies involves cooperation between the transit agency and the local government. These are important considerations when examining control or restoration strategies.

Another piece of research on restoration involved the best location for a control point along a bus route (Abkowitz et al., 1986). In another paper, this is addressed along with the optimal threshold headway to be used for holding strategies. The result of the research implied that both the control stop location and the threshold headway were influenced by the passenger boarding profile. A Monte Carlo simulation was used and the resulting output included the headway variation for each combination of scheduled headway, running time, and running time variation that was used in the experiment. Major implications that were seen included that the control point should be located just prior to a group of stops where many passengers will be boarding and that control is more effective near the control point, becoming less and less effective downstream.

Continuing the previous research, Abkowitz and Lepofsky (1990) took a deeper look at headway-based reliability control in real time. This type of control involves holding a bus at a control point until a minimum headway has been reached. The headway-based technique is particularly effective on high frequency routes where the headways are short enough that there is roughly a random arrival of passengers to the stops along the route. This research attempted to improve how regular passengers perceived service to be while also allowing operator resources to be used more efficiently. The research ran into problems, with the street supervisors failing to follow holding instructions and the point checkers failing to obtain adequate field data. This is also very important in the present project as data collection efforts in the field involve coordinating with supervisors and obtaining a sufficient amount of data to make accurate comparisons.

2.4 Use of Automatic Vehicle Location (AVL) Data to Improve Service Reliability

There are many different applications of AVL data that have been conducted and implemented. AVL studies have varied in many ways, including the presence of a simulation model and the type of model used, as well as the type of data, historical (referred to as archived data) or real-time. AVL systems can provide data that may be archived for evaluating bus service or their data can be used to try to improve service in real time. This research recognizes the potential usefulness of archived AVL data to transit agencies, especially in terms of analyzing service reliability. Furth et al. (2003) asserted the important potential for archived AVL and APC data because large amounts of data can be collected at a relatively low cost to the agency. These data, however, must be methodically gathered and stored. Included in this process are numerous questions that, according to Furth et al., aid in determining the precise archived data needs. They fall under four categories:

1. System Design and Data Capture
2. Analysis and Decision Support Tools
3. Quality and Integration of Other Data Sources
4. Organizational Issues

In our case, archived AVL data will be used to model service of a bus route, but improving real-time service reliability with AVL data is one of our major focuses as well.

A review of AVL data uses reveals an array of different approaches. Strathman et al. (2002) made use of archived AVL and APC data to evaluate running time variation, comparing it to Tri-Met's scheduled service. Operator behavior, previously deemed too expensive to study, was determined to be the cause of much of the variation using the data. Given their results, the authors assert that AVL and APC data, as it becomes more widely available, can be very beneficial in validating and/or changing agencies' service standards. In further research, Strathman et al. (2003) were able to use AVL and APC data to determine that deviations in headway lead to passenger overloads and were able to make recommendations as to what control actions should be made given the results. Thus, AVL and APC information was once again demonstrated to have the potential to significantly increase service reliability.

Cham (2006) used time point AVL data downloaded nightly from the MBTA Silver Line's on-board system. As part of her analysis, these data were employed to find what service problems existed along the route as well as the locations where problems were most frequent. Thus, strategies that address the sources of each service issue can be determined more easily and implemented to correct or prevent them.

Particular to the CTA, with which this study is being conducted, Haynes (2007) focused on the conversion of time point location data, obtained from AVL software, into run time data that can be used to improve scheduling efforts at the CTA. While the goals of the current project differ from those of Haynes, the issue of taking such a plentiful amount of automatically collected data and making it into something useable can be a daunting and intimidating task. Haynes has made great strides to develop an interactive, web-based system that makes this task easier for planners and schedule makers to accomplish.

Also specific to the CTA, Pangilinan (2006) noted that the agency's AVL pilot on the Route 20 could aid dispatchers at the control center in making real-time decisions. Focusing more on the communication of information to improve bus service performance, Pangilinan asserted that through a good communication framework and real-time AVL data, service disruptions can be detected automatically at the control center. Dispatchers can then quickly give the appropriate service restoration instructions for field supervisors to implement. A strategy for implementing this type of supervision, given an adequate future state of agency resources, was laid out by Pangilinan with a key component being access to real-time AVL data.

2.5 Literature Review Summary

Throughout the literature review described above, the several main topics were investigated thoroughly. It is apparent that service reliability is important and that there are many factors that affect it. In fact, several strategies for improving reliability have been considered in this review, many of which look at restoring service which has been disrupted. Our current project takes service reliability issues very seriously and intends to seek ways to improve service reliability as well, but also to look at preventive measures which can be taken to maintain reliability. The use of AVL data is instrumental in this attempt to antecede service unreliability, and previous studies have shown its value in enhancing transit performance. The way in which our project differs from those studies is that we aim to find conditions which tend to lead to service gaps so that the control center and/or supervisors can instruct operators to take action to prevent the large gaps from occurring.

3 CURRENT PRACTICES IN THE UNITED STATES

One important piece of this research was to see what is occurring at other transit organizations in major metropolitan areas, in terms of maintaining and improving service reliability. Contacts were made at a number of the largest transit agencies and their responses to our phone questionnaire (see Appendix B) are summarized below. Overall, these summaries give very good insight into new approaches and technologies, as well as time-tested techniques which have proven successful for the respective agencies.

King County Metro Transit

King County Metro Transit, the transit agency that covers Seattle's metropolitan area, operate 269 bus routes with around 1300 buses (1104 in use during the AM peak period and 1136 in use in the PM). The unique hour-glass shape of Seattle causes a great deal of congestion and delay in the central part of the city. This contributes to the way in which Metro handles disruptions and delay. For the most part, delayed buses are allowed to continue running with minimal intervention so that service is not lost. In some instances inserting a bus or expressing a bus is an option, with short-turning a bus as a last resort because of the loss of service and because the AVL system on the bus is thrown off. Preventative measures have been put in place, in the form of traffic signal priority and "queue jumping". Queue jumping allows the bus to get out of its stopped position before the other traffic on the road. The agency is currently in the process of increasing the deployment of both of these technologies and has found both to be very helpful in improving service.

Metro has AVL on 100% of their buses, with its system installed about 15 years ago. This system is signpost-based, as opposed to GPS-based, with times recorded only once a bus enters a time point. It has been good for how old it is and is adept to monitoring service to find problem areas or behaviors. New headway management will become available as the agency's "Rapid Ride" project is completed. In addition, new AVL technologies are expected to be more user friendly, with coordinators more able to control buses and operators constantly reminded if they are running late or early. The plan is to use AVL much more frequently for service restoration in the future.

Communication is currently done through a radio stem, in which a field supervisor can contact the coordinators and they can patch the field supervisor through to the operators. This occurs instantly but can be problematic when coordinators are busy, especially in peak periods. Field supervisors for Metro are assigned to a geographical area with the charge of supervising all the routes in that area. 4 or 5 are located downtown and another 7 or 8 are outside downtown, with a very large county under the agency's coverage. The field supervisors only know the location of buses based on the schedule information, but in the future they will be equipped with computers that display real-time locations.

Los Angeles Metro

Los Angeles Metro owns 2,500 buses, about 1900 of which are in operation on a typical workday, with 122 routes and ridership of about one million daily. The metropolitan area that the agency covers is Los Angeles County, populated by about 4 million residents. AVL, installed on 99% of the buses, is used primarily for locating buses and visually detecting bus bunching. On the rapid bus routes AVL is used to make sure the buses are spaced properly because they are headway-scheduled. Communication is done via 2-way radio through a CAD system. Supervisors are assigned to areas, similar to the CTA system, with special checks usually done on the heaviest rapid routes. When the supervisors are stationed on a route there are usually three of them, located at the beginning, middle, and end of the route. Each supervising unit has AVL so that they can watch buses coming down the street. The downside to their system is that the refresh time for the AVL is five minutes.

The operations philosophy for Metro is just to keep the buses rolling. They do not use holding but instead rely on line bumping or relaying, and only for routes with headways longer than about 20 minutes. Other methods of restoration are not used much if at all. A line bump is when the headway from a breakdown bus is given to its follower to try to decrease the gap caused by the breakdown. The positives of this method are that it tends to cut service delay and overcrowding. The negatives stem from Metro's use of interlining, where an operator goes to one line then deadheads back to another line to work that one. Thus, a line bump or relay may cause a longer delay on the other route. The effects of the methods are observed using Metro's ATMS system, where scheduling and planning look at the data for ridership numbers. Presently, the agency is satisfied with its methods and does not intend to change them in the near future.

Massachusetts Bay Transportation Authority (MBTA)

MBTA owns 1000 buses with a peak pullout of 803 buses. There are 220 routes which include 1.1 million trips per weekday. The agency operates on a $1.26 billion budget to serve over 2.6 million people in the greater Boston area. Only about 7% of MBTA's buses on three routes are fully equipped with the AVL system. However, MBTA is in the process of rolling out a new CAD/AVL system so that number is anticipated to be rising quite soon.

Dispatchers at MBTA can see the locations of all buses with AVL, along with the adherence and relative position of all the buses. Thus, headway problems that might go unreported until later can be seen immediately, facilitating faster intervention. In the event of a more serious disruption, more informed decisions can also be made based on the knowledge of where all buses are. Overall, MBTA sees AVL technology as a great opportunity but a challenge as well. Learning the best way to use the system is a process that they are currently undertaking because AVL in and of itself cannot redistribute responsibility or make decisions.

The service restoration policy at MBTA is to return operators to schedule as quickly as possible with as little negative impact on customers as possible. To do this, they mostly rely on expressing buses. Expressing occurs when two or more buses are bunched. The first bus in the bunch will be expressed to a pre-determined point, where it will again begin to pick up passengers. The downsides to this method are that it is not very customer-friendly and often times the same conditions which caused the first bus to be delayed (traffic, etc.) will make expressing ineffective. In addition to expressing, short-turning is used occasionally. On certain routes buses have the ability to drop passengers off at their destinations just before the terminal, then turn back outbound and begin its return trip without dwelling at the terminal. The new CAD/AVL system has been used to find even more locations where this is possible.

The benefits of holding have been recognized at MBTA and various attempts have been made to implement this strategy. It has generally been unsuccessful but there is hope that the new system will help. Holding is used at terminals in cases where there is a bus running 10-15 minutes late approaching the terminal. In this case, buses waiting to depart from the terminal will be held to try to close the gap. MBTA is also looking at mid-route holding where, if a bus is running early approaching a published midpoint, it is held to get it back on time. Also, in these cases MBTA is trying to train operators to drag the line so that they maintain their schedule. For the most part, holding is seen as a very beneficial method, but it requires officials on the street to have a lot more knowledge of where buses are on the route. Thus, a CAD/AVL system must be in place to make it work. The hope at MBTA is that the new system will allow the movement from a reliance on expressing to an increased holding emphasis. In addition, traffic signal priority is being investigated and piloted, with the hopes of a system-wide rollout.

Metro St. Louis

Metro St. Louis has a unique situation due to its geography. Across the state boundary, the agency has a sister operator, Madison County Transit (MCT). There are 400 buses owned by Metro and 76 owned by MCT. 330 Metro buses and 64 MCT buses are in operation on a typical workday, covering 80 Metro routes and 20 MCT routes. There are 54 million annual riders for Metro and 2 million for MCT, served by budgets of $200 million and $12 million, respectively. The service areas consist of 1.75 million people for Metro and 250,000 for MCT.

In terms of AVL, only 64 of the 400 Metro buses have AVL installed. Presently, the system is not used for service restoration, rather it used to evaluate where and why disruptions occur as well as to retime routes. Dispatchers are focused mostly on answering radio calls, not on proactively managing the system.

In terms of restoration, if a service disruption is of significant duration, another bus will be added to pick up missed service. Normally, this occurs if the delay will exceed the headway or if the bus can be dispatched quickly. If the delay occurs at a time when other buses and drivers are turning in, dispatch will request assistance to fill in the service. Turnback operators are also put in for some cases to get drivers back on schedule. If there is a missed trip or an operator is later than the next bus, a late bus may be deadheaded to the end of the line to start the next trip on time. This is used for accidents or delays that are long enough that the next bus has caught up. MCT utilizes strategic buses, similar to that of WMATA, which can be deployed to carry an overload or address a missed trip.

The effects of employed methods have been observed by monitoring via radio but data have not been analyzed to show effectiveness. They have seen that expressing or deadheading is very effective for getting a bus back on schedule but the lost service behind the expressed bus often causes the follower to become overloaded and delayed. In cases where recovery time is enough to cover a delay the turnback method works well but if the delay is more substantial the bus may not be able to get back on time. Overall, Metro’s current methods will likely continue to be used, although the agency may adopt some of the methods used by MCT.

New York City Transit (NYCT)

The NYCT is a very large agency, with over 4000 buses. During the typical workday about 90% of those buses are put in use on the over 5000 bus routes which are operated. For the “big bus” service, as NYCT refers to it, only 2% of the buses have AVL. However, they are looking forward to increasing this number to about 10% in 2008 and are in the process of piloting a new bus depot that will cover 4 or 5 routes. The AVL system is used primarily for bus bunching, to hold buses at certain control points along the route. The control points are decided based on whether or not they are physically good places to hold a bus and are generally found at major points along the route or at the endpoints.

In Manhattan, all routes are major with high frequency service and congested conditions making headway-based holding the favored service restoration method. However, data has not been collected on the effectiveness of the holding strategies because they are just recently starting to use AVL for this purpose, and the projects underway are still in their infancies. NYCT has been able to observe the effects, with the alleviation of bus bunching and more regular schedule adherence noticeable. The AVL has also given the ability to see where buses are, which has been very helpful for control purposes and, thus, maintaining service reliability.

In terms of other restoration actions, the geometry of New York City streets makes it difficult and more complicated to implement measures such as short-turning. Other measures such as expressing are being explored but are not currently widespread. The pilot project is only on a few routes right now so the methods being used have not permeated the entire system yet, but monitoring alone gives much more ability to hold buses and have a better idea where the buses are.

For communication purposes, Nextel Push-to-talks are used, messaging can be used to notify buses of bad or clear areas, and notification of the rescheduling of a run can be sent through the AVL system. The last communication ability occurs through an interface between a separate scheduling system and the AVL system, with the operator receiving the notification through AVL. Field supervisors generally communicate via walkie-talkie, but are not out on route very often. When they are, there are usually 3 or 4 during peak periods and they record the arrival and departure times of buses and check in on drivers. The expectation is that some of the need for field supervisors will decrease with the increase in AVL usage.

Tri-County Metropolitan Transportation District of Oregon (Tri-Met)

Portland Tri-Met owns 606 buses, operating about 80% of them at peak times over 92 routes. They serve a population of about 1.4 million, with an annual budget of $823 million and an annual ridership total of about 96.9 million. Tri-Met tries to focus on scheduling as a way of maintaining performance and does not utilize restorations very frequently. Of the limited intervention that they do, short-turning a bus or expressing a bus is most common. They also have traffic signal priority in the form of Opticom emitters, installed on each bus, which operators can use to request longer greens or shorter reds at upcoming signals. Tri-Met has noticed systemic improvements in running time variation with traffic signal priority implementation, saving the agency money because not as much schedule time needs to be allowed.

All of their buses are equipped with AVL technology. This technology is about 10 years old, making Tri-Met one of the first to install this type of equipment. There are a lot of data collected via data cards which operators load into the bus when they make runs. These data are uploaded daily and analysis and reports are then generated regularly from them. In addition, the agency has an incident tracking database, designed to determine the number of lost service hours incurred due to events such as accidents, delays, and missed pullouts. A report from this source is regularly generated with the information used to attempt to minimize future lost service in the future.

Tri-Met's ultimate goal is to make everything as automated as possible, so that they can avoid sending people out to tend to problems. With the development of a new AVL system, the agency hopes to increase its functionality. This process is in the planning phase, with a request for proposals to be sent out in the next few months. Currently headway-based holding is not performed, but the new AVL system will likely allow for this to be done.

VIA Metropolitan Transit

San Antonio VIA owns 448 buses, 354 of which are in service on a typical workday. There are 91 bus routes and 41.3 million annual riders served by a $145 million budget. The population of the area served is 1.3 million. All of VIA's buses are equipped with AVL, which is used for service restoration purposes. Dispatchers use the TransitMaster BusOps application to monitor the fleet in real-time. Through this they can immediately see where a specific bus or an entire route is indicating headway problems. Specific features include the Schedule tab which tracks route blocks by time point and visually provides the actual adherence and the projected arrival at the next time point. The Route tab is used the same way but can display all blocks or buses by direction or all trips simultaneously. The Roster tab and Pull-out/pull-in tab are used can be used to determine if a bus is late pulling out to start a run or pulling in to end a run. The map feature and route ladder show dispatchers up-to-date information on where buses are located to detect service disruptions and how to deal with them.

The methods used to restore service at VIA include spacers/overloads, turnbacks, bus changes, schedule changes, and short loops. Spacers/Overloads are done when a bus is running late and involve putting another bus in at a time point so that when the late bus gets to the time point it will run on time. For turnbacks, a late bus turns back to get on time and can be decided upon by the operator. There are two types of bus changes; a dead bus and a change along the route. The determining factors for which method to use include service time of day, headway problems, and mechanical breakdowns. Mechanical breakdowns are generally solved using a bus change. Observations of the effects of each method are done immediately through the TransitMaster AVL system, which updates every 60 seconds. They are also made by analyzing daily canned and custom reports for adherence by route, block, operator, and vehicle.

While new technology may make other methods possible in the future, VIA is not planning on changing because the current methods work well. Traffic signal priority is a possibility but would require a different transponder.

Washington Metropolitan Area Transit Authority (WMATA)

WMATA owns 1,475 buses, 1,203 in operation on a typical workday, covering 338 routes. It serves a population of 3.5 million people with a budget of $1.9 billion and has an annual ridership of 131.5 million. 100% of the buses are equipped with AVL technology, which is used for service restoration purposes by monitoring interruptions through the CAD/AVL performance queue. The system indicates the on-time performance of each bus in revenue operation, with all delays managed by voice radio communication and real-time fleet management. A new AVL system is anticipated in 2008, with more monitoring ability available.

WMATA uses strategic buses to restore disrupted service. When a disruption occurs it is reported to the Bus Operations Control Center (BOCC), which then calls the operator who is standing by with the strategic bus. The bus is then deployed at a strategic location within the service area to minimize the disruption. BOCC decides where to place the buses based on how close the location is to stations and whether or not it is a good place to enter the route. The number of strategic buses available varies by time of day; 16 in the AM, 9 in the midday, and 22 in the PM. WMATA also uses reblocking buses and bus bridges to restore service. Short-turning is only used when there is construction or a blockage, holding is not used much, and pulling a bus off one route to restore service on another tends to be ineffective. Strategic buses are always preferred because there are enough deployed that other methods are seldom used.

WMATA observes the effects of their efforts through the performance queue of its CAD/AVL system, in addition to the street monitoring and reports written by street supervisors. The queue shows if a bus is late or early. The controller then asks the operator why the bus is late or early. Operators are required to report when they are late and controllers can then call for a strategic bus if need be. The performance queue indicates the number of blocks a bus is late as well as a count of the number of trips lost.

In the future, controllers will be able to tell if a bus is overloaded through the new AVL system. In addition, 100% operator sign-on, access to video cameras on the street to visually manage the fleet, real-time traffic flow from the city traffic control system, and traffic signal priority are planned or are being considered. The agency is also attempting to include a contract provision which would allow penalty when an operator is in violation of reporting requirements and when tardiness or service disruption is attributable to an operator’s action or inaction.

4 ANALYSIS AND RESULTS

Introduction

The current operations of other transit agencies, in terms of maintaining service reliability, demonstrate potential applications that can be made at the CTA. The analysis section investigates current operations at the CTA, and aims to look within the CTA for potential areas of improvement. The results of several analyses, along with the state of the practice, will provide the basis of our conclusions and recommendations.

The following analyses, including figures and tables, describe the research conducted to determine various aspects of gaps and bunching along the Route 20 in Chicago. The methodology for each type of analysis is a detailed account of how the analysis was performed and all of the steps involved. The results obtained from each type of analysis include any summary tables produced along with interpretations that lead to the bottom-line, which is the most important piece to take away from each analysis.

The analysis section includes the following elements:

1) A summary of total gaps showing the existence of large gaps along with the location and time periods in which they exist.
2) A gap and bunching regression analysis demonstrating the severity of large gaps and the degree to which they propagate down the route.
3) A look at what patterns exist for gap trips in terms of the fluctuation of headway ratios at time points along the route.
4) Establishing conditions or thresholds which tend to lead to large gaps in service and so may be used to prevent such gaps from occurring.

The data used in the analysis come mainly from two sources. The first is a static data source called HASTUS which includes schedule data with fields such as trip number, sequence, pattern ID, time point ID, and schedule time. The other source is AVAS, which consists of active data reported from the buses themselves. Within the AVAS data the fields include bus ID, trip ID, run ID, time point ID, event time, and dwell time. These data were obtained for a week's time, July 9-15, 2007, for the Route 20 – Madison. A solitary database was then created by joining the AVAS data collected from each bus to the HASTUS data which has the times each bus is scheduled to reach each time point (see Appendix C for an example of the database). This database is at the time point level, reflecting the schedule data's format.

An important measure used in the analysis is the headway ratio. To calculate it the actual headway at a time point is divided by the scheduled headway at the same time point. The headway ratio can be used to indicate bus bunching as the ratio nears zero or the presence of large service gaps when the ratio is high. Large gaps are identified using the internal CTA standard of headway ratios of

1.5 or greater. From the data it is also possible to calculate measures like the difference between the actual and scheduled times at a time point or the difference between the actual and expected travel times between two time points.

Summary of Total Gaps and Trips by Time Point/Direction/Time of Day

Methodology

The goal of this analysis was to compare gap trips to total trips to get a sense of how the Route 20 operates in terms of the frequency and location of large gaps. For this analysis, the number of gap trips was determined for each time point and time period. A gap trip is a trip that has at least one large gap at a given time point. To begin, any record with a large gap was identified, as previously defined. These records were then totaled according to their time points and the time periods they fell into. The total trips were then summed in the same way, with all trips included.

Results

Tables 1-3 summarize the comparison of gaps trips to total trips. Table 1 is the raw number of gap trips at each of six major Route 20 time points, for each time period. Tables 2 and 3 give the number of gap trips and total trips as well as the percentage of gap trips, for each time point and time period.

Table 1: Number of Gap Trips at Each Time Point

Time Period	Direction	Austin	Cicero	Pulaski	Kedzie	Ashland	Halsted	Michigan	Wabash	Columbus	Total
6:30am-9:00am	eastbound	14	18	12	11	17	23	28	3	27	153
	westbound	40	40	32	19	22	21	13	3	10	200
9:00am-3:00pm	eastbound	45	46	48	57	61	69	69	63	8	466
	westbound	91	88	83	79	67	56	5	47	7	523
3:00pm-6:00pm	eastbound	17	32	35	36	31	33	47	10	32	273
	westbound	55	54	48	48	39	39	22	6	23	334
6:00pm-12:00am	eastbound	20	31	37	29	41	44	40	31	7	280
	westbound	45	43	44	45	31	25	6	21	4	264
Total	eastbound	96	127	132	133	150	169	184	107	74	1172
	westbound	231	225	207	191	159	141	46	77	44	1321

Directions: eastbound (direction 3), westbound (direction 4).

From the results in Tables 2 and 3 a general pattern can be seen and a better understanding of how the Route 20 operates can be obtained. Overall, the pattern for time points is similar in both directions. Eastbound, the percentage of gap trips increases going east along the route. The beginning time point, Madison/Austin, has 10.78% gap trips overall while the ending time points, Madison/Wabash and Randolph/Columbus, have 21.59% and 24.10%, respectively. The percentage of gap trips rises continuously between the beginning and end of the route, as well. Westbound, the pattern is similar. The beginning time points, Randolph/Columbus and Madison/Wabash, have 13.13% and 18.57% gap trips overall, respectively, while the ending time point, Madison/Austin, has 26.66%. Again, the percentage of gap trips rises continuously between the beginning and end of the route.

When broken into time periods, however, the pattern is not quite as clear. In most cases the percentage of gap trips increases going through the day but in several cases this is not true. The peak afternoon period (3:00pm-6:00pm) tends to have the highest occurrence of gaps, with some anomalies occurring mostly in the eastbound direction in the evening hours.

Table 2: Total Trips and Gap Trips by Time Point – Eastbound

Time Period	Timepoint→ Trip↓	Austin	Cicero	Pulaski	Kedzie	Ashland	Halsted	Michigan	Wabash	Columbus	Total
6:30am-9:00am	Gap trips	14	17	12	11	16	20	23	0	27	140
	Total trips	125	130	148	141	137	139	131	13	117	1081
	Gap trip %	11.20%	13.08%	8.11%	7.80%	11.68%	14.39%	17.56%	0.00%	23.08%	12.95%
9:00am-3:00pm	Gap trips	36	38	35	40	41	47	50	44	8	339
	Total trips	257	268	270	240	239	237	234	183	45	1973
	Gap trip %	14.01%	14.18%	12.96%	16.67%	17.15%	19.83%	21.37%	24.04%	17.78%	17.18%
3:00pm-6:00pm	Gap trips	12	24	27	28	25	25	36	0	32	209
	Total trips	150	155	168	136	137	136	139	0	132	1153
	Gap trip %	8.00%	15.48%	16.07%	20.59%	18.25%	18.38%	25.90%	N/A	24.24%	18.13%
6:00pm-12:00am	Gap trips	14	23	26	25	33	33	30	21	7	212
	Total trips	173	171	174	142	142	141	124	105	13	1185
	Gap trip %	8.09%	13.45%	14.94%	17.61%	23.24%	23.40%	24.19%	20.00%	53.85%	17.89%
Total	Gap trips	76	102	100	104	115	125	139	65	74	900
	Total trips	705	724	760	659	655	653	628	301	307	5392
	Gap trip %	10.78%	14.09%	13.16%	15.78%	17.56%	19.14%	22.13%	21.59%	24.10%	16.69%

Table 3: Total Trips and Gap Trips by Time Point – Westbound

Time Period	Time point→ Trip↓	Austin	Cicero	Pulaski	Kedzie	Ashland	Halsted	Michigan	Wabash	Columbus	Total
6:30am-9:00am	Gap trips	39	40	31	18	21	19	13	0	10	191
	Total trips	148	152	151	107	109	107	105	0	103	982
	Gap trip %	26.35%	26.32%	20.53%	16.82%	19.27%	17.76%	12.38%	N/A	9.71%	19.45%
9:00am-3:00pm	Gap trips	69	67	66	64	56	50	5	39	7	423
	Total trips	251	262	281	257	253	255	45	201	46	1851
	Gap trip %	27.49%	25.57%	23.49%	24.90%	22.13%	19.61%	11.11%	19.40%	15.22%	22.85%
3:00pm-6:00pm	Gap trips	45	42	40	40	31	34	22	0	23	277
	Total trips	155	156	157	153	156	154	139	0	132	1202
	Gap trip %	29.03%	26.92%	25.48%	26.14%	19.87%	22.08%	15.83%	N/A	17.42%	23.04%
6:00pm-12:00am	Gap trips	40	38	41	39	23	23	6	18	4	232
	Total trips	170	171	190	172	172	171	55	106	54	1261
	Gap trip %	23.53%	22.22%	21.58%	22.67%	13.37%	13.45%	10.91%	16.98%	7.41%	18.40%
Total	Gap trips	193	187	178	161	131	126	46	57	44	1123
	Total trips	724	741	779	689	690	687	344	307	335	5296
	Gap trip %	26.66%	25.24%	22.85%	23.37%	18.99%	18.34%	13.37%	18.57%	13.13%	21.20%

Bottom-line:

The percentage of trips with large gaps tend to increase as buses travel along the route in both the eastbound and westbound directions, with higher gap trip percentages at the end of the route than at the beginning, and the amount of trips with gaps seem to increase along the route. Comparing time periods does not yield an obvious pattern, but the peak afternoon period tends to have the highest occurrence of gap trips. The exceptions are mostly eastbound, where several time points have higher gap trip percentages in the evening hours.

Gap and Bunching Propagation Analysis

Methodology

The gap and bunching regression was based on the definitions of gap (previously defined) and bunching, which is the arrival of two buses at a given time point within 1 minute of one another. The objective of this analysis is to see if the gap and bunching trips propagate into next time points. Separate regression models were run for records with large gaps and for records where bunching occurred. Within each model, the dependent variable is the actual headway at a given time point and the independent variable is actual headway at the previous time point.

Once the regressions were run for each given time point and previous time point, those sets of records with high R^2 (>= 0.8) and relatively large sample sizes (>= 20) were looked at in more detail. An additional previous time point was added to the regression so that the impact of actual headway at two previous time points could be examined to determine whether and how far the gap trips propagate to the next time points.

Results

The regression results for bunching were left off because there were very few significant coefficients. This is a significant finding, however, because it indicates that bunching, as it is defined, does not propagate into following time points. The most plausible reasons for this result are that the follower in a bunch overtook its leader between time points or that a restoration action, such as expressing or switching back a bus, eliminated the bunch.

Tables 4-12 show the result of regression models for gap trips for the major time points. The results show that the actual headway at the previous time point has a significant impact on the actual headway at the following time points. The R^2 values are quite high in most cases, indicating there is a strong relationship between the actual headway at the current time point and the actual headway at a previous time point. The positive coefficients, mostly slightly less than 1, indicates that once the bus is delayed in the previous time point, it tends to lead to delay in the following time point and service gaps do propagate to the next time point for the most part. But the effect of propagation diminishes as indicated by the less than one coefficient.

Table 4: Regression Result of Gaps at Madison and Ashland

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	3	0.316	6.665	4.642	Headway	0.377*	2.449	15
9:00am-3:00pm	3	0.553	5.551	3.993	Headway	0.673*	6.764	39
3:00pm-6:00pm	3	0.674	2.797	1.650	Headway	0.903*	6.741	24
6:00pm-12:00am	3	0.703	0.728	0.283	Headway	1.097*	8.431	32
6:30am-9:00am	4	0.936	0.885	1.212	Headway	0.946*	16.288	20
9:00am-3:00pm	4	0.886	1.774	2.667	Headway	0.897*	20.330	55
3:00pm-6:00pm	4	0.835	2.445	2.579	Headway	0.875*	12.110	31
6:00pm-12:00am	4	0.906	4.809	4.783	Headway	0.759*	14.235	23

**: with significance level below 5%*
Previous time points: Kedzie (Direction 3), Halsted (Direction 4)

Table 5: Regression Result of Gaps at Madison and Austin

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	4	0.349	6.464	6.744	Headway	0.415*	4.453	39
9:00am-3:00pm	4	0.709	4.437	4.971	Headway	0.765*	12.277	64
3:00pm-6:00pm	4	0.858	1.788	2.460	Headway	0.875*	15.724	43
6:00pm-12:00am	4	0.792	3.816	2.876	Headway	0.847*	12.027	40

**: with significance level below 5%*
Previous time points: Cicero (Direction 4)

Table 6: Regression Result of Gaps at Madison and Cicero

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	3	0.674	4.728	4.961	Headway	0.513*	5.181	15
9:00am-3:00pm	3	0.682	4.120	3.493	Headway	0.730*	8.151	33
3:00pm-6:00pm	3	0.483	6.845	6.335	Headway	0.466*	4.099	20
6:00pm-12:00am	3	0.848	0.329	0.152	Headway	1.131*	10.017	20
6:30am-9:00am	4	0.794	3.590	5.719	Headway	0.694*	11.457	36
9:00am-3:00pm	4	0.859	3.988	7.101	Headway	0.774*	19.723	66
3:00pm-6:00pm	4	0.800	3.100	3.748	Headway	0.795*	12.644	42
6:00pm-12:00am	4	0.747	4.310	2.802	Headway	0.889*	10.153	37

**: with significance level below 5%*
Previous time points: Austin (Direction 3), Pulaski (Direction 4)

Table 7: Regression Result of Gaps at Randolph and Columbus

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	3	0.266	7.491	5.845	Headway	0.322*	2.883	25
9:00am-3:00pm	3	0.580	6.170	2.163	Headway	0.568	2.349	6
3:00pm-6:00pm	3	0.457	3.617	1.462	Headway	0.832*	4.587	27
6:00pm-12:00am	3	0.667	2.617	0.428	Headway	0.901*	2.832	6

**: with significance level below 5%*
Previous time points: Michigan (Direction 3)

Table 8: Regression Result of Gaps at Madison and Halsted

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	3	0.583	3.787	3.068	Headway	0.619*	4.580	17
9:00am-3:00pm	3	0.587	3.786	2.540	Headway	0.823*	7.902	46
3:00pm-6:00pm	3	0.875	3.186	3.454	Headway	0.837*	12.391	24
6:00pm-12:00am	3	0.912	-0.589	-0.446	Headway	1.069*	17.294	31
6:30am-9:00am	4/Wab	-	-	-	Headway	-	-	0
6:30am-9:00am	4/Mch	0.757	1.120	0.721	Headway	0.962*	7.062	18
9:00am-3:00pm	4/Wab	0.447	6.339	3.667	Headway	0.674*	5.547	40
9:00am-3:00pm	4/Mch	0.036	7.112	1.498	Headway	0.24*	0.513	9
3:00pm-6:00pm	4/Wab	-	-	-	Headway	-	-	0
3:00pm-6:00pm	4/Mch	0.735	4.322	4.617	Headway	0.750*	9.421	34
6:00pm-12:00am	4/Wab	0.537	5.492	1.657	Headway	0.756*	4.026	16
6:00pm-12:00am	4/Mch	0.722	7.414	2.505	Headway	0.620*	3.601	7

**: with significance level below 5%*
Previous time points: Ashland (Direction 3), Wabash and Michigan (Direction 4)

Table 9: Regression Result of Gaps at Madison and Kedzie

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	3	0.625	4.695	3.007	Headway	0.598*	3.655	10
9:00am-3:00pm	3	0.478	7.424	6.291	Headway	0.533*	5.662	37
3:00pm-6:00pm	3	0.382	6.149	2.874	Headway	0.584*	3.144	18
6:00pm-12:00am	3	0.801	5.702	2.926	Headway	0.771*	7.772	17
6:30am-9:00am	4	0.731	3.729	2.644	Headway	0.797*	6.795	19
9:00am-3:00pm	4	0.791	3.144	3.838	Headway	0.856*	15.173	63
3:00pm-6:00pm	4	0.838	3.548	4.752	Headway	0.826*	14.002	40
6:00pm-12:00am	4	0.880	1.127	1.022	Headway	1.031*	16.036	37

**: with significance level below 5%*
Previous time points: Pulaski (Direction 3), Ashland (Direction 4)

Table 10: Regression Result of Gaps at Washington and Michigan

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	3	0.293	7.848	5.581	Headway	0.425*	2.653	19
9:00am-3:00pm	3	0.481	5.587	3.843	Headway	0.662*	6.382	46
3:00pm-6:00pm	3	0.542	6.162	4.690	Headway	0.618*	6.054	33
6:00pm-12:00am	3	0.826	2.985	1.713	Headway	0.906*	10.877	27
6:30am-9:00am	4	0.520	6.023	4.641	Headway	0.519*	3.452	13
9:00am-3:00pm	4	0.034	10.961	3.432	Headway	-0.143	-0.378	6
3:00pm-6:00pm	4	0.147	8.042	3.523	Headway	0.309	1.607	17
6:00pm-12:00am	4	0.996	0.910	1.800	Headway	0.964*	33.714	6

**: with significance level below 5%*
Previous time points: Halsted (Direction 3)

Table 11: Regression Result of Gaps at Madison and Pulaski

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	3	0.293	4.501	1.647	Headway	0.538	1.930	11
9:00am-3:00pm	3	0.533	6.736	5.978	Headway	0.503*	5.851	32
3:00pm-6:00pm	3	0.015	10.577	7.351	Headway	0.056	0.497	18
6:00pm-12:00am	3	0.822	3.590	1.799	Headway	0.794*	9.366	21
6:30am-9:00am	4	0.832	1.895	1.466	Headway	0.781*	7.030	12
9:00am-3:00pm	4	0.895	2.146	3.603	Headway	0.893*	21.252	55
3:00pm-6:00pm	4	0.923	1.166	1.963	Headway	0.902*	20.755	38
6:00pm-12:00am	4	0.975	1.892	3.869	Headway	0.917*	34.439	33

**: with significance level below 5%*
Previous time points: Cicero (Direction 3), Kedzie (Direction 4)

Table 12: Regression Result of Gaps at Madison and Wabash

Time Period	Direction	R Square	Constant	T Value	Coefficient (T_{-1})		T Value	N
6:30am-9:00am	3	-	-	-	Headway	-	-	0
9:00am-3:00pm	3	0.312	8.474	4.902	Headway	0.440*	4.153	40
3:00pm-6:00pm	3	-	-	-	Headway	-	-	0
6:00pm-12:00am	3	0.955	1.863	1.754	Headway	0.929*	19.983	21

**: with significance level below 5%*
Previous time points: Michigan (Direction 3)
Note: Patterns for the Route 20 do not run through Madison and Wabash in the AM and PM peak periods.

Table 13 is a gap regression analysis for three consecutive time points. The results confirm that a previous time point’s headway tends to have a positive yet decreasing impact on the current service gap but going back to the second previous time point, there appears to be no or little relationship. Thus, it appears that a large gap does not necessarily propagate down the route from time point to time point beyond the immediately following time point. A potential reason for this result may be that large gaps were more easily identified when they covered multiple time points and restoration actions were then be taken by field supervisors to reduce the size of each gap.

Table 13: Three Time Point Regression Result for $R^2 > 0.8$ (and $N > 20$) in Tables 4-12

Time Period	Time Point	Dir	Gap regression with actual headway of two previous time points: T_{-1} and T_{-2}									
			R Square	Constant	T Value	Coefficient (T_{-1})		T Value	Coefficient (T_{-2})		T Value	N
6:30am-9:00am	MadAsh	4	0.937	0.858	1.143	Headway	0.882*	5.387	Headway	0.071	0.423	20
9:00am-3:00pm	MadAsh	4	0.898	1.536	2.204	Headway	1.029*	13.606	Headway	-0.137	-1.652	52
3:00pm-6:00pm	MadAsh	4	0.878	2.135	2.560	Headway	0.665*	7.248	Headway	0.264*	3.165	31
6:00pm-12:00am	MadAsh	4	0.904	4.465	4.026	Headway	0.791*	7.549	Headway	-0.018	-0.185	22
3:00pm-6:00pm	MadAus	4	0.625	4.304	4.010	Headway	0.679*	3.241	Headway	0.025	0.123	45
9:00am-3:00pm	MadCic	4	0.824	3.042	3.762	Headway	0.686*	5.917	Headway	0.068	1.126	24
3:00pm-6:00pm	MadCic	4	0.803	3.083	3.606	Headway	0.561*	2.296	Headway	0.241	1.030	40
3:00pm-6:00pm	MadHal	3	0.877	3.070	3.203	Headway	0.918*	5.856	Headway	-0.085	-0.578	24
6:00pm-12:00am	MadHal	3	0.935	0.300	0.254	Headway	1.323*	13.817	Headway	-0.334*	-3.212	31
3:00pm-6:00pm	MadKed	4	0.838	3.544	4.690	Headway	0.876*	5.458	Headway	-0.053	-0.334	40
6:00pm-12:00am	MadKed	4	0.880	1.325	1.039	Headway	0.963*	3.596	Headway	0.063	0.262	37
6:00pm-12:00am	WasMch	3	0.842	3.679	2.106	Headway	1.416*	4.277	Headway	-0.581	-1.589	27
6:00pm-12:00am	MadPul	3	0.835	4.481	2.293	Headway	1.062*	4.499	Headway	-0.357	-1.233	20
9:00am-3:00pm	MadPul	4	0.892	2.296	3.669	Headway	0.909*	10.309	Headway	-0.026	-0.315	53
3:00pm-6:00pm	MadPul	4	0.927	0.813	1.275	Headway	0.987*	7.779	Headway	-0.069	-0.588	37
6:00pm-12:00am	MadPul	4	0.945	2.389	3.426	Headway	0.883*	8.317	Headway	-0.010	-0.085	36
6:00pm-12:00am	MadWab	3	0.957	1.771	1.500	Headway	0.724*	4.989	Headway	0.219	1.500	18

**: with significance level below 5%.*

Note: Madison-Cicero/Direction 3/6:00pm-12:00am was excluded because there are less than two previous time points.

Bottom-line:

The results indicate that a large gap at one time point leads to a large gap in the following time point, although the gap tends to be slightly smaller in the next time point. But a large gap does not necessarily propagate down the route beyond the next immediate time point. This result may be caused by easier identification of a large gap when it spread over multiple time points and subsequent actions by field supervisors to reduce the gap.

Category Analysis of Gap Trips

Methodology

The objective of this analysis was to establish the daily patterns for gap trips among time points on the Route 20. Several different types of gap changes were investigated, including increasing gaps, decreasing gaps, increasing then decreasing gaps, and decreasing then increasing gaps. Each of these will be broken down and explained more thoroughly in the following section. In general, each type of gap change was determined by looking at the changes of the headway ratio at each time point over individual trips.

In addition, a summary of all gap trips by time period was included. For this part, each individual trip was followed along the route and the number of large gaps in each trip was counted. These trips were then categorized by the number of gaps each incurred and the time period in which they occurred.

Results

Tables 14-23 reveal different types of gap trips found in this analysis. Tables 14 and 15 are summaries of the number and percent of gap trips found in each time period. A “one gap trip” is defined as one large gap occurring on a trip. So a “two gap trip” has two large gaps, a “three gap trip” has three large gaps, and so on. But these multiple gaps do not necessarily represent consecutive gaps. The distributions are similar in each direction. Most trips incurring large gaps have these gaps at more than one time point, but the number of trips in each gap trip type gets fewer and fewer as the number of gaps increases. This indicates again, that large gaps may not propagate down the route to a high degree. In terms of time periods, there is no definitive pattern. It should be noted that midday (9:00am-3:00pm) has more gap trips and higher percentages, but also has significantly more total trips.

Table 14: Summary of Gap Trips by Time Period – Eastbound

Time Period	Total Trips	One Gap Trips		Two Gap Trips		Three Gap Trips		Four Gap Trips		Five Gap Trips		Six Gap Trips		Seven Gap Trips		Eight Gap Trips	
6:30am-9:00am	150	16	10.67%	13	8.67%	8	5.33%	3	2.00%	3	2.00%	2	1.33%	3	2.00%	1	0.67%
9:00am-3:00pm	292	33	11.30%	22	7.53%	11	3.77%	11	3.77%	6	2.05%	8	2.74%	4	1.37%	8	2.74%
3:00pm-6:00pm	179	32	17.88%	14	7.82%	7	3.91%	6	3.35%	2	1.12%	4	2.23%	6	3.35%	2	1.12%
6:00pm-12:00am	184	9	4.89%	12	6.52%	11	5.98%	8	4.35%	11	5.98%	1	0.54%	4	2.17%	2	1.09%
Total	**805**	90	11.18%	61	7.58%	37	4.60%	28	3.48%	22	2.73%	15	1.86%	17	2.11%	13	1.61%

Note: The number of total trips in Column 2 is the number of total trips by time period at the beginning time point in direction 3

Table 15: Summary of Gap Trips by Time Period – Westbound

Time Period	Total Trips	One Gap Trips		Two Gap Trips		Three Gap Trips		Four Gap Trips		Five Gap Trips		Six Gap Trips		Seven Gap Trips		Eight Gap Trips	
6:30am-9:00am	155	27	17.42%	14	9.03%	19	12.26%	3	1.94%	2	1.29%	3	1.94%	4	2.58%	1	0.65%
9:00am-3:00pm	290	34	11.72%	15	5.17%	22	7.59%	24	8.28%	10	3.45%	12	4.14%	7	2.41%	2	0.69%
3:00pm-6:00pm	162	23	14.20%	20	12.35%	10	6.17%	12	7.41%	7	4.32%	7	4.32%	6	3.70%	1	0.62%
6:00pm-12:00am	195	22	11.28%	8	4.10%	9	4.62%	14	7.18%	4	2.05%	5	2.56%	6	3.08%	1	0.51%
Total	**802**	106	13.22%	57	7.11%	60	7.48%	53	6.61%	23	2.87%	27	3.37%	23	2.87%	5	0.62%

Note: The number of total trips in Column 2 is the number of total trips by time period at the beginning time point in direction 4

Tables 16-23 show four types of events which demonstrate the behavioral patterns of large gaps which have spanned multiple time points. Each type was identified as the headway ratios were compared at time points over an individual trip. In Tables 16 and 17, increased gap trips are defined as gaps that are increased over two or more time points. In Tables 18 and 19, decreased gap trips are defined as gaps that are decreasing over two or more time points. In Tables 20 and 21, an increasing-decreasing gap occurs when a large gap first increases then decreases over three or more time points. In Tables 22 and 23, a decreasing-increasing gap occurs when a large gap first decreases then increases over three or more time points.

In general, large gaps did not tend to increase or decrease over more than two consecutive time points and only a small percentage increased or decreased at all. In addition, the percent of increasing then decreasing gap trips or decreasing then increasing gap trips was very small. This is consistent with our previous analysis results, which indicate that the large gap does not seem to propagate down the route.

Table 16: Summary of Increasing Gap Trips by Time Period – Eastbound

Time Period	Total Trips	Increased Gap (2 tp)		Increased Gap (3 tp)		Increased Gap (4 tp)		Increased Gap (5 tp)		Increased Gap (6 tp)	
6:30am-9:00am	150	3	2.00%	1	0.67%	0	0.00%	0	0.00%	0	0.00%
9:00am-3:00pm	292	13	4.45%	3	1.03%	1	0.34%	3	1.03%	0	0.00%
3:00pm-6:00pm	179	3	1.68%	3	1.68%	0	0.00%	0	0.00%	2	1.12%
6:00pm-12:00am	184	4	2.17%	6	3.26%	3	1.63%	1	0.54%	1	0.54%
Total	**805**	23	2.86%	13	1.61%	4	0.50%	4	0.50%	3	0.37%

Note: (2 tp) means a gap increased only over 2 consecutive time points, (3 tp) means a gap increased only over 3 consecutive time points, etc.

Table 17: Summary of Increasing Gap Trips by Time Period – Westbound

Time Period	Total Trips	Increased Gap (2 tp)		Increased Gap (3 tp)		Increased Gap (4 tp)		Increased Gap (5 tp)		Increased Gap (6 tp)	
6:30am-9:00am	155	9	5.81%	3	1.94%	0	0.00%	0	0.00%	0	0.00%
9:00am-3:00pm	290	11	3.79%	6	2.07%	5	1.72%	1	0.34%	1	0.34%
3:00pm-6:00pm	162	6	3.70%	1	0.62%	0	0.00%	0	0.00%	0	0.00%
6:00pm-12:00am	195	6	3.08%	4	2.05%	3	1.54%	0	0.00%	1	0.51%
Total	**802**	32	3.99%	14	1.75%	8	1.00%	1	0.12%	2	0.25%

Note: (2 tp) means a gap increased only over 2 consecutive time points, (3 tp) means a gap increased only over 3 consecutive time points, etc.

Table 18: Summary of Decreasing Gap Trips by Time Period – Eastbound

Time Period	Total Trips	Decreased Gap (2 tp)		Decreased Gap (3 tp)		Decreased Gap (4 tp)		Decreased Gap (5 tp)		Decreased Gap (6 tp)	
6:30am-9:00am	150	3	2.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
9:00am-3:00pm	292	9	3.08%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
3:00pm-6:00pm	179	4	2.23%	1	0.56%	0	0.00%	0	0.00%	0	0.00%
6:00pm-12:00am	184	7	3.80%	1	0.54%	1	0.54%	0	0.00%	0	0.00%
Total	**805**	23	2.86%	2	0.25%	1	0.12%	0	0.00%	0	0.00%

Note: (2 tp) means a gap decreased only over 2 consecutive time points, (3 tp) means a gap decreased only over 3 consecutive time points, etc.

Table 19: Summary of Decreasing Gap Trips by Time Period – Westbound

Time Period	Total Trips	Decreased Gap (2 tp)		Decreased Gap (3 tp)		Decreased Gap (4 tp)		Decreased Gap (5 tp)		Decreased Gap (6 tp)	
6:30am-9:00am	155	6	3.87%	3	1.94%	0	0.00%	0	0.00%	0	0.00%
9:00am-3:00pm	290	8	2.76%	7	2.41%	1	0.34%	0	0.00%	0	0.00%
3:00pm-6:00pm	162	11	6.79%	4	2.47%	0	0.00%	0	0.00%	0	0.00%
6:00pm-12:00am	195	2	1.03%	1	0.51%	0	0.00%	0	0.00%	0	0.00%
Total	**802**	27	3.37%	15	1.87%	1	0.12%	0	0.00%	0	0.00%

Note: (2 tp) means a gap decreased only over 2 consecutive time points, (3 tp) means a gap decreased only over 3 consecutive time points, etc.

Table 20: Summary of Increasing-Decreasing Gap Trips by Time Period – Eastbound

Time Period	Total Trips	Inc-Dec Gap (3 tp)		Inc-Dec Gap (4 tp)		Inc-Dec Gap (5 tp)		Inc-Dec Gap (6 tp)		Inc-Dec Gap (7 tp)	
6:30am-9:00am	150	0	0.00%	0	0.00%	1	0.67%	1	0.67%	0	0.00%
9:00am-3:00pm	292	4	1.37%	4	1.37%	1	0.34%	3	1.03%	0	0.00%
3:00pm-6:00pm	179	2	1.12%	2	1.12%	2	1.12%	1	0.56%	0	0.00%
6:00pm-12:00am	184	4	2.17%	3	1.63%	2	1.09%	0	0.00%	0	0.00%
Total	**805**	10	1.24%	9	1.12%	6	0.75%	5	0.62%	0	0.00%

Note: (3 tp) means a gap increased over 2 consecutive time points then decreased at the next time point, etc.

Table 21: Summary of Increasing-Decreasing Gap Trips by Time Period – Westbound

Time Period	Total Trips	Inc-Dec Gap (3 tp)		Inc-Dec Gap (4 tp)		Inc-Dec Gap (5 tp)		Inc-Dec Gap (6 tp)		Inc-Dec Gap (7 tp)	
6:30am-9:00am	155	3	1.94%	0	0.00%	0	0.00%	1	0.65%	0	0.00%
9:00am-3:00pm	290	4	1.38%	3	1.03%	2	0.69%	1	0.34%	0	0.00%
3:00pm-6:00pm	162	0	0.00%	4	2.47%	2	1.23%	3	1.85%	2	1.23%
6:00pm-12:00am	195	2	1.03%	4	2.05%	0	0.00%	3	1.54%	0	0.00%
Total	**802**	9	1.12%	11	1.37%	4	0.50%	8	1.00%	2	0.25%

Note: (3 tp) means a gap increased over 2 consecutive time points then decreased at the next time point, etc.

Table 22: Summary of Decreasing-Increasing Gap Trips by Time Period – Eastbound

Time Period	Total Trips	Dec-Inc Gap (3 tp)		Dec-Inc Gap (4 tp)		Dec-Inc Gap (5 tp)		Dec-Inc Gap (6 tp)		Dec-Inc Gap (7 tp)	
6:30am-9:00am	150	4	2.67%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
9:00am-3:00pm	292	4	1.37%	2	0.68%	0	0.00%	2	0.68%	0	0.00%
3:00pm-6:00pm	179	1	0.56%	1	0.56%	0	0.00%	0	0.00%	0	0.00%
6:00pm-12:00am	184	1	0.54%	1	0.54%	0	0.00%	0	0.00%	0	0.00%
Total	**805**	10	1.24%	4	0.50%	0	0.00%	2	0.25%	0	0.00%

Note: (3 tp) means a gap decreased over 2 consecutive time points then increased at the next time point, etc.

Table 23: Summary of Decreasing-Increasing Gap Trips by Time Period – Westbound

Time Period	Total Trips	Dec-Inc Gap (3 tp)		Dec-Inc Gap (4 tp)		Dec-Inc Gap (5 tp)		Dec-Inc Gap (6 tp)		Dec-Inc Gap (7 tp)	
6:30am-9:00am	155	6	3.87%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
9:00am-3:00pm	290	9	3.10%	3	1.03%	2	0.69%	3	1.03%	0	0.00%
3:00pm-6:00pm	162	3	1.85%	1	0.62%	1	0.62%	0	0.00%	0	0.00%
6:00pm-12:00am	195	2	1.03%	3	1.54%	0	0.00%	0	0.00%	0	0.00%
Total	**802**	20	2.49%	7	0.87%	3	0.37%	3	0.37%	0	0.00%

Note: (3 tp) means a gap decreased over 2 consecutive time points then increased at the next time point, etc.

Bottom-line:

Although we identified four different patterns of gap propagation over different time points, there are only very small cases that fit into those patterns. There seems to be no dominant pattern. In general, the fluctuation of a large gap from time point to time point is very small and there is little evidence showing the gaps propagate over more than two time points.

Predicting Large Gaps

Methodology

The goal of this analysis is to find what leads to large gaps by time point and time of day in each direction, so that we may be able to develop strategies to predict and prevent the occurrence of specific types of gaps. The calculation of each piece of this analysis involves some equations which are defined here:

For a given time point,

- Actual Headway (Bus k) =
    - Actual bus arrival Time (Bus k) – Actual arrival time (Bus k-1)
- Schedule Headway (Bus k) =
    - Scheduled arrival Time (Bus k) – Scheduled arrival Time (Bus k-1)
- Headway Ratio (Bus k) =
    - Actual Headway (Bus k) ⁄ Scheduled Headway (Bus k)
- Earlier =
    - Actual arrival Time (Bus k) – Scheduled arrival Time (Bus k) < 0
    - When we say that a bus (Bus k) arrives earlier at a give time point, it means that this bus arrives at this time point earlier than its scheduled arrival time.
- Later =

  - Actual arrival Time (Bus k) – Scheduled arrival Time (Bus k) > 0
  - When we say that a bus (Bus k) arrives later at a give time point, it means that this bus arrives at this time point later than its scheduled arrival time.
- Slower =
  - Actual Travel Time (Bus k from time point i to time point j) – Scheduled Travel Time (Bus k from time point i to time point j) > 0
  - When we say that a bus (Bus k) runs slower from the previous time point to the given time point, it means that the actual travel time is longer than the scheduled travel time between two time points (i, j).
- Quicker =
  - Actual Travel Time (Bus k from time point i to time point j) – Scheduled Travel Time (Bus k from time point i to time point j) < 0
  - When we say that a bus (Bus k) runs quicker from the previous time point to the given time point, it means that the actual travel time is shorter than the scheduled travel time between two time points (i, j).

According to our theoretical analysis and the experience at the CTA, the gap reasons were grouped into 6 main categories, with 4 sub-categories for category 3 due to the high number of cases in this category. Each category is described below, with Bus k as the observed bus with a gap, Bus k-1 as the previous bus, and Bus k-2 as the second preceding bus. All analyzed buses are on the same bus route and run from the same selected time point to the same next time point.

No Overtaking

- Category 1: Bus k has slower than expected travel time from one time point to the next time point, Bus k-1 is normal running from the same time point to the next time point.
- Category 2: Bus k is normal, Bus k-1 has quicker than expected travel time
- Category 3: Bus k has slower than expected travel time, Bus k-1 is quicker
  - Sub-category 3.1: Bus k has slower than expected travel time, Bus k-1 is quicker
  - Sub-category 3.2: Bus k has slower than expected travel time, Bus k-1 also has slower than expected travel time
  - Sub-category 3.3: Bus k has quicker than expected travel time, Bus k-1 is also quicker
  - Sub-category 3.4: any situation for category 3 not included in sub-categories 3.1, 3.2, or 3.3

Overtaking

- Category 4: Bus k is too quick so it overtakes Bus k-1, but Bus k-1 is slower or bus k-2 is quicker
- Category 5: Bus k-1 is too slow so it falls behind Bus k (Bus k may be normal or a little quicker or slower), Bus k-2 becomes previous to Bus k

- Category 6: Bus k-1 is too quick so it overtakes Bus k-2, Bus k-2 becomes previous to Bus k (Bus k is normal or a little quicker or slower)

A statistical method was then used to verify the theoretical classification. To perform this, large gaps at selected time points were identified according to each category or sub-category and the total gap times were summed. Then, for each sub-category of category 3, the actual and scheduled travel time from the previous time point to this selected time point were calculated. Next, further statistics were computed, including the mean and standard deviation of the difference between the actual and scheduled travel time. Finally, the calculation of average travel time difference plus or minus two times the standard deviation is given to further depict the gap reason categories.

Results

Tables 24 and 25 display the number of gap trips falling under each of the six category definitions, organized by time point and time period. These tables serve as a summary of the distribution of gap trips, showing a high number in almost every instance for category 3, and illustrating the rationale for the four sub-category distinctions.

Table 24: Gap Category Summary for 6 Main Categories – Eastbound

Time Point	Time Period	No Overtaking Categories				Overtaking Categories			
		1	2	3	Total	4	5	6	Total
Cicero	6:30am-9:00am	0	0	12	12	3	0	1	4
	9:00am-3:00pm	0	0	22	22	7	0	5	12
	3:00pm-6:00pm	1	0	14	15	7	0	2	9
	6:00pm-12:00am	0	0	14	14	5	0	4	9
	Total	1	0	62	63	22	0	12	34
Pulaski	6:30am-9:00am	1	1	7	9	2	0	1	3
	9:00am-3:00pm	1	1	18	20	5	2	4	11
	3:00pm-6:00pm	1	1	13	15	9	1	2	12
	6:00pm-12:00am	0	0	13	13	7	2	4	13
	Total	3	3	51	57	23	5	11	39
Kedzie	6:30am-9:00am	0	0	8	8	0	0	3	3
	9:00am-3:00pm	0	1	23	24	2	2	8	12
	3:00pm-6:00pm	0	0	15	15	1	3	7	11
	6:00pm-12:00am	0	0	14	14	1	1	9	11
	Total	0	1	60	61	4	6	27	37
Ashland	6:30am-9:00am	0	0	13	13	1	1	1	3
	9:00am-3:00pm	2	0	23	25	3	5	6	14
	3:00pm-6:00pm	0	0	13	13	2	4	5	11
	6:00pm-12:00am	0	0	14	14	3	3	10	16
	Total	2	0	63	65	9	13	22	44
Halsted	6:30am-9:00am	0	0	16	16	2	2	0	4
	9:00am-3:00pm	0	0	24	24	2	8	10	20
	3:00pm-6:00pm	0	0	13	13	1	5	6	12
	6:00pm-12:00am	1	0	16	17	2	2	10	14
	Total	1	0	69	70	7	17	26	50
Michigan	6:30am-9:00am	0	0	16	16	0	4	3	7
	9:00am-3:00pm	4	0	23	27	2	12	7	21
	3:00pm-6:00pm	0	0	16	16	0	8	10	18
	6:00pm-12:00am	0	0	17	17	1	1	9	11
	Total	4	0	72	76	3	25	29	57
Wabash	6:30am-9:00am	0	0	0	0	0	0	0	0
	9:00am-3:00pm	0	0	23	23	9	3	9	21
	3:00pm-6:00pm	0	0	0	0	0	0	0	0
	6:00pm-12:00am	0	0	13	13	1	0	4	5
	Total	0	0	36	36	10	3	13	26
Columbus	6:30am-9:00am	0	0	19	19	3	1	4	8
	9:00am-3:00pm	0	0	4	4	0	0	1	1
	3:00pm-6:00pm	1	1	12	14	4	1	11	16
	6:00pm-12:00am	0	0	1	1	1	0	4	5
	Total	1	1	36	38	8	2	20	30

Table 25: Gap Category Summary for 6 Main Categories – Westbound

Time Point	Time Period	No Overtaking				Overtaking			
		1	2	3	Total	4	5	6	Total
Austin	6:30am-9:00am	0	1	21	22	4	3	9	16
	9:00am-3:00pm	0	0	39	39	6	10	12	28
	3:00pm-6:00pm	0	0	21	21	3	10	10	23
	6:00pm-12:00am	0	0	18	18	1	5	13	19
	Total	0	1	99	100	14	28	44	86
Cicero	6:30am-9:00am	0	0	31	31	4	2	3	9
	9:00am-3:00pm	0	0	46	46	3	8	9	20
	3:00pm-6:00pm	0	0	24	24	7	2	7	16
	6:00pm-12:00am	0	0	23	23	2	1	11	14
	Total	0	0	124	124	16	13	30	59
Pulaski	6:30am-9:00am	1	5	18	24	4	0	2	6
	9:00am-3:00pm	1	3	38	42	3	11	7	21
	3:00pm-6:00pm	0	0	23	23	7	1	8	16
	6:00pm-12:00am	2	1	27	30	4	1	2	7
	Total	4	9	106	119	18	13	19	50
Kedzie	6:30am-9:00am	1	0	10	11	2	1	1	4
	9:00am-3:00pm	0	0	33	33	5	11	13	29
	3:00pm-6:00pm	0	1	19	20	6	1	13	20
	6:00pm-12:00am	0	1	17	18	5	3	5	13
	Total	1	2	79	82	18	16	32	66
Ashland	6:30am-9:00am	0	0	15	15	1	1	3	5
	9:00am-3:00pm	0	0	26	26	12	2	12	26
	3:00pm-6:00pm	0	0	20	20	2	3	5	10
	6:00pm-12:00am	0	0	12	12	3	1	5	9
	Total	0	0	73	73	18	7	25	50
Halsted	6:30am-9:00am	0	0	13	13	2	0	2	4
	9:00am-3:00pm	1	0	26	27	6	1	13	20
	3:00pm-6:00pm	1	0	21	22	2	1	6	9
	6:00pm-12:00am	1	0	15	16	1	0	4	5
	Total	3	0	75	78	11	2	25	38
Michigan	6:30am-9:00am	0	0	7	7	0	0	5	5
	9:00am-3:00pm	0	0	4	4	0	0	1	1
	3:00pm-6:00pm	1	0	10	11	1	4	3	8
	6:00pm-12:00am	1	0	5	6	0	0	0	0
	Total	2	0	26	28	1	4	9	14
Wabash	6:30am-9:00am	0	0	0	0	0	0	0	0
	9:00am-3:00pm	0	0	24	24	0	0	14	14
	3:00pm-6:00pm	0	0	0	0	0	0	0	0
	6:00pm-12:00am	0	0	11	11	0	0	3	3
	Total	0	0	35	35	0	0	17	17

From the data experiment results, we can make some general observations about the sub-categories. The following explanations are based on the average scheduled (i.e. expected) times for each time period and depict the conditions which lead to a large gap over 95% of the time:

For Category 3.1, here are some typical observations:

- From 6:30am to 9:00am, when the first bus (Bus k-1) is 2.5 minutes quicker than the scheduled travel time, and if the second bus (Bus k) is 1 minute slower than the scheduled travel time, there is a 95% probability that a large gap will result.
- From 9:00am to 3:00pm, when the first bus (Bus k-1) is 1.5 minutes quicker than the scheduled travel time, and if the second bus (Bus k) is 4-5 minutes slower than the scheduled travel time, there is a 95% probability that a large gap will result.
- From 3:00pm to 6:00pm, when the first bus (Bus k-1) is 2.5 minutes quicker than the scheduled travel time, and if the second bus (Bus k) is 2.5 minutes slower than the scheduled travel time, there is a 95% probability that a large gap will result.
- From 6:00pm to 12:00am, when the first bus (Bus k-1) is 2 minutes quicker than the scheduled travel time, and if the second bus (Bus k) is 3 minutes slower than the schedule travel time, there is a 95% probability that a large gap will result.

There is no typical pattern for category 3.2.

For Category 3.3,

- from 6:30am to 9:00am, when the first bus (Bus k-1) is 2.5 minutes quicker than the schedule travel time, and if the second bus (Bus k) is 1.5 minutes quicker than the scheduled travel time, there is a 95% probability that a large gap will result.
- From 9:00am to 3:00pm, when the first bus (Bus k-1) is 4.5 minutes quicker than the scheduled travel time, and if the second bus (Bus k) is 3 minutes slower than the scheduled travel time, there is a 95% probability that a large gap will result.
- From 3:00pm to 6:00pm, there are too few cases to make a definitive statement.
- From 6:00pm to 12:00am, when the first bus (Bus k-1) is 3 minutes quicker than the scheduled travel time, and if the second bus (Bus k) is 1 minutes slower than the scheduled travel time, there is a 95% probability that a large gap will result

5 FIELD OBSERVATIONS

In an attempt to better understand the service restoration activities at the CTA, field observations were conducted with a mobile supervisor of the K-52 territory, which includes the Route 20. The observations and experience provide background information for the data analysis previously presented, helping to make reasonable and educated speculations about reasons behind the analysis results. This section describes the results of the field experience, which may shed some light on why large gaps do not propagate down the route.

The K-52 territory runs south to north from Roosevelt Road to Lake Street and west to east from Kedzie Avenue to Halsted Avenue. The supervisor for the K-52 territory is responsible for responding to bus incidents in the zone and some times outside the zone if needed. The CTA uses 11 different types of service restoration methods, whose selection depend on the route's specific characteristics and the amount of delay that has occurred. The most frequently used methods on the Route 20, which is found within the K-52 zone, are the switchback, express, put follower ahead, and tradeoff defective bus with a pull-in. The fill, not used much on the Route 20 due to its short headway, is usually only performed if the delay is substantial, 2 or 3 times the headway. This is used more frequently on some other CTA routes. The switchback involves having a bus turned back short of its terminal when it is running late. So, for instance, if a bus is running late traveling east on the Route 20, the bus may be switched back and sent westbound before it reaches the eastern terminal. Expressing a bus entails only picking up passengers at main stops and may require passengers already aboard to alight and board a following bus. Putting a follower ahead deals with a bus bunching incident and involves sending the bus following a delayed bus ahead of that bus. In the case of a defective bus, trading this bus off for one that just pulled in to a terminal can be done.

The issue with trading off a bus on the Route 20 is that the replacement bus may not be equipped with the AVAS technology so it does not report. This is unfortunate because it may cause a large gap to appear in the AVL data when, in fact, a large gap does not exist. For our purposes this has a negative effect on the analysis, but fortunately the number of cases where the trade-off occurs is marginal and should not have a significant impact on the results. Overall, CTA's primary goal is to provide efficient, reliable service and this takes precedence over after-the-fact analysis.

The mobile supervisor currently has a laptop station docked inside of his/her vehicle. It has BusTracker installed, allowing the locations of all buses to be viewed thanks to AVAS. Unfortunately, the laptop was not present at the time of the ride-along because there was a problem with the docking station. Normally, however, this ability to see all the buses on the route substantially aids the efforts of restoring disrupted service because bunching locations can be easily determined.

There are some issues with the software that could improve its use, nonetheless. First, even with the use of the software, the paper run guides are still necessary in order for the supervisor to find where exactly he/she is supposed to be. Also, some times the buses on the route are not present in the computer which obviously affects his actions. And lastly, having the ability to send text messages to operators through AVAS, currently not possible, would be of great benefit. To make this work, however, there would need to be a way of notifying the operator that he/she has a message.

Another form of technology, being piloted by the CTA, is the use of the Supervisor Information Management System (SIMS). Supervisors are currently being trained to use this technology, with the hope that it will speed up the reporting process, and thus restoration. This system is likely be helpful to supervisors, but during training many of supervisors made it seem quite difficult to use, likely due to a lack of basic computer knowledge. This is something that is a concern at the CTA, but the new software, when used correctly, will hopefully increase the reporting proportion and the speed in which reporting occurs.

Another aspect of the supervisor’s job is point monitoring, which includes checking the schedule adherence of buses at major stops. The process requires the supervisor to write the schedule information from the run guide on a checking slip, then to collect the actual arrival time and estimated on-board passenger count of each bus that passes, and then take action to get buses back on time in the case of early or late arrivals. The supervisor then makes a check mark to indicate that service was restored.

Overall, these observations were very helpful in forming a basis of knowledge about CTA service restoration procedures. The data analysis demonstrated that large gaps tend to propagate only to the next time point and generally not down the rest of the route. This may be related to the specific characteristics of the Route 20, but it is also very possible that corrective actions, like those taken by mobile supervisors, are the cause. Though there are limitations to what can be done to identify disrupted service in a timely manner and to deal with this disruption, restoration activities have been taking place for many years and many attempts have been successful. The aspiration for this report is that these attempts can become more successful through our recommendations.

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

At the outset of the report, we intended to answer the following questions:

1) How serious is the problem of bus trips with large gaps due to unreliable services? Do the service gaps propagate throughout the bus route?
2) What are the main identifiable conditions that tend to lead to large service gaps?
3) How can the CTA identify these conditions in real-time so that proper service restoration actions can be taken?
4) What other suggestions can be made to the CTA to help improve the organization's service restoration approach?

As shown in our previous analysis, we can provide some answers to these questions. This section first summarizes what we have found, then provides some recommendations for implementation based on the findings.

1. Characteristics of Spatial and Temporal Patterns of Large Service Gaps

We found there are large gaps (i.e., actual headway is more than 1.5 times of scheduled headway) and bus bunching (i.e., two buses arrives within one minute of each other). Overall, 16.69% of total trips eastbound contained large service gaps, while 21.20% had large gaps in the westbound direction.

We further found that the percentage of gap trips rises continuously between the beginning and end of the route, for both eastbound and westbound trips. However, when broken into time periods, this spatial pattern is not quite as clear. Comparing time periods does not yield an obvious pattern, but the peak afternoon period tends to have the highest occurrence of gap trips. The exceptions are mostly eastbound, where several time points have higher gap trip percentages in the evening hours.

2. Severity and Propagation of Large Service Gaps

Bunching, as it is defined, does not appear to propagate into following time points. The pattern for large gaps is more distinctive, however. In almost all cases it is likely that the actual headway at a time point with a large gap was significantly impacted by the actual headway at the previous time point. Thus, it indicates that once the bus is delayed in the previous time point, it tends to lead to delay in the immediate following time point and gaps do propagate down the route for the most part. However, the effect of propagation is diminishing as the bus travels down the route. Furthermore, the appearance of a large gap does not appear to be significant at the time point beyond the immediate next time point, indicating that a large gap does not necessarily propagate down the route over multiple time points.

The causes for the results are speculative but are very significant to the analysis. The nature of the Route 20 is such that each trip is dynamic. It is a heavily traversed route, carrying passengers from the west side of Chicago right into downtown and vice versa. The CTA has also indicated that there are sections of the route in which buses incurring large gaps or bunching can space themselves by speeding up or slowing down. In addition, there is a mid-route terminal in which buses begin or terminate trips, potentially causing large gaps to appear or alleviating them simply by their presence or absence. Another possibility is the intervention of supervisors to better space the route using the current restoration practices. Field observations with a mobile supervisor indicated this may be the case, but empirical testing was not possible with the available data.

3. Patterns of Gap Trips

The distributions of the number and percentage of gap trips found in each time period are similar in each direction. Most trips incurring large gaps (i.e. "gap trips") have large gaps at more than one time point. However, the highest number of gap trips fall in the one gap category, and as the number of gaps increases, the number of gap trips in generally decreases. For instance, in the eastbound direction 11.18% of trips have one large gap, 7.58% have two, 4.60% have three, and so on. In terms of time periods, there is no definitive pattern.

In terms of patterns of gap propagation, a small percent of trips had increasing or decreasing gaps, and those that did tended not to increase or decrease over more than two time points. Overall, four different patterns of gap propagation were identified and analyzed but the number of gap trips in each category was trivial. Thus, no dominant pattern appeared. Despite this, there is a strong indication that the pattern of large gaps is consistent with the other analysis results that these large gaps do not propagate over numerous time points.

4. Identifying Conditions Leading to Large Gaps

We have identified prior conditions that could lead to large gaps in the following time points by analyzing the AVL data. The presence of large gaps was broken down into categories based on a comparison of the expected and actual travel time for a set of consecutive buses. From these categories the conditions were determined which most lead to large gaps. These conditions are defined in terms of the how quick or slow a bus was when compared to what was expected, and are separated time period. The results are previously described in detail in the analysis and results section of this report.

With the proper implementation, these conditions can be used to prevent large gaps. The proposed method is described in the recommendations below.

Recommendations

The CTA has a large, intricate system of urban buses and high-speed rail. Thus, it is important to consider any recommendations within the context of the entire system. The effect on one mode must be considered when improving the other. Everything is connected.

After careful examination of the related literature, current practices at agencies around the country, analysis results, and field observations at the CTA, recommendations for improving service restoration can be made. We recommend creating a flag system that notifies the control center supervisors of a potential oncoming large gap in service, allowing said supervisors to advise bus operators to take action. These actions may include: slow down, speed up, hold at a specified location, run express for a specified distance, switchback at a specified location, etc.

The conditions are determined by the AVAS data of consecutive buses along the route, and based on the threshold values identified in this report. The Gap Reason Analysis revealed the conditions that indicate when the onset of a large gap is almost a certainty. For example, when bus k is slower than the expected travel time by 2 standard deviations of the average travel time and bus k-1 is faster by 2 standard deviations of the average travel time, a large gap will occur about 95% of the time. To re-iterate, bus k is the current bus and bus k-1 is the previous bus.

When this condition is met, with the proposed flag system, a control center employee will receive an alert warning of a potential large gap in service. This person can then directly instruct the operator of bus k or bus k+1 to take action to prevent the large gap from forming. In certain cases, such as heavy traffic, excessive ridership, or a breakdown, it may not be possible for the bus operator to completely prevent the large gap. However, merely making an operator aware that a large gap is imminent encourages the operator to take corrective action.

Implementing the flag system will be a considerable challenge, but the CTA already has many of the tools it needs. AVAS data collected real-time provide the exact location of each bus equipped with the AVL technology. BusTracker displays these locations on a map in real-time.

One issue, discussed by Pangilinan (2006), is communication between the control center, supervisors, and operators. With the ability to communicate comes the ability to act quickly in times of service interruption. Pangilinan asserted, and we agree, that improved communications would decrease supervisor needs and allow the control center to easily respond to disruptions and manage service. The mobile supervisor would also benefit, as seen from the field observations, by being able to send a message to an operator. Thus, the flag system requires an updated communication system that allows control center personnel and supervisors to quickly convey messages to operators. The analysis results of this study provide a strong foundation to feed into the algorithms of signal priority.

In addition to the flag system, there are several other improvements that the CTA can pursue to advance its service restoration process. One innovation mentioned by several of the contacts at other transit agencies is queue jumping, which allows a bus to get out of the stopped position before the other traffic at a traffic signal. Related to the queue jumping technology is traffic signal priority, in which a bus has an emitter equipped that can be used to request a longer green light or a shorter red light at an approaching signal. This allows a late bus to get back on time quicker, decreasing running time variation, and resulting in less schedule time needed.

The potential for holding strategies to improve service restoration is significant. Many agencies use or desire to use holding as part of their toolbox. It is recommended that the CTA attempt to implement holding at terminals, as well as mid-route, when approaching buses have been significantly delayed or are running early. When a delay has occurred, the bus currently at the terminal or specified mid-route time point should be held to decrease the large gap which has been formed. When a bus is early, it can be held at a time point to get it back on time, or the operator can drag the line to accomplish this without stopping for an extended period of time. Control points for holding should be decided upon based primarily on the physical characteristics of the location and the ridership preceding the location. Holding strategies should be integrated into the flag system in the control center.

In closing, there are a number of different improvements that the CTA can make to increase its ability to fully use the service restoration toolbox it has at its fingers. A flag system to identify conditions that tend to lead to large gaps forming can be used to prevent these gaps. Increased communication will aid in the flag system’s implementation, in addition to improving other service restoration techniques. Queue jumping and traffic signal priority will help buses to get on time and stay on time more effectively. And finally, holding strategies at terminals and mid-route control points can help to decrease some of the large gaps detected in this research. It is recommended that the CTA explore all of these options to improve its service restoration approach, and incorporate service restoration strategies and signal priority systems into an intelligent flag system in the control center.

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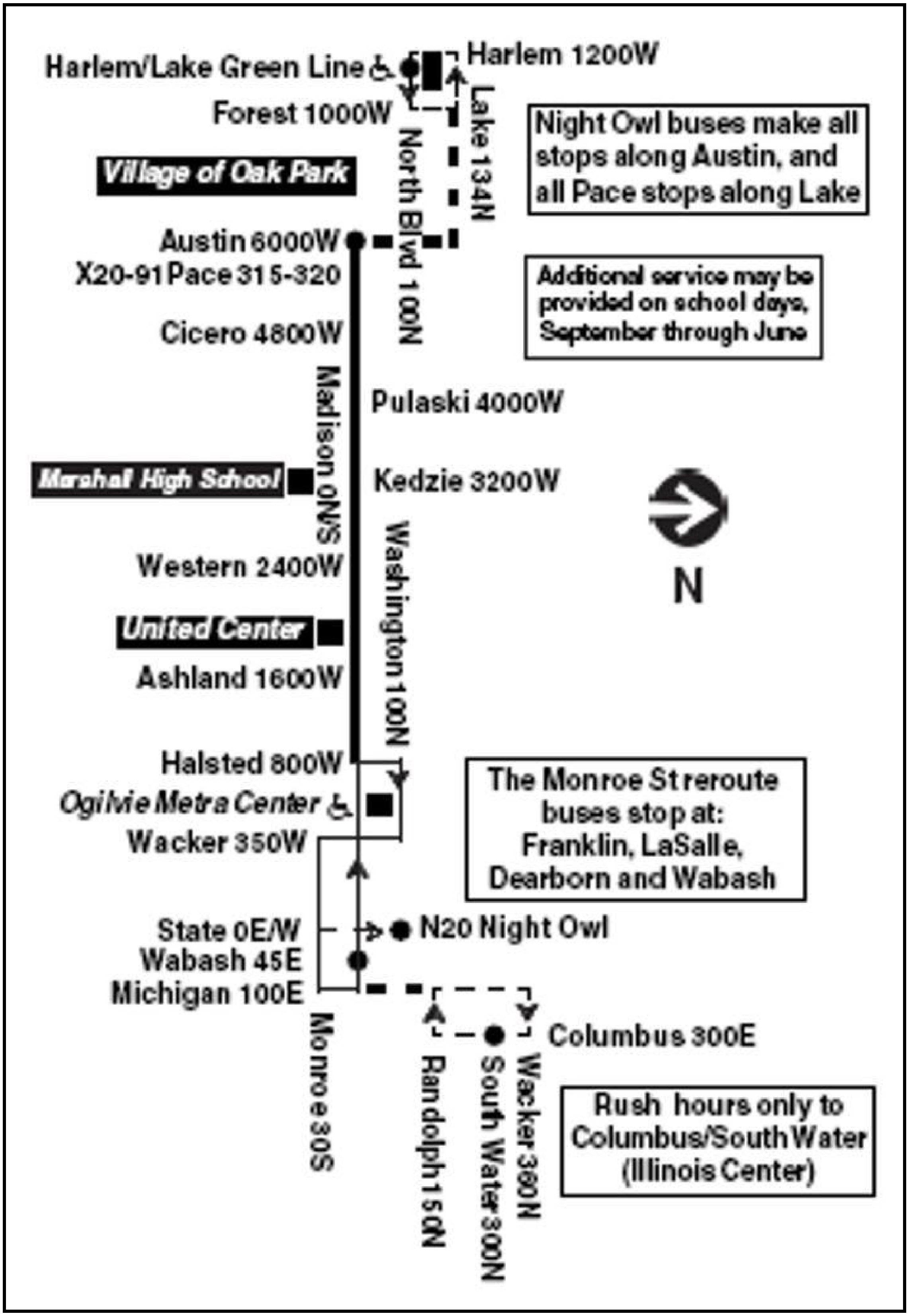
APPENDIX A: MAP OF CTA ROUTE 20 – MADISON



APPENDIX B: SAMPLE TRANSIT AGENCY QUESTIONNAIRE

Service Restoration Questionnaire

The University of Wisconsin-Milwaukee is conducting this survey to determine the methods of restoring disrupted bus service that are used by large transit agencies in the United States. The term “service restoration” is used here to refer to the transit agency’s effort to re-establish disrupted service back to a standard once it has been interrupted by one of a number of sources. In particular, we are interested in the potential application of automatic vehicle location (AVL) technologies. Your responses are very valuable to us in determining the extent to which transit agencies attempt to restore service, including methods that have been successful in the past, have failed in the past, and new methods that are being experimented with.

Instructions

1. The intent of this survey is to evaluate the use of service restoration practices for bus systems. Please read the questions carefully and respond by making notes in the spaces provided.

2. Once you have had a chance to read through and think about each question, we will ask you to conduct a phone interview and set up the best time for you to do so.

3. During the phone interview your responses will be recorded (with your permission) and our notes will be sent to you for verification. The resulting information will be used to aid us in our research efforts.

We hope that you agree to participate in this survey. Your answers will remain strictly confidential and will help us to determine the use of service restoration practices within transit agencies. Thank you very much for your cooperation.

Target Completion Date: **October 8, 2007**

Contact Information: Eric Lynde (XXX) XXX-XXXX or XXXXXXX@uwm.edu

The Questions

1. **WHAT ACTIONS DO YOU TAKE DO WHEN BUS SERVICE IS DISRUPTED (E.G., BUS BUNCHING, LONG DELAYS DUE TO INCIDENTS, MECHANICAL PROBLEMS, TRAFFIC CONGESTIONS, AND OTHER FACTORS)?**

2. **WHAT TYPE OF SERVICE RESTORATION METHODS DO YOU USE AND HOW EXACTLY DO YOU USE IT?**

   Please list all methods and describe how each is used.

   Examples: Scheduled-based holding, Headway-based holding, Short-turning buses, Expressing buses, Traffic Signal Priority, etc.

3. **WHEN AND UNDER WHAT CONDITIONS DO YOU USE EACH METHOD SELECTED?**

   For each method selected in #2, please describe the conditions under which it is employed.

   Examples: High frequency route, Low frequency route, Long headways, Short headways, Congested, Uncongested, etc.

4. **HAVE YOU OBSERVED THE EFFECTS OF ANY OF THE METHODS SELECTED?**

   ☐ YES ☐ NO

   If yes, please list all methods from #2 for which observations have been made.

5. **IF YES ABOVE, HOW WERE EFFECTS OBSERVED AND MEASURED?**

   For each method selected in #2, please indicate how it was observed and measured.

6. **WHAT ARE THE PROS OF EACH METHOD SELECTED?**

   For each method selected in #2, please list all of its POSITIVE aspects.

7. **WHAT ARE THE CONS OF EACH METHOD SELECTED?**

   For each method selected in #2, please list all of its NEGATIVE aspects.

8. **WHAT ARE THE MOST EFFECTIVE METHODS?**

   Please list the MOST effective methods from those selected in #2.

9. **WHAT ARE THE LEAST EFFECTIVE METHODS?**

   Please list the LEAST effective methods from those selected in #2.

10. **WHAT METHOD(S) DOES YOUR AGENCY PLAN TO USE IN THE FUTURE?**

    Please list all future methods.

11. **WHAT METHOD(S) DOES YOUR AGENCY WISH IT USED BUT DOES NOT?**

12. **WHY ARE THE ABOVE METHOD(S) NOT USED?**

13. **DO YOU USE AVL TO FACILITATE SERVICE RESTORATION?**

14. **IF YES TO #13, HOW IS AVL USED?**

15. **IF NO TO #13, WHY IS AVL NOT USED?**

16. **WHAT GENERAL THOUGHTS DO YOU HAVE ABOUT SERVICE RESTORATION?**

(More questions on the back)

BASIC INFORMATION ON TRANSIT AGENCY

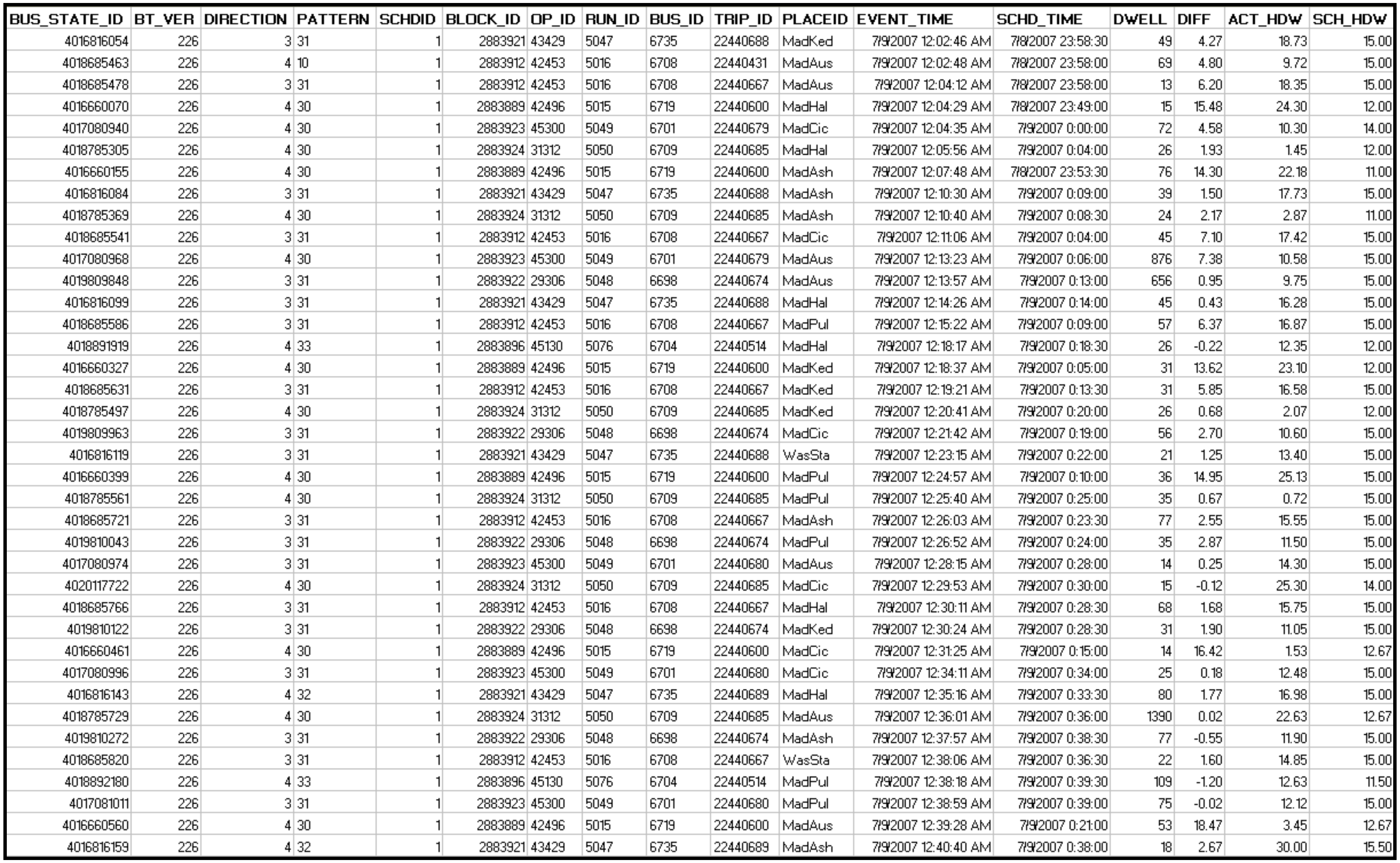
17. How many buses/vehicles do you own? ____
18. How many buses/vehicles are in use on a typical workday (i.e. Monday-Friday 6:00 a.m. to 8:00 p.m.)? ____
19. How many bus routes do you operate? ____
20. What is your annual system ridership? ____
21. What is your total agency annual budget? ____
22. What is the population of the entire area that the transit agency serves? __________________
23. What percent of your bus vehicles has AVL installed? __________________%

Please list your contact information below in case we need to contact you for further details.

NAME ______________________________ TITLE _______________________________
PHONE _____________________________ EMAIL _______________________________

Thank you very much for your help.

APPENDIX C: SAMPLE OF AVAS AND HASTUS DATABASE



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4016816054	226	3	31	1	2883921	43429	5047	6735	22440688	MadKed	7/9/2007 12:02:46 AM	7/8/2007 23:58:30	49	4.27	18.73	15.00
4018685463	226	4	10	1	2883912	42453	5016	6708	22440431	MadAus	7/9/2007 12:02:48 AM	7/8/2007 23:58:00	69	4.80	9.72	15.00
4018685478	226	3	31	1	2883912	42453	5016	6708	22440667	MadAus	7/9/2007 12:04:12 AM	7/8/2007 23:58:00	13	6.20	18.35	15.00
4016660070	226	4	30	1	2883889	42496	5015	6719	22440600	MadHal	7/9/2007 12:04:29 AM	7/8/2007 23:49:00	15	15.48	24.30	12.00
4017080940	226	4	30	1	2883923	45300	5049	6701	22440679	MadCic	7/9/2007 12:04:35 AM	7/9/2007 0:00:00	72	4.58	10.30	14.00
4018785305	226	4	30	1	2883924	31312	5050	6709	22440685	MadHal	7/9/2007 12:05:56 AM	7/9/2007 0:04:00	26	1.93	1.45	12.00
4016660155	226	4	30	1	2883889	42496	5015	6719	22440600	MadAsh	7/9/2007 12:07:48 AM	7/8/2007 23:53:30	76	14.30	22.18	11.00
4016816084	226	3	31	1	2883921	43429	5047	6735	22440688	MadAsh	7/9/2007 12:10:30 AM	7/9/2007 0:09:00	39	1.50	17.73	15.00
4018785369	226	4	30	1	2883924	31312	5050	6709	22440685	MadAsh	7/9/2007 12:10:40 AM	7/9/2007 0:08:30	24	2.17	2.87	11.00
4018685541	226	3	31	1	2883912	42453	5016	6708	22440667	MadCic	7/9/2007 12:11:06 AM	7/9/2007 0:04:00	45	7.10	17.42	15.00
4017080968	226	4	30	1	2883923	45300	5049	6701	22440679	MadAus	7/9/2007 12:13:23 AM	7/9/2007 0:06:00	876	7.38	10.58	15.00
4019809848	226	3	31	1	2883922	29306	5048	6698	22440674	MadAus	7/9/2007 12:13:57 AM	7/9/2007 0:13:00	656	0.95	9.75	15.00
4016816099	226	3	31	1	2883921	43429	5047	6735	22440688	MadHal	7/9/2007 12:14:26 AM	7/9/2007 0:14:00	45	0.43	16.28	15.00
4018685586	226	3	31	1	2883912	42453	5016	6708	22440667	MadPul	7/9/2007 12:15:22 AM	7/9/2007 0:09:00	57	6.37	16.87	15.00
4018891919	226	4	33	1	2883896	45130	5076	6704	22440514	MadHal	7/9/2007 12:18:17 AM	7/9/2007 0:18:30	26	-0.22	12.35	12.00
4016660327	226	4	30	1	2883889	42496	5015	6719	22440600	MadKed	7/9/2007 12:18:37 AM	7/9/2007 0:05:00	31	13.62	23.10	12.00
4018685631	226	3	31	1	2883912	42453	5016	6708	22440667	MadKed	7/9/2007 12:19:21 AM	7/9/2007 0:13:30	31	5.85	16.58	15.00
4018785497	226	4	30	1	2883924	31312	5050	6709	22440685	MadKed	7/9/2007 12:20:41 AM	7/9/2007 0:20:00	26	0.68	2.07	12.00
4019809963	226	3	31	1	2883922	29306	5048	6698	22440674	MadCic	7/9/2007 12:21:42 AM	7/9/2007 0:19:00	56	2.70	10.60	15.00
4016816119	226	3	31	1	2883921	43429	5047	6735	22440688	WasSta	7/9/2007 12:23:15 AM	7/9/2007 0:22:00	21	1.25	13.40	15.00
4016660399	226	4	30	1	2883889	42496	5015	6719	22440600	MadPul	7/9/2007 12:24:57 AM	7/9/2007 0:10:00	36	14.95	25.13	15.00
4018785561	226	4	30	1	2883924	31312	5050	6709	22440685	MadPul	7/9/2007 12:25:40 AM	7/9/2007 0:25:00	35	0.67	0.72	15.00
4018685721	226	3	31	1	2883912	42453	5016	6708	22440667	MadAsh	7/9/2007 12:26:03 AM	7/9/2007 0:23:30	77	2.55	15.55	15.00
4019810043	226	3	31	1	2883922	29306	5048	6698	22440674	MadPul	7/9/2007 12:26:52 AM	7/9/2007 0:24:00	35	2.87	11.50	15.00
4017080974	226	3	31	1	2883923	45300	5049	6701	22440680	MadAus	7/9/2007 12:28:15 AM	7/9/2007 0:28:00	14	0.25	14.30	15.00
4020117722	226	4	30	1	2883924	31312	5050	6709	22440685	MadCic	7/9/2007 12:29:53 AM	7/9/2007 0:30:00	15	-0.12	25.30	14.00
4018685766	226	3	31	1	2883912	42453	5016	6708	22440667	MadHal	7/9/2007 12:30:11 AM	7/9/2007 0:28:30	68	1.68	15.75	15.00
4019810122	226	3	31	1	2883922	29306	5048	6698	22440674	MadKed	7/9/2007 12:30:24 AM	7/9/2007 0:28:30	31	1.90	11.05	15.00
4016660461	226	4	30	1	2883889	42496	5015	6719	22440600	MadCic	7/9/2007 12:31:25 AM	7/9/2007 0:15:00	14	16.42	1.53	12.67
4017080996	226	3	31	1	2883923	45300	5049	6701	22440680	MadCic	7/9/2007 12:34:11 AM	7/9/2007 0:34:00	25	0.18	12.48	15.00
4016816143	226	4	32	1	2883921	43429	5047	6735	22440689	MadHal	7/9/2007 12:35:16 AM	7/9/2007 0:33:30	80	1.77	16.98	15.00
4018785729	226	4	30	1	2883924	31312	5050	6709	22440685	MadAus	7/9/2007 12:36:01 AM	7/9/2007 0:36:00	1390	0.02	22.63	12.67
4019810272	226	3	31	1	2883922	29306	5048	6698	22440674	MadAsh	7/9/2007 12:37:57 AM	7/9/2007 0:38:30	77	-0.55	11.90	15.00
4018685820	226	3	31	1	2883912	42453	5016	6708	22440667	WasSta	7/9/2007 12:38:06 AM	7/9/2007 0:36:30	22	1.60	14.85	15.00
4018892180	226	4	33	1	2883896	45130	5076	6704	22440514	MadPul	7/9/2007 12:38:18 AM	7/9/2007 0:39:30	109	-1.20	12.63	11.50
4017081011	226	3	31	1	2883923	45300	5049	6701	22440680	MadPul	7/9/2007 12:38:59 AM	7/9/2007 0:39:00	75	-0.02	12.12	15.00
4016660560	226	4	30	1	2883889	42496	5015	6719	22440600	MadAus	7/9/2007 12:39:28 AM	7/9/2007 0:21:00	53	18.47	3.45	12.67
4016816159	226	4	32	1	2883921	43429	5047	6735	22440689	MadAsh	7/9/2007 12:40:40 AM	7/9/2007 0:38:00	18	2.67	30.00	15.50