December 2011

Transit in Montgomery County

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Transit System Analysis and Optimization in Montgomery County

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
And
MONTGOMERY COUNTY GOVERNMENT RIDE ON

in partial fulfillment of the requirements for the
Degree of Bachelor of Science
By

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In cooperation with Mr. Alfie Steele
Montgomery County Government

Date: December 15, 2011

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Acknowledgements

This project would not have been possible without the guidance and help of certain important individuals. We would first like to thank our liaison from Montgomery County Ride On, Mr. Alfie Steele, for all of his help during the course of our project with Montgomery County. Mr. Steele's assistance was vital in the understanding and task-making process of our project. We would also like to thank Mr. Andy Mangene, a program specialist for Ride On. His assistance in understanding the OrbCAD system and its terminology was vital to the success of the project.

We continue our thanks to Mr. Howard Benn, who helped us understand certain details and terms that we would encounter throughout our project. Mr. Phil McLaughlin, the Head Scheduler for Ride On, provided us with a thorough description of the scheduling of all the runs and explained to us in detail how layovers are formed in the scheduling, which was a very important piece of information needed to progress through the project. Mr. Steve Wells was also very helpful, providing us with answers to occasional questions as well as an organizational chart of Ride On personnel.

We would also like to extend our thanks to all three depot chiefs, Ms. Kathy Healy, Mr. Pete Buckley, and Mr. Dan Hibbert. Without their support of interviewing the bus operators and willingness to sit down with us and go through details about their respective depots, this project would have been near impossible.

Finally, we would like to thank our project advisors, Prof. John Orr and Prof. Joshua Rosenstock. Their guidance throughout the project, as well as their willingness to edit all the sections of our final paper multiple times, made this project possible.

Authorship

In the list below are all the works contributed to the paper by each group member. Some sections were completed individually, while some sections were completed by two group members or the whole group. Without the consistent and dedicated effort from everyone in the group, this project could not have been completed.

All Group Members
- Conducted interviews with Operators, Depot Chiefs, and Head Scheduler
- Data collection through OrbCAD
- Methodology
- Introduction
- Algorithm Design

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- Layovers
- Human Factors
- ATIS Systems (half)
- Ride On Layovers
- Executive Summary (half)
- Results and Analysis (half)
- Conclusion and Recommendations
- Appendix B
- Appendix H (half)
- Appendix G
- Debug Algorithm
- Data Analysis

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- Acknowledgements
- Authorship

From the Background
- Societal Benefits
- Environmental Benefits
- ATIS Systems (half)
- Montgomery County Government Ride On
- Ride On Organization
- Ride On Operations
- SmartTraveler Analysis
- Appendix A
- Appendix F

- Appendix H (half)

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- o AVL Systems
- o Integration with WMATA (Washington Metro Area Transit Authority)
- Executive Summary (half)
- Group Editor

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- o Transit System Route Planning and Scheduling
- o Closed Loop Systems
- o Interlining
- o Reliability
- o Scheduling Optimization Software
- o Scheduling Algorithms
- Results and Analysis (half)
- Appendix A (half)
- Appendix E
- Appendix D
- Debug Algorithm
- Data Analysis
- Programmed Algorithm

Executive Summary

Public transportation is a valuable asset in the communities that utilize it, but it is not as widely used as it could be. This is in part due to issues often beyond bus operators' control that put buses off schedule, causing customers to doubt the reliability and convenience of the service. One way transit systems can appear more reliable and become more convenient for their customers is by providing real-time information on bus arrival times through an Automated Traveler Information System (ATIS). This project seeks to improve Montgomery County Government Ride On bus system's ATIS software, SmartTraveler, by formulating a model of an algorithm that will increase the accuracy of its predictions. This algorithm will more effectively account for layover times, the adjustment, break, or recovery time for bus operators, when calculating its predictions. The parameters for this algorithm are based upon: 1) a series of interviews with the head scheduler, depot chiefs, and operators; 2) interpretation of historical data collected by the system; and 3) analysis of how the software currently functions. From this research, an algorithm was developed that could more effectively incorporate layover time than the current program, thus allowing for more accurate predictions of bus arrival times.

Figure 0.1 Picture of a Ride On Bus

Layovers play the central role in this project. Operators cannot drive for the entire day without rest, as this presents a dangerous situation for both the operators and passengers. Bus labor union contract language also requires this break to be included in the schedules of operators. In some transit systems, layover time poses no problem to transit systems because they are scheduled. Ride On's interlined system complicates layover time slightly, as there are several layover locations, not one centralized location, and delays along one route will affect multiple routes throughout the day. If a bus is running late, often an operator's layover time is sacrificed. While conversely, if an operator needs to use the restroom, the layover has the potential to run

over. The shifts between projected and actual layover times are affected by many variables, and thus are very difficult to predict. SmartTraveler cannot currently account for these discrepancies; therefore, many of the predicted bus arrival times become incorrect. Interviews with operators will help explain how some of these variables have contributed to the shifts. Being able to predict and account for these shifts will allow for more accurate predictions of bus arrival times.

The project began with a detailed interview with the head scheduler, Phil McLaughlin, to understand how layovers fit into Ride On's interlined system. This was followed by three weeks of interviews with the depot chief and operators of each Ride On depot: Silver Spring, Nicholson Court, and Gaithersberg/Rockville. As these interviews were being conducted, layover data from Ride On's AVL system, OrbCAD, was being organized by Schedule Adherence Crystal Reports and transferred into data points that could be graphed. In all, data was collected with layover information from 70 runs over the course of three weeks. The graphs made from this data were then analyzed to determine correlations between several layover variables, including arrival and departure deviations, time of day (rush hour), and duration of layover. The graphs with the strongest correlations were then given trend lines that could be incorporated into the algorithm. Several days were also spent analyzing SmartTraveler with relation to OrbCAD data to determine how the software was currently accounting for layovers in its predictions.
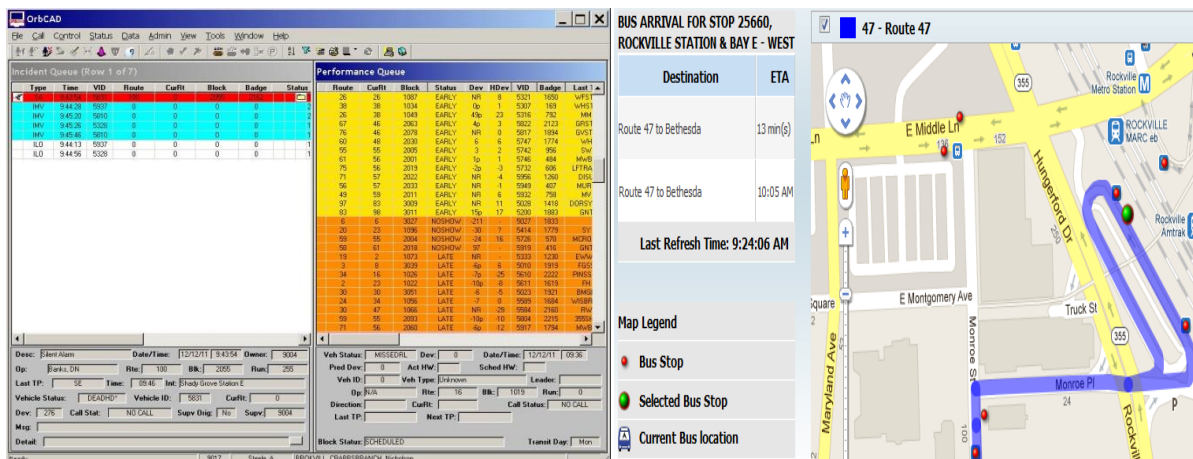
Figure 0.2 Side by Side picture of Comparative Smart Traveler

In the end, an algorithm was successfully created that predicted arrival times for buses throughout the day. This algorithm incorporated findings from the historical data analysis on operator behavior during layovers by accounting for correlations with arrival and departure deviations, layover lengths, and time of day. Not all of the information gathered from the operator interviews could be incorporated into the algorithm. A separate report was written to record operator concerns about restroom availability, conditions that put operators off schedule, a list of routes that were consistently off schedule, and recommendations to improve schedule adherence with respect to layovers. SmartTraveler observations were also recorded and analyzed.

Upon the completion of the project, three recommendations for improvements were developed. These included recoding the algorithm in more appropriate software, incorporating layover location into the algorithm, and modeling the algorithm to incorporate SmartTraveler to make it more compatible with the system, instead of needlessly replacing it. Excel limited the number of compound operations in a single cell to seven, and a different program would expand the algorithm's capabilities. Layover location would have been the next variable added to the algorithm if not for this limitation, as the data analysis revealed strong correlations. Finally, if a contact at ACS, the company that manufactured SmartTraveler, could have been reached, the algorithm could have been designed to better integrate with the system. This would be ideal, as Ride On has already put many resources into this program, and they should not be wasted.

1   Introduction

The benefits offered by a public transportation system can be tremendous. In 2010, Americans took more than 10.2 billion trips using public transportation; that is more than 35 million times each weekday. (APTA, 2009) Each year, public transportation cuts down on the gasoline consumption of the United States by 4.2 billion gallons. It also reduces the nation's carbon footprint by 37 million metric tons annually. Despite all the benefits of public transportation, only 14 million people use it, while almost 90 percent of commuting is done by car. To make public transportation more attractive, transit systems worldwide are looking for ways to make their services more efficient and responsive to passengers' needs.

Ride On, Montgomery County's public bus system, is looking to respond to the needs of its customers by providing them with real time bus arrival information. Ride On currently provides transportation options for over 970,000 citizens in this county in Maryland (US Census Bureau, 2010). Many of these citizens commute to the DC area for work, and therefore rely on this bus system to connect them to the Washington Metropolitan Area Transit Authority (WMATA) Metrobus and rail systems. However, actual bus arrival times do not always match up with scheduled arrival times, making it more difficult for customers to connect to WMATA. Communicating bus arrival times to customers is an indirect way that Ride On can make this connection easier for customers. In this way, if a bus will be late, customers know how much longer they can expect to wait and can plan accordingly. Providing such information to customers requires accurate real time predictions of bus arrivals. Ride On is planning to use an Automated Traveler Information System (ATIS) called Ride On Real Time to communicate these predictions to customers.

Figure 1.1 Picture of a Ride On Bus

Ride On Real Time will combine Ride On's existing Computer-Aided Dispatch/Automatic Vehicle Locater (CAD/AVL) system, known as OrbCAD, with a prediction software called SmartTraveler to obtain real time predictions of bus arrivals. This information will then be communicated to customers through phone calls, text messaging, the internet, or electronic signs. Although all eight phases of the project will not be complete until late 2012, it is expected to benefit customers, and the system as a whole, greatly by increasing customer satisfaction and ridership. A Return on Investment study of Real-time Bus Arrival Information Systems conducted by the Federal Transit Administration found that these systems "have a direct impact upon reduced passenger wait times" and may provide customers with perceived benefits of "less safety and security risk" and better transit performance overall (FTA, 13). However, the software is currently in its beta phase, and still may contain some minor issues that will need to be addressed before the system is widely released to the public.

One of the SmartTraveler issues that may need to be addressed before wide release is the handling of layover variables. A layover is the scheduled downtime between routes. Routes are defined as the geographic paths buses take from one central location to the next which include several intermediate stops. Layover time serves 3 main purposes for Ride On: it provides 1) an operator's break time; 2) recovery time to get buses back on schedule; and 3) adjustment time to shift buses from one route or operator to another. Because the actual length of a layover depends heavily on operator behavior and driving conditions that are beyond their control such as traffic, construction, and passenger loads, it is difficult to predict bus arrival times around them. Indeed, the guidelines the SmartTraveler software currently contains for handling layovers have yet to be determined and may benefit from further research into layover trends. Due to the unpredictable nature of layovers and the many variables that influence them and their relation to bus arrivals, very little research on transit system optimization addresses the problem of bus reliability with respect to layovers. A better understanding of the variables that affect layovers and how they in turn affect bus arrivals is needed to make Ride On's real time bus arrival predictions more accurate.
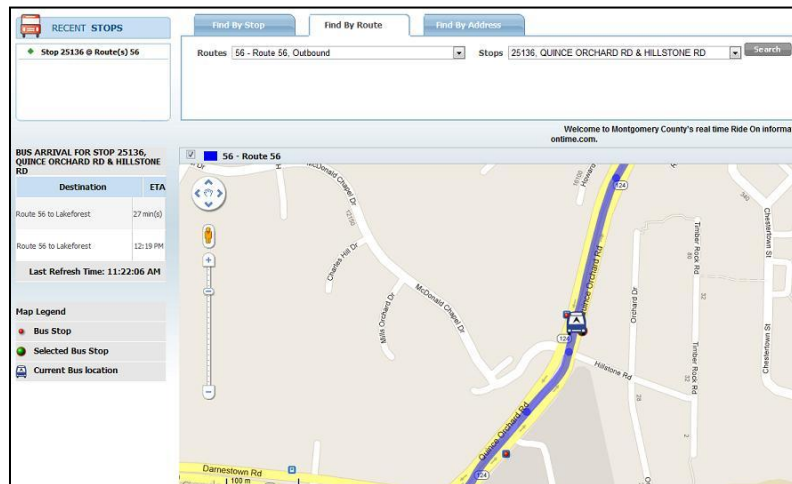
Figure 1.2 Screen capture of SmartTraveler

This project strives to make Montgomery County Ride On's prediction software more effective by developing an algorithm that can incorporate the variables related to layovers. We hope this will improve real time predictions of bus arrivals, making the system more reliable. A more reliable system for Ride On could benefit Ride On personnel, Montgomery County citizens, and the environment. Predicted bus arrival times that are more accurate could reduce work stress by potentially reducing customer complaints, as customers who know when a bus will arrive may be less focused on how off schedule it may be. They could also reduce passenger wait times, increasing customer satisfaction. This increased satisfaction could in turn lead to increased ridership, reducing the number of vehicles on the road, alleviating some traffic and emissions problems in this heavily populated suburb of DC. Layover variables are a good area to focus on improving the software because little research exists in the area and layover time is a complex matter that could benefit from the multi-faceted approach of an IQP.

2   Goals and Deliverables

The goal of this project is to design an algorithm that will increase the accuracy of predicted bus arrival times for Montgomery County citizens by accounting for prominent layover variables between bus trips. By adding this algorithm to Ride On bus system's preexisting prediction software, SmartTraveler, this project strives to enhance the reliability of the system and increase customer convenience and satisfaction. The deliverables for this project include:

- A model of an algorithm that can adjust SmartTraveler's predictions during the time between bus trips according to three distinct layover variables: 1) arrival and departure deviations at layovers; 2) layover duration; and 3) rush hour or non-rush hour; aand an accompanying description of how it works.
- A report on the findings on general operator behavior during layovers and operator concerns regarding layovers, conditions that put operators off schedule, a selection of routes that were consistently off schedule, and recommendations to improve layover time for schedule adherence and operator wellbeing.
- A final report detailing the entire project which includes a summary of the findings and recommendations listed above, as well as the findings on layover trends as analyzed from the historical data of Ride On's CAD/AVL system that were used to determine the parameters of the algorithm, a description of the construction and functionality of the algorithm, the methodology behind the project, and some background information to understand the fundamental concepts underlying the project.

Ideally, the algorithm will shift the predictions of SmartTraveler appropriately every time the bus is not on schedule, using the researched layover variables to adjust predictions around layovers, allowing Ride On to provide its customers with more accurate predicted bus arrival times before the operator begins his/her next trip. For example, if a bus departs its layover late during a rush hour route, it will predict the bus will arrive anytime within the near future at a later time than what the schedule may indicate. The algorithm will work in multiple steps, each step accounting for a specific variable which commonly affects layovers. The model will be a working prototype that will work for a single run with inputted data.

Over the course of this project, a variety of both statistical and anecdotal information about layovers will be collected which may not fit into the scope of the project. Issues surrounding layovers have never been studied in depth, and Ride On personnel may benefit from studying this information. Therefore these findings and recommendations on how to best utilize them will be included in a separate report for Ride On.

The final report will detail each step of the project including the literature review, methodology, results, and conclusions, along with an executive summary and several appendices. This report will also be submitted to Worcester Polytechnic Institute.

3 Background

Public transportation reliability is a complex problem. Bus transit systems must first plan and schedule their routes according to customer's needs, and then work to minimize delays and plan around them to get customers where they need to go at the desired time. Transit systems can use optimization scheduling software and consider the unique needs of their areas when choosing route layouts to help alleviate problems. They can also use prediction software to maintain customer satisfaction and confidence in the transit system by providing real time predictions of bus arrivals to customers. Montgomery County Ride On, the county-wide public bus system for Montgomery County, Maryland, uses optimization scheduling software to make their own system more reliable, and is currently beta testing their prediction software. However, the guidelines this system contains for layover time, the scheduled downtime between routes, are not yet determined and could benefit from further research. This chapter addresses the complexity of this problem by first reviewing Montgomery County's unique system and how they use layovers, and then providing more general background information on transit systems by: 1) reviewing public transportation's role in society; 2) describing how planning and scheduling general transportation systems work; 3) explaining how layovers work in the transit industry in general, and the complexities that make them difficult to take into account in ATIS software; and 4) discussing the general technologies used to optimize these systems.

3.1 Montgomery County Government Ride On

The Montgomery County Government Division of Transit Services Ride On program is a large public transportation system in Maryland. It supplies 2.5 million passengers with transportation services monthly and makes nearly 30 million trips a year with 76 total bus routes (Montgomery County Government, 2011). Included in those 76 routes are two weekend-only routes and nine routes which started service on May 1, 2011, showing that the system is still growing. With an extensive bus system that encompasses nearly the entire county, most people who want or need public transportation have a ready source available to them.

3.1.1 Ride On Organization

The Ride On bus system is a very complex and useful system, but without the personnel employed by the county, Ride On wouldn't be nearly as successful as it is today. The whole operation starts with the head scheduler and his team who make the bus schedules for the entire county. They take feedback from the operators and coordinators and work to adapt the schedule to the needs of the county employees and customers. The operators drive the buses and have a first person view of what happens on the road throughout the entire day. To supervise the bus operators on the job, the county has coordinators. Coordinators watch bus operators during layovers and passenger pick up/drop offs. They also respond to any accidents that occur with the buses. Figure 3.6 shows an organizational chart of Ride On personnel, including the positions of importance of each depot.
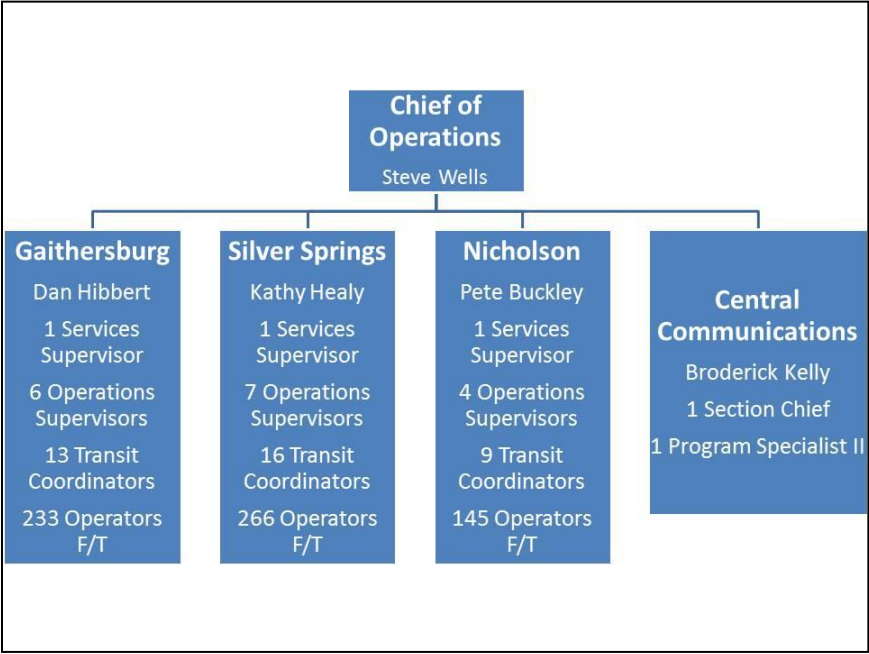
Figure 3.1 Organizational Chart of Ride On

There are three bus depots in Montgomery County: Silver Spring Depot, Nicholson Court Depot, and Gaithersburg/Rockville Depot. This is where bus operators pick up their buses at the start of their shift and drop them off before they head home. Each depot has a Depot Chief, and there are many different roles performed by each chief. They manage all the bus operators, coordinators, and office staff assigned to their depot, and provide any important or requested information to customers and the public.
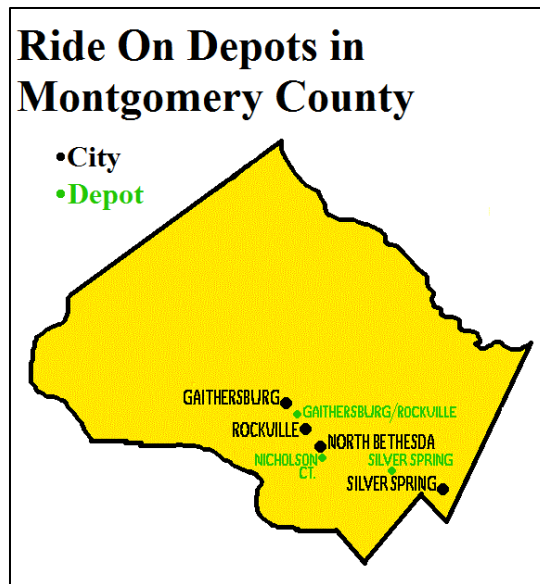
Figure 3.2 Map of Montgomery County indicating bus depots

Montgomery County is a charter county, and as such, boasts a powerful government. Because of this, powers and offices usually reserved for cities are given to the county. The emergency, law enforcement, and educational systems are all managed by the county along with the bus system. Therefore, Ride On is integrated with many of the other services offered by the county. In the case of an emergency on the bus, the police could be dispatched from the central control center. Also, the traffic county monitors could manipulate traffic signals on a bus route to allow a bus to catch up if it is running late, although this is rarely done.

3.1.2   Ride On's Interlined System

Transportation systems are very complex and require a large amount of work to make them the most efficient, reliable, and productive systems they can be. Scheduling is generally the most difficult part of making a successful transportation system, especially one with buses. There are two ways to schedule buses, one is a closed loop system, the second is an interlined system, see section 3.3.1 and 3.3.2, respectively, for more information. Ride On currently operates an interlined system.

Switching to an interlined system has provided Ride On with many benefits. One of the benefits is it allows Ride On to continue to abide by the established rule of a three minute minimum layover, or 10% of the route time. The reason for this was routes that were scheduled in years past were scheduled for a certain time, and in more recent years, that time has increased because of ridership and changes in route. Bus operators like the interlined bus schedule because it provides them with a change of pace every day. The largest disadvantage of interlining for Ride On is that delays on one route could affect several trips throughout the day.

3.1.3   Ride On's Optimization Software

Ride On has three types of optimization software they currently use to make their system more efficient and reliable: an Automatic Vehicle Locator (AVL) system called OrbCAD, a scheduling optimization software called Trapeze Fixed Route, and an Automated Traveler Information System (ATIS) called SmartTraveler. For more information on AVL, scheduling optimization, and ATIS software in the general transit industry, please see section 3.9 and the sections that follow it.

OrbCAD

Montgomery County Ride On currently uses a Computer Aided Dispatch and Automatic Vehicle Location (CAD/AVL) system developed by Affiliated Computer Services Inc. (ACS) called OrbCAD to manage their operations. OrbCAD allows Ride On to keep track of the location and status of all the buses in their fleet that are equipped with the right OrbCAD hardware, which includes a GPS system (ACS, 2010). The CAD portion of the OrbCAD system has a two-way data messaging system to minimize voice traffic, as well as providing incident form templates for accidents and customer incidents. It also allows for the tracking of vehicle statuses for schedule and route adherence, deadheading, and operator log-on. Another feature of OrbCAD is a tool that has a sorting and filtering option of performance and incident reports.

Data collected by the OrbCAD system is stored in a database where it can be accessed and analyzed to improve Ride On operations. Ride On currently uses Crystal Reports to organize OrbCAD's historical data into categories that make it easier to analyze.

Trapeze Fixed Route

Making the schedule is arguably the most difficult part of providing a successful transit system. For years, Ride On made their schedules with pen and paper and an Excel Spread sheet. After years of struggling to make a quality schedule, a software program was purchased called Trapeze Fixed Route. Trapeze is a scheduling software used to help create the most efficient and rider-friendly schedules possible.

Trapeze starts by accessing stored data about all the routes, trips, runs, and blocks and then starts a five step process that creates the best schedule with the information given. The five steps are: 1) Building routes/stops – this is where the specific routes and bus stops are entered into the program; 2) Building trips/running times – this is where the system builds the best trips based on the routes given and calculates the best run times; 3) Vehicle assignment phase, or also known as blocking – this is where the system takes into account the condition of all the buses and assigns the youngest buses (least amount of miles) to the mile-heavy runs and visa-versa; 4) Run cutting – this is the daily schedule produced by the scheduling staff to make sure operators don't go over a certain number of hours and have the correct amount of layover time, and 5) Rostering – this is where the administrative staff picks the days that each run will be idle for (these days are always consecutive), and each bus operator picks their run weekly.

The best possible efficiency is always one of the primary goals when creating a bus schedule. Prior to having the Trapeze software, scheduling was done using 75 Excel spreadsheets. Each of those spreadsheets was linked to a blocking source, which was used to

help make the schedules. After purchasing the Trapeze software, approximately 4-6 hours were saved per schedule. There are 12 schedule changes per sign up, or pick, and there are three picks per year. Using this software saved the scheduling team roughly six days while making each individual schedule over the course of an entire year. Because of how efficient the Trapeze software is, the scheduling team is able to complete multiple iterations of the scheduling to come up with ultimately the best, most efficient schedule. Without the Trapeze software, it took the same amount of time to do just one iteration.

Ride On Real Time

Montgomery County Ride On is currently developing an eight-part Automated Traveler Information Software (ATIS) that they are calling Ride On Real Time.The eight components of Ride On Real Time include: 1) SmartTraveler Plus, 2) SmartTraveler Mobile, 3) 3rd Party Mobile, 4) Signs of the Times, 5) Bus Stop Numbers—phone, 6) Bus Stop Numbers—pseudo text, 7) Bus Stop Numbers—regular text, and 8) Bus Stop Numbers—e-mail. SmartTraveler Plus is the name of the prediction software developed by Affiliated Computer Systems (ACS) that will run all the predictions needed for the separate parts of Ride On Real Time. SmartTraveler Plus is an internet based system used to provide customers with real-time information about a bus' predicted arrival time. SmartTraveler Mobile provides the same information as regular SmartTraveler, just to the customers' mobile device. 3rd Party Mobile is the same as SmartTraveler Mobile, but provided by a 3rd party(ies). Signs of the Times will be mounted in bus shelters and will display real time arrival and departure information for the buses servicing that stop, in a similar fashion to the sign shown in Figure 3.5. Bus Stop Numbers provide the customers with an opportunity to call, text, and email Ride On to receive accurate, up-to-date information about any bus using the stop's individual five digit number.

The first two components of Ride On Real Time are currently in beta-testing, but are available for the public's use. The website version allows customers to search for bus arrival times by stop number, route, or stop address. It provides customers with not only the closest arrival time, but also the predictions for the next few buses servicing that same stop. Unlike the mobile application, the online version provides a Trip Planner tool which allows customers to map out the route to the desired destination. The mobile version allows customers to search for bus arrival times by the bus stop number only, and can prevent customers from waiting in poor weather or extreme heat or cold longer than necessary.

3.1.4   Integration with WMATA

Another way that transit systems can optimize their services is by working together. Around the country, a survey conducted by the California PATH Program found that transit systems with overlapping service areas are integrating their systems through shared stops, fare payment methods, and integrated schedules (Miller, Englisher, et al, 2005). At the time of this survey, at least 60 transit systems in the US reported integration practices with neighboring systems. One of the transit systems surveyed was the WMATA, the transit system providing bus and rail transportation directly to the DC area.

The WMATA was formed in 1966 as a collaborative effort between the District of Columbia and its two adjacent states, Maryland and Virginia. It included state governments as well as the governments of two counties from each state, most notably Montgomery County, as well as the governments of three cities in Virginia. Since then, it has become the regional bus provider and operates all buses within the District (Miller, Englisher, et al, 2005, 46). It now integrates its services with over 8 local bus systems, including Montgomery County's Ride On, through the use of shared routes and stops, a shared fare payment method, the SmarTrip card, and an integrated schedule that allows customers to more easily transfer from one system to the next.
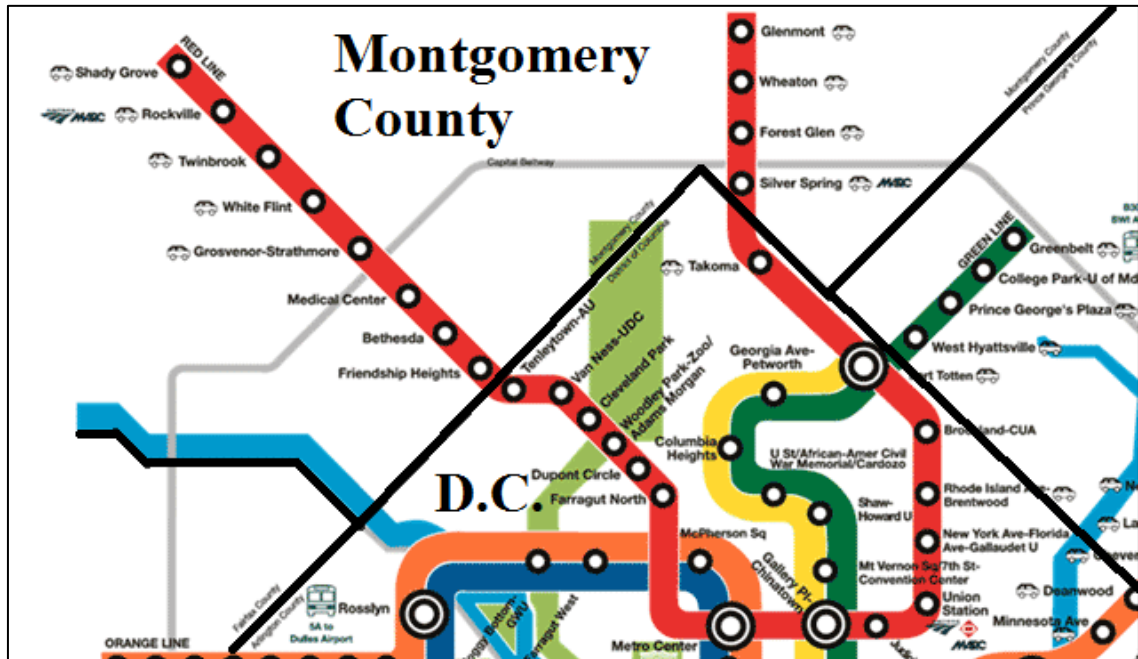
Figure 3.3 Map of WMATA service. The red line goes into Montgomery County.

Ride On integrates with the WMATA most notably through the Metro's Red Line, which loops through the southwestern part of the county, as seen in Figure 3.7 (Montgomery County Government, 2011). Twelve stops along this line are within the county and serviced by both Ride On and Metro buses. In fact, the two systems even distribute the operation of certain routes, with Routes L8, T2, and Z2 being run by Metrobus on the weekdays, and by Ride On on the weekends. In addition, Ride On directly supports use of the SmarTrip card, a payment method used by WMATA, Ride On, and several other nearby systems, by offering discounts to passengers as incentives. Using an integrated electronic payment method increases convenience for customers and cuts waiting time.

3.1.5 Scheduling Ride On Layovers

In Montgomery County Ride On, layovers are not scheduled as much as they are the result of the scheduling process. When the head scheduler is ready to plan for a new pick, he decides how much coverage of service he wants. Based on that he picks the start and end time for each

route. Each route begins and ends at a transit center, or other type of important area. Since the system is interlined, no bus is necessarily going to go back on the same route it came out on. Instead they determine the schedule through a first-in-first-out method. The scheduler will have all bus arrival times to that stop in one column and all bus departure times in another column. Then he will go through and match an arrival time with the first possible departure time that was a minimum of 3 minutes or 10% of the route's total time. An example of this process is shown in the figure below.

Arrival	Departure
1:30 (Route1)	1:32 (Route 1)
1:37 (Route 2)	1:34 (Route 4)
1:50 (Route 4)	1:50 (Route 3)
2:02 (Route 3)	2:05 (Route 2)
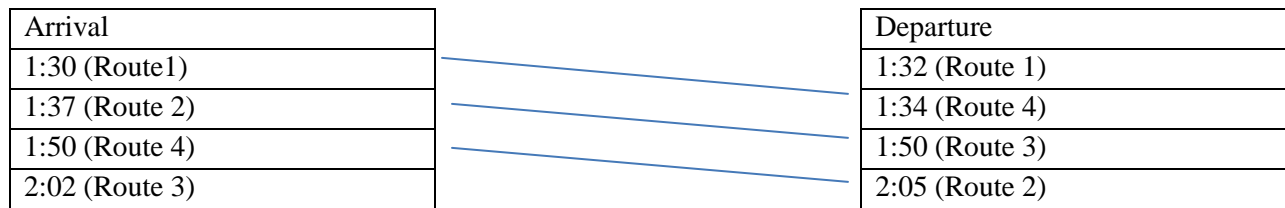
Figure 3.8 Example of "First In, First Out"

3.1.6 Ride On Layovers

The Montgomery County Division of Transit Services Ride On bus system uses interlined bus routes. Within these interlined bus routes, layovers are scheduled to occur right after each trip has been completed (Foley, MacDonald & Tate, 2008). Layover time serves 3 purposes for Ride On: it acts as recovery time to ensure an on time departure for the next route in the case of delays, break time for the operators, and adjustment time in the case of seasonal changes in the system. The primary purpose is recovery time. For example, in the case of a bus arriving early back to the station, more layover time is given to the bus operator, while in the instance of a bus arriving late, the operator will lose some of his allotted time during the layover to recovery. For the customers, this may translate into a late bus, leading to bus unreliability.

Now that Ride On's operations have been described in great detail, they will be placed in the greater context of public transportation and transit systems in general with the information in the sections to follow. These sections start with the significance of public transportation overall and then detail more general route planning and scheduling techniques before describing transit system optimization software use in the broader sense of the public transportation industry as a whole. They also provide information on the role of layovers in general transit systems and the human factors that make layover predictability and system reliability complex issues.

3.2 Public Transportation

People often have a great need for transportation for the purposes of accessing employment, education, or child care facilities. However, not everyone has access to his or her own private vehicle. In some communities, the local government can provide its citizens with a public transportation system to help meet this need. In fact, over 200 million Americans in approximately 77,000 communities have access to these systems (APTA, 2010).

Public transportation is a growing industry in the United States. Between 1995 and 2010, ridership of public transportation increased 31%; a growth rate higher than the increase in the U.S. population and the growth in the use of the nation's highways over the same period (17% and 24%, respectively) (APTA, 2010). Americans board some form of public transportation a combined 35 million times each weekday, totaling 10.2 billion trips in the year 2010. Not only is public transportation widely used, with more than 7,200 systems across the country, but it also provides a multitude of benefits. Using public transportation can not only bring convenience to people's lives, but also have a positive environmental impact.

3.2.1 Societal Benefits

When driving is not an option, public transportation can be an affordable and necessary alternative, providing personal mobility and freedom to those who cannot afford a private vehicle. Owning a personal car can be expensive and is not always an option for every American. The average household spends 18 cents of every dollar on transportation, and roughly 94% of those 18 cents goes into buying, maintaining, and operating private cars (APTA, 2010). However, households choosing to use public transportation over private vehicles can save more than $10,000 every year. For some people, public transportation provides the only means of getting to medical appointments, making it to school, or going to work.

Public transportation not only makes it possible for some Americans to have jobs they otherwise wouldn't, but also creates jobs. Investment in public transportation creates and supports over 1.9 million public and private sector jobs annually and is a $55 billion a year industry (APTA, 2010). In addition, public transportation makes it easier for everyone to get to work by reducing traffic congestion. In fact, without the growth of the public transportation industry, the cost of congestion, such as lost work time and wasted fuel, would have increased by an additional $19 billion in the year 2010 alone.

3.2.2 Environmental Benefits

Using public transportation over private vehicles can drastically reduce the nation's use of fuel and the costs associated with it. By living in an area served by public transportation, Americans save 785 million hours in travel time and 640 million gallons of fuel annually in congestion reduction alone (APTA, 2010). As a more practical example, households near public transit drive an average of 4,400 fewer miles than households without access to public transit, which equates to an individual household reduction and savings of over 220 gallons of gasoline per year. Not only does public transportation benefit the economy, but it also helps reduce the dependence on fuels from foreign countries. The use of public transportation has saved the

United States 4.2 billion gallons of gasoline annually, which is more than three times the amount of gasoline imported from Kuwait.

Reducing fuel usage not only saves money, but also helps the environment by reducing carbon emissions. According to the American Public Transportation Association, one of the largest contributors to global climate change is the greenhouse effect, which is primarily caused by carbon dioxide emissions (2010). Cars and vans are leading contributors to our carbon dioxide output. If one person switched from driving to using public transportation, it could reduce daily carbon emissions by 20 pounds or more than 4,800 pounds annually and could reduce a household's carbon emissions by 10%, or up to 30% by eliminating a second car. In addition, using public transportation can reduce 10 times more carbon monoxide emissions compared to other household actions.

3.3 Transit System Route Planning & Scheduling

Two fundamental parts of any transit system are the layout of its routes and the design of its schedule. Transit systems want to provide coverage to important places in the community such as shopping centers, schools, hospitals, government buildings, airports, and other transportation stations (Mistretta, 2005). This involves not only careful planning of geographic routes to link residential areas to these significant locales, but also careful scheduling of the service available on these routes. For example, some routes will carry more people at certain points of the day, such as routes connecting commuters to their places of employment at the beginning and end of the workday. To make effective use of its resources, a transit system schedules its system to accommodate the changing volume of its passengers throughout the day, causing the system to balance the areas it covers with how frequently it serves them. A bus transit system will be limited by either the number of buses it owns or the number of driver-hours it can afford. The Transportation Research Board (TRB), defines a driver-hour as one driver driving for one hour (TRB, 2009). Ideally, if money was not a constraint, a bus could be on each individual street at very frequent time intervals. However, bus systems must cover the costs of maintaining a fleet of vehicles and employing a large work force to operate them. While local government funding and bus fares can help cover these costs, government budgets are tight and fares must be reasonably priced so that community members can effectively use the system. Simply adding more buses whenever they would be convenient would put too much of a strain on the system's budget. Instead, systems must focus on making the best use of the buses they can afford. One way they can do this is through the use of scheduling optimization software. Another way is by choosing the correct route pattern to fit their area's unique needs.

3.3.1   Closed-loop Systems

In a closed loop system, one loop is two complete trips along the same route through a community (TRB, 2009). A trip is a full one-way ride along a single route, which is the geographic path a bus follows from one point of interest to another. These points of interest could be major shopping centers, transportation stations, government buildings, or even heavily populated residential areas. A closed-loop system is made up of many loops, as shown in Figure

1. This is the easiest way to create a network of routes. Closed-loop systems identify the most traveled and populous locations in the area, and join the points together. The buses move both ways along these routes. This system can be made somewhat more efficient by running through a central hub, as shown by the black circle in the middle of Figure 1. With a central hub, operators can easily substitute out, and have no trouble beginning and ending routes.

Figure 1 is a very simplified example of a closed-loop system, which only shows three routes with only one bus operating several trips on a single route. In a real system, there would be many more routes, and multiple buses would service a single route, starting at different locations along the route and running trips in different directions along it throughout the day. In Figure 1, each route is represented by a different colored loop, signifying that each bus operates several trips along a single route during the day. Black stars are used to represent layover locations.
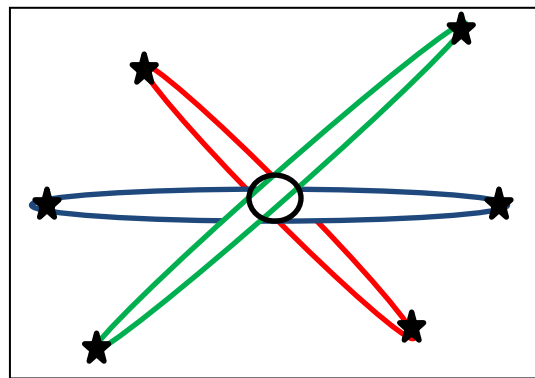
Figure 3.4 Simple diagram of closed loop system

3.3.2   Interlining

In interlined bus systems, routes are made in much the same way as in a closed-loop system, with buses either connecting two points of interest, or traveling down popular streets (TRB, 2009). Interlined routes tend to be more scattered throughout the region than closed-loop routes, and instead of driving one specific route for an entire day, operators are scheduled on multiple connecting routes throughout the day (PR Newswire, 2000).

Figure 2 is a very simplified example of an interlined bus system. As before, there are three buses, each denoted by a different colored arrow. But each bus is responsible for trips on three different routes over the course of the day, not just one.
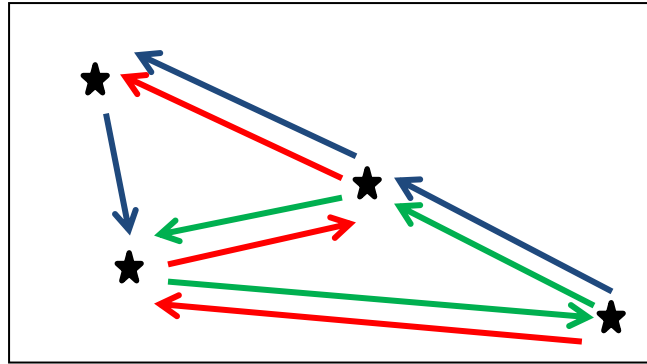
Figure 3.5 Simple diagram of interlined system

There are advantages and disadvantages to each type of route system. Interlined systems often reduce the number of vehicles needed to cover the same schedule, and familiarize bus operators with more of the route system (TRB, 2009). Closed-loop systems are easier to set up, and allow bus operators to develop specialized knowledge of a single route.

3.4 Transit System Technologies

After creating a viable public transit system, a difficult problem faced by operators and managers is optimization (TRB, 2008b). It is easy to arbitrarily assign route times, but attempting to move the largest number of people with the least amount of resources has always been the goal. If the transit system is not scheduled properly, it can be almost as useless as not having a system in the first place. The same is true for a system that cannot be depended upon by its customers due to delays, especially unreported ones. In today's modern world, transit systems can employ several types of technology to make their services more efficient and dependable. Three examples of commonly used transit technologies include: 1) Automatic Vehicle Locator (AVL) systems; 2) scheduling optimization software, and 3) Automatic Traveler Information Systems (ATIS). Ride On's use of these systems has already been described in sections 3.1.3-3.1.7. Below are more general transit system uses of these technologies.

### 3.4.1 Automatic Vehicle Locator systems

Transit systems can employ a variety of technologies to collect real-time information on the locations of all vehicles in the system. These can sometimes be grouped under the umbrella term AVL systems, and can incorporate a multitude of technologies that together "supports real-time fleet operations management by providing operators with real-time schedule adherence feedback and by providing dispatchers with real-time data on the locations and status of all fleet vehicles" (TRB, 2008a, 91). AVL systems provide the opportunity to collect large quantities of data at low cost and to correct any issues in performance, schedule planning, and operations control (Cham, 2006). By using AVL technology, transit systems can more accurately predict variables that will negatively affect their buses and their arrival times. While the components and capabilities of AVL systems are unique to each transit system, most will include GPS receivers and antennae, vehicle logic unit (VLU) computers, mobile data terminal (MDT) operator

interface terminals, Automatic Passenger Counter (APC) subsystems, and a wireless network to transfer data (93). The diagram in Figure 3.3 shows how AVL information is transferred between the bus fleet and the dispatch center via a wireless network (represented by the radio tower). It also depicts the GPS antenna and MDT components listed above.
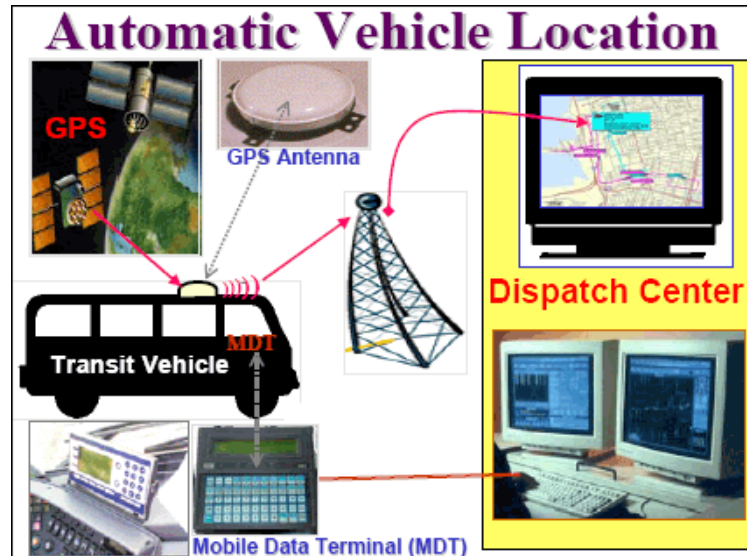
Figure 3.6 Information flow in an AVL system

Although AVL systems vary, there are some general benefits enjoyed by most transit systems. For example, real time information on bus locations can help dispatchers and supervisors address service disruptions and operational issues more effectively as well as provide detailed historical data for use in schedule adjustments that can be used to make the systems more efficient (TRB, 2008a, 64-65). APC subsystems can provide data on ridership for particular routes, which can also be effective in designing routes and schedules for optimum use.

Due to the variable usage and contents of AVL systems, individual transit systems report a variety of benefits, both monetary and productivity-related. According to a Transit Cooperative Research Program's (2008) report on improving public transportation technology implementations, the Denver Regional Transportation District was able to "decrease the number of late (bus) arrivals by 21 percent" by deploying a GPS-based Computer-Aided Dispatch/AVL system on its 1,355-vehicle fleet (26). Also included in this report was the success of the Metropolitan Atlanta Rapid Transit Authority, which estimated a savings of "approximately $1.5 million per year through schedule adjustments using APC and AVL data." In fact, these systems have been around in various deployments as early as 1997, when Portland, Oregon, first began evaluating the data from their own system. Around the same time, both Ann Arbor Transportation Authority and the Chicago Transit authority began using AVL and APC technologies, using the data to "improve schedule adherence and increase system performance" and "evaluate schedule adherence, calculate equality-of-service measures, and identify where and why bus bunching occurs", respectively (Geneidy, Horning, & Krizek, 2010, 2).

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3.4.2   Scheduling Optimization Software

Please note that this section contains information about general scheduling optimization software practices in the transit industry. For specific information on the software Ride On uses, Trapeze Fixed Route, please see section 3.3.

The rise of computer use in the world has affected everyone, including the transit sector and the way they operate their systems. This computer age has brought in new software that can assist transit schedulers with their tasks in the system (Mistretta, 2005). This new scheduling software provides more advanced methods for scheduling, enabling agencies to upload the parameters of their work rules into it and automate certain aspects of the scheduling process, ideally producing more efficient schedules. Adding the software to the systems may come with several benefits, including the reduction of staff and staff time needed for the scheduling process, the reduction of vehicles and/or operator hours, and the flexibility and functionality inherent with the computer software program. One of the largest benefits of adding scheduling software to a system is that it may speed up the scheduling process, making it more efficient than having an operator manually create schedules.

The software may be a very beneficial addition to transit systems, however, there are some disadvantages. While the software may be very useful, it can be very expensive, averaging between $100,000 to $200,000 for up to 200 vehicles, with a $20,000 annual maintenance fee, depending on the manufacturer (Mistretta, 2005). The cost of the software will vary greatly by transit system, as it is dependent upon the number of vehicles in the system and may include add-ons averaging $50,000 each that increase the ability of the software in areas such as route-planning and customer service. Also, the installation period of the software may take excessively long and delay use for transit systems. The two most used scheduling software providers are Trapeze and GIRO HASTUS. While HASTUS can be significantly more costly than Trapeze, it is typically found to be better integrated with Windows and more compatible with other transit software. Montgomery County Ride On currently uses Trapeze Fixed Route to help design their schedule. More information on Ride On's scheduling practices and how they use Trapeze will be covered later in the background in section 3.7.

3.4.3   Scheduling Algorithms

Scheduling optimization software works by applying data from AVL systems to various algorithms contained in the software. Each algorithm is specifically prepared to deal with a single aspect of the transit system, such as the frequency of service based on ridership (TRB, 2009). However, most transit algorithms require several variables to operate, such as number of vehicles, operators, working hours, and route information. As these software products get more advanced, the algorithms are able to handle more variables and provide even more optimized results, assuming the AVL system is kept up to date with the software.

For example, a famous breakthrough in bus transit occurred in 2007 when an algorithm was created to determine the optimal amount of slack time to schedule into a route (Bukkapatnam, Dessouky, Zhao, 2007). This algorithm is now an "industry standard" in scheduling optimization software. Slack time is extra time put into the route to account for

delays. This extra time acts as a buffer to prevent buses from being late and upsetting customers. If the time between stops should be 15 minutes, and the bus schedule lists the time between stops as such, the bus may be late which will aggravate customers. If slack time is included, however, the bus will actually be on time in the case of a delay, and early without one. However, the balance is delicate, as too much slack time would mean that buses may run too early, or not run as frequently as they could be.

To determine the optimal slack time, an algorithm was designed to calculate the slack ratio, the optimal amount of slack time to add to a route per time to complete the route. This algorithm uses both random and nonrandom variables to create a function for slack ratio (Bukkapatnam, Dessouky, Zhao, 2007). It then determines the max of the function while still taking into account the level of frequency needed to properly service the route. The equation for slack ratio is given below in Figure 3.4:

$$S_r = \frac{ST}{E(RT)} - 1$$

Figure 3.7 Equation of Slack Ratio

Two of the primary variables used in the calculation are ST, the scheduled amount of time a route is supposed to take, and RT, the actual time a route takes (Bukkapatnam, Dessouky, Zhao, 2007). ST is determined by calculating how long the operator would take to arrive at a stop under completely average conditions. RT is a random variable usually given a normal distribution over a set range. The range of this variable and parameters assigned to the distribution are all determined by looking at historical data, or working in conjunction with an AVL system.

To calculate the expected delay, the function first calculates the expected value, or E, of RT (Bukkapatnam, Dessouky, Zhao, 2007). The slack ratio takes these and several other less significant variables into account, to create a single variable with a range of possible values attributed to it. In order to ensure an optimal slack time calculation, the range of this single variable is bounded. For example, if a bus operator is supposed to complete twelve trips along a route in a single day, the upper bound of the slack time calculated will be the value that allows the longest period of time between trips while still allowing enough time for all twelve trips to be completed in a single day.

3.4.4 Automated Traveler Information Systems

One of the primary concerns of transit systems is customer satisfaction, therefore providing reliable, convenient service for customers is very important. One way transportation systems can make their service more convenient for customers is by providing up to the minute predictions on buses, trains, or taxis in their system. Having a prediction system in place can help transit systems work around delays along routes while still providing quality service to the

general public. Such prediction systems are known as Automated Traveler Information Systems (ATIS).

An ATIS pairs the GPS information from AVL systems with information on the transit system's schedule to make real-time next bus predictions. These predictions can be provided to customers "both pre-trip and en route, which can help increase ridership by reducing customer anxiety, enhancing perceived reliability, and generally presenting a more 'modern' image" (TRB, 2008a, 65). Today's commercial navigational systems incorporate 2D as well as 3D graphical representation of offline environmental data such as roads and buildings. Some systems also make use of online satellite information systems which enables them to inform drivers about traffic related incidents such as accidents, congestion, road construction sites, etc. ATIS was designed with the goal of incorporating offline as well as online features of a real-world state-of-the-art navigational system (Klee & Weeks).

There are many different types of ATIS, of which NextBus Incorporated is an example. NextBus provides customers with data that can be acquired from computers, cell phones, and LED electronic message boards located at passenger waiting areas (Brill 2009). These all provide mini-reports of the specified location which are updated every minute for the customer. These mini-reports provide customers with real-time predictions of when a bus will be arriving at the requested stop. NextBus makes these predictions by using information the vehicle has sent, such as a vehicle identification and location, in addition to schedule information on its routes and its next stop. This allows NextBus to calculate and predict the time of arrival. However, some predictions may be disrupted because of variables that cannot be accounted for such as traffic congestion, weather, and accidents.

NextBus has been leased to approximately fifty different transit systems around the US. Each company that has leased NextBus is able to modify the software according to its unique vehicle fleets and passenger waiting areas. For example, the San Francisco Municipal Transit Agency (MUNI), a client of NextBus, has over 800 NextBus digital signs positioned throughout its system. These signs are mainly located in bus shelters, MUNI's buses, and Light Rail Vehicle (LRV) platforms. The digital signs display route destinations, stop alerts, and real time indicators of arrivals (Brill 2009). An example of one of MUNI's Nextbus signs is shown in Figure 3.5 (LA Blog, 2010). This sign shows the bus route, 10 Townsend, and the wait time for the next two buses servicing the stop.

Figure 3.8 Next bus information sign

3.4.5   Layovers

One factor that comes into play in transit system efficiency is layover time. Layovers can be defined as the time between the scheduled arrival and departure of a vehicle from a transit terminal (TRB, 2009). Another term used widely in transit groups is recovery time. The terms are very similar, but the meanings are slightly different. Layover time refers to the rest time given to the operator between trips, while recovery time is the time built into the schedule to ensure an on-time departure for the next trip. As mentioned previously, for Ride On, layover time is used for recovery foremost and rest time for the operators if there is any additional time left over after operators can ensure an on time departure for their next trip. The following is information on layovers as they pertain to general transit systems, not Ride On operations.

Layovers are typically 10-30 minutes long, depending on transit system practices and union contracts (TRB, 2009). Because layovers are required by bus operator unions, it is important that operators can successfully have their layover time even in the case of a service interruption. Layovers are often calculated based on the routes given to the operator. A required layover typically varies from none at all to 10% or 15% of the route's running time, and usually the time is paid for operators.

Transit systems often schedule layovers at the end of trips to avoid causing any inconvenience to customers. The location of the layover during a route, however, does depend on the kind of route the transit system runs (TRB, 2009). For routes that are tough for operators to stop on due to passengers who ride the entire route, it is common to find a key mid-route transfer area, usually a location which is situated with multiple transfer points for customers, whether it be train, taxi, etc. At times schedulers may rearrange trips in multiple spots in the schedule in order to give more or less layover at the end of the route, since in certain cases, operators who are forced to take layovers in areas other than the terminal may not be able to park effectively

due to lack of area to park the bus. The scheduler's main purpose while creating the best schedule possible for operators is to ensure reliability and efficiency in daily operations, while meeting operator needs and expectations for layover time.

3.4.6   Human Factors

Many human factors can disrupt the flow of the route and decrease the overall reliability of a transit system for other passengers. Factors that may affect the scheduling process and timeliness of the transportation include the loads that passengers carry on their travels, handicapped people who embark or disembark from the bus, amount of traffic, and turning around at the end of the route (TRB, 2009). Important considerations include the passenger load and the number of passengers carried on one or more vehicles at any point on a route. The maximum passenger load on a route is often the most used statistic when developing schedules for routes.

The reliability of public transportation is not only affected by the customers of the system, but the operators themselves may also significantly impact on-time departures and vehicle speeds (Cham, 2006). Operators, like other employed people, have the choice of taking days off from work. However, the absence of an operator may affect the system because there may be an insufficient number of operators to take over the shifts needed, which in turn causes late departures and possibly even missed trips.

Operators may also affect the reliability of the system depending on their performance and experience. Usually operators with more experience are said to be more reliable because they are more familiar with the vehicles and routes (Cham, 2006). However, since they are more acquainted with the system, experienced operators tend to drive faster than less experienced operators because they are more accustomed to the routes and more comfortable maneuvering the bus. This may lead to unsafe riding conditions if the operator is speeding, and could cause a bus to arrive early, potentially making passengers miss their bus.

There may also be poor performers who tend to act more carelessly on the job. These operators tend to report late to work, take longer personal breaks, drive more aggressively, and disregard the schedule (Cham, 2006). An operator reporting to work late may automatically guarantee a late departure for the first route of the day. By taking longer personal breaks and disregarding the schedule, these operators will periodically cause late departures and confusion in the field, which also greatly reduces the reliability of the system.

3.5 Reliability

Public transportation can provide a cheaper, more environmentally friendly way to get around a city than owning a private vehicle. However, it is not as widely used as it could be (Cham, 2006). A major reason for this could be inconvenience due to unreliability of service. Off-schedule bus arrivals and departures are one of the most significant causes of service unreliability; passenger loads, running times, environmental factors (or externalities) and operator behavior are also reoccurring issues.

The bus company is responsible for creating time tables for buses. If these are unreliable, customers may lose confidence in the system and ridership may decrease. Passengers expect to have bus service provided to them in a timely and professional manner with minimal delays and acceptable satisfaction. They expect the bus they are riding to be at the terminal at the exact time that it is projected to be there, otherwise, they feel inconvenienced and sometimes mistreated. To customers, a poorly managed bus system "affects their perception of service quality and transit utility compared to other mode choices," while to the bus system itself, this means a decrease in ridership and revenue and higher costs to provide additional service to recover for their lapse in service (Cham, 2006).

Most people who ride the bus do so for commuting to or from work. It is important for them to be able to depend on the transit system to get them to work on time. The fares paid by these riders partially pay for the system itself, meaning that decreases in ridership will force the system to cut back due to less funding. This is why it is imperative that bus arrival times are as close as possible to the schedule. Optimization of transit systems is largely focused on making bus arrival times more dependable. Today, transit systems can employ a variety of technologies to make their operations more reliable.

From this foundational understanding of bus transit systems, optimization software, and layovers, we hope to develop a framework of knowledge that we can use to analyze how layovers affect Ride On's specific interlined system with respect to the optimization software they currently have in place.

4   Methodology

This section presents the tasks that were completed in order to accomplish the project, together with the different methods that were appropriate for each task. Due to the complexity of layovers and dependence of human factors, a multifaceted approach to understanding them was adopted. This multifaceted approach included: 1) gathering background information on scheduling; 2) collecting historical data; 3) conducting interviews with operators and other Ride On personnel; and 4) developing an algorithm based on the historical data. All three approaches, analyzing historical data and conducting interviews, as well as riding buses, were needed in order to develop a complete understanding of layover variables that would allow recommendations to be made and findings to be quantified into an algorithm to account for them. While historical data analysis revealed trends in operator behavior regarding layovers, interviews with the operators were necessary to determine the causal relationships behind those trends. With these relationships, it was more possible to determine which data represented quantifiable trends in layover behavior, and thus were worth considering for the algorithm, and which were unique conditions that could not be quantified. The interviews also allowed for direct collection of operator opinions, and thus potentially facilitated more realistic layover recommendations. It was hoped that bus riding would act as a check on operator interviews, revealing any discrepancies between how the operators said they behaved and their actual behavior. In this way, information could be gathered on layover trends that included explanations for operator behavior and lessened operator bias, making the final recommendations and algorithm as realistic and useful for Ride On as possible. However, not all of the methods listed below produced information that was valuable to the project, and bus riding was one such method.

4.1 Ride On Scheduling

In order to address layovers in Ride On's complex system, a better understanding of how their schedule works was necessary. General knowledge of scheduling practices was obtained from a manual developed by the Transit Cooperative Research Program (TCRP, 2009). Additionally, an IQP from 2008 identified Ride On's own system as interlined (TRB, 2009; Foley, McDonald, &Tate, 2008). However, more specific information on how Ride On operates this interlined schedule was needed. This information was collected through a semi-structured interview with their head scheduler (see Appendix C for interview protocol). This interview was a more direct way of obtaining the information needed about scheduling for Ride On, making it more time efficient and accurate than researching secondary knowledge sources. In addition, the structure of this interview allowed for a few leading questions that could be followed by more specific questions as familiarity with Ride On's interlining system grew. Ride On operates many routes, and interlined systems are difficult to manage, so it was important to learn why Ride On chose this method, how it worked in their system, and what specific benefits and disadvantages it offered. An examination of how Ride On's scheduling optimization software, Trapeze, interfaced with the scheduler to make the schedules was also necessary to determine how Ride On incorporated layover time into the schedule. This examination identified what factors were considered when calculating layover time into specific trips. Consequently, it also identified

which variables were not considered, and thus could be valuable to incorporate into the algorithm predictions for when layovers ran longer or shorter than scheduled.

4.2 SmartTraveler and Layovers

In order to address layovers in Ride On's prediction software, SmartTraveler, it was necessary to determine how layovers were already accounted for in the predictions. It was planned that this phase would be split into two main sections: determining how the software was designed to handle layover variables, and evaluating how the software actually made its predictions. Originally, the first section was designed to determine how the software already functioned, making it possible to recommend an algorithm that could more easily be incorporated into the existing software. The second section would then have evaluated how effective the software was, if it was working correctly, and trends in inaccurate predictions. This would have provided a starting point when formulating the algorithm so that it could potentially improve these predictions. As the project was specifically about layovers, predictions between a bus' last trip and the first stop on its next one were the focus, an area prediction software typically struggles with that has not been heavily studied. In addition, it was believed that gaining information on this software would potentially provide some examples of variables that would be beneficial to analyze within the system's historical data when looking for trends between early/late buses and unscheduled layover times.

In order to determine how the software functioned, in the first phase a semi-structured telephone interview would have been conducted with the programmer from ACS who ran the software for Ride On (see Appendix C for interview protocol). From this interview, information would be gathered on what variables SmartTraveler took into account when making its predictions, especially between trips, and where it got this data, as well as what difficulties the software was encountering. However, the first phase could not be conducted, as a contact at ACS, the company that manufactured SmartTraveler, could not be reached. Therefore, the second phase shifted from an evaluation of known information to an attempt to reverse engineer the software and determine how it worked.

To determine how the software was actually working without any manufacturer information, the real-time SmartTraveler predictions for specific trips were recorded and compared to data from OrbCAD on when the bus actually arrived. This allowed for an assessment of how accurate the predictions were and if the software was accounting for layovers as recovery time. From this information, how SmartTraveler actually handled layover variables, as well as what changes could be made to improve this process, could be determined.

4.3 Historical Data Analysis

Once Ride On's scheduling process was better understood, it was more possible to analyze how layover time actually affected trip times. To do this, historical data from Ride On's CAD/AVL system was collected and analyzed via the Crystal Report program to determine correlations. This program provides Ride On with quantifiable and organized information from

runs in the past by sorting the raw data from the CAD/AVL system into categorized Crystal Reports. For the purpose of the project, the most relevant Crystal Report was Schedule Adherence by Time Point.

Due to the size of the Ride On system, all 76 routes that Ride On operates could not be studied. In order to narrow the focus of the data analysis, a list of routes that carried the most people and were some of the longest geographically was provided by the project liaison. From this list, a list of all of the runs that included those routes was created. To collect a data set representative of the whole system, 70 runs to analyze were randomly selected from this list, and data points were made from specific layover variables. These points were then graphed in order to identify patterns between layover discrepancies and bus arrival times that could be applicable to the system as a whole, and whether bus operators were early/late due to factors while driving or leaving layovers early/late.

There were many layover variables that could be examined, but the analysis was focused on early/late bus arrivals and departures, layover length, rush hour vs. non rush hour, and layover location. There were two reasons for this focus. First, it was hypothesized that these would be the most general layover variables with the greatest influence on the relationship between layovers and trip times, and thus the most useful for an algorithm that would address the entire system. Second, the Crystal Report program used to organize the CAD/AVL system data facilitated focus on these variables. From the graphs of the data points of these variables, Pearson correlation values were calculated. These values were then used to determine the relationships between the variables in the algorithm design.

4.4 Causal Relationships- Interviews and Riding Buses

To fully understand the correlations found through the data analysis, the causal relationships behind them needed to be identified. While it was hypothesized that factors enroute played a role, operator behavior during layovers could also affect if a bus would be early/late to the first stop of its next trip. This phase of the project was designed to determine what caused discrepancies in layovers and to quantify how far off schedule certain layover locations and activities could put operators starting their next trip. The information received was not actually quantifiable, and so information gathered from this section was predominantly used to formulate the Layover Observations and Recommendations report.

Layover time serves multiple purposes for Ride On personnel. To understand more definitively how layovers were used by operators, it would be necessary to complete two tasks. The first would be to actually ride the buses and observe what bus operators did during their allotted layover time. From this observation, it was believed that firsthand experience could be gained that could be used to identify trends in operator behavior, layover location, and early/late departures from layovers. However, little useful information was actually gathered from riding buses, especially because layovers were difficult to observe without telling the operator, and thus potentially altering their behavior.The second task was to interview operators to find reasons for extending or shortening layovers, as well as arriving to layovers late. Interviews allowed for information and explanations about operator behavior during layovers to be directly collected

from the operators themselves. Using direct observation and interviews would have allowed for not only the gathering of accurate information free of operator bias, but also the collection of much more information than solely direct observation would have provided. Combined, these methods would have made it easier to identify trends in operator behavior while remaining as objective as possible, making the recommendations for the algorithm more realistic overall. However, as only the interviews produced useful results, the results of this section were not free of operator bias.

5 Results and Analysis

The final goal of this project was to design an algorithm that would increase the accuracy of predicted bus arrival times for Montgomery County citizens by accounting for prominent layover variables between bus trips. After collecting data points from Crystal reports and conducting interviews with bus operators, the variables that would be included in the algorithm were determined. These variables were arrival and departure deviation from the layover, time of day, meaning either rush hour or non-rush hour, and the duration of the layover. With further analysis of the data, high correlations were also found between the location of layovers and the arrival and departure deviation from the layover. However, these variables could not be implemented into the algorithm due to the limitations of Excel's capabilities. All of the additional research from operator interviews can be found in Appendix G, while the full results of the data collection are in Appendix H.

5.1 Data Collection

This section will detail the data collected and how it was utilized. From the operator interviews detailed in Appendix G, it was found that the most influencing factors on operator behavior during layovers are the time of day, duration, and location of each layover. Based on this, data was collected on each of these variables. In all, data on 769 occurrences was collected. Each occurrence was a specific instance a bus departed from its layover more than 1 minute early or 5 minutes late. They were chosen based on a list of runs developed from a list of routes indicated by the project liaison as routes that carried the most passengers or were the longest geographically. The routes listed were only part of the Silver Springs and Gaithersburg/Rockville regions, as many Nicholson Court buses lacked the equipment necessary to connect to OrbCAD. From this list, each run was identified that included one of the aforementioned routes. Then, through clustered random sampling, 70 runs were selected to create a sample representative of the system as a whole. The clusters used were Silver Spring's runs and Gaithersburg/Rockville runs, and 35 from each region were selected to create the entire sample. The same list of runs was examined for three continuous weeks, looking at data from October 31 to November 18 2011, to reduce the impact of anomalies in the data.

5.1.1 Graphical Distributions

Once the data was in a suitable form to be graphed, it was decided that the layover departure deviation would be the dependent variable for all graphs and layover arrival would be independent variables for each graph.

The first graph was arrival deviation against departure deviation for all points. This graph would show if there was a strong general relationship between a bus arriving at its layover early or late, and a bus departing from its layover early or late. The connection appeared to be positive which implies that an early bus will depart early, and a late bus will depart late. After evaluation, the Pearson coefficient, or r value, (refer to Appendix D), obtained for this graph was very low, which implied that the data needed to be broken up in different ways.

Rush hour is usually estimated in between the times of 6:30am-9:30am, and later in the day at 3:30pm-6:30pm. Next the same graphs described above were looked at again, but this time the data was separated into rush hour and non-rush hour groupings. This was because during the course of the interviews, several operators described reacting to rush hour differently than at regular times throughout the day.

When the arrival deviation against departure deviation was graphed for all non-rush hour points, an r value of .6326 was obtained. This implies that operators are more likely to arrive late/early and take the allotted time for the layover. This is most likely due to operators not being as rushed as during rush hour and thus feeling more relaxed.
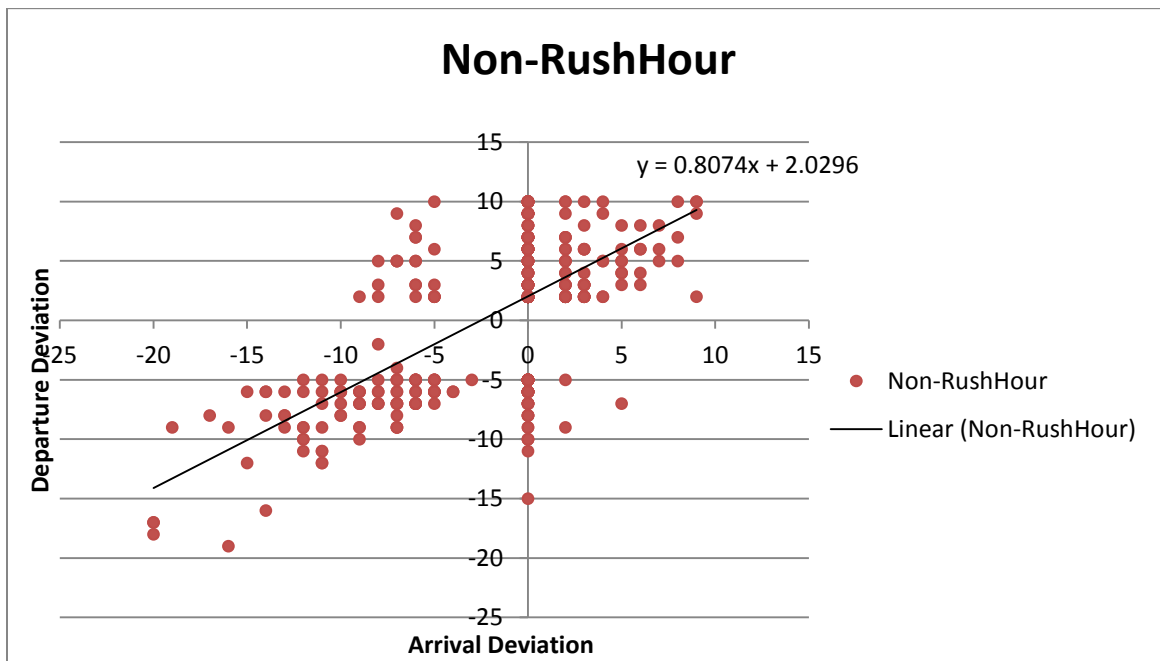
Figure 5.1 Graph of Arrival Deviation against Departure Deviation for all non-rush hour points

When the arrival deviation against departure deviation was graphed for all rush hour points, an r value of .6353 was obtained. This implies that operators are more likely to arrive late and leave as soon as possible to keep up with the flow of rush hour. And if operators were to arrive early, they would leave slightly early in order to anticipate the delays of the ongoing rush hour.
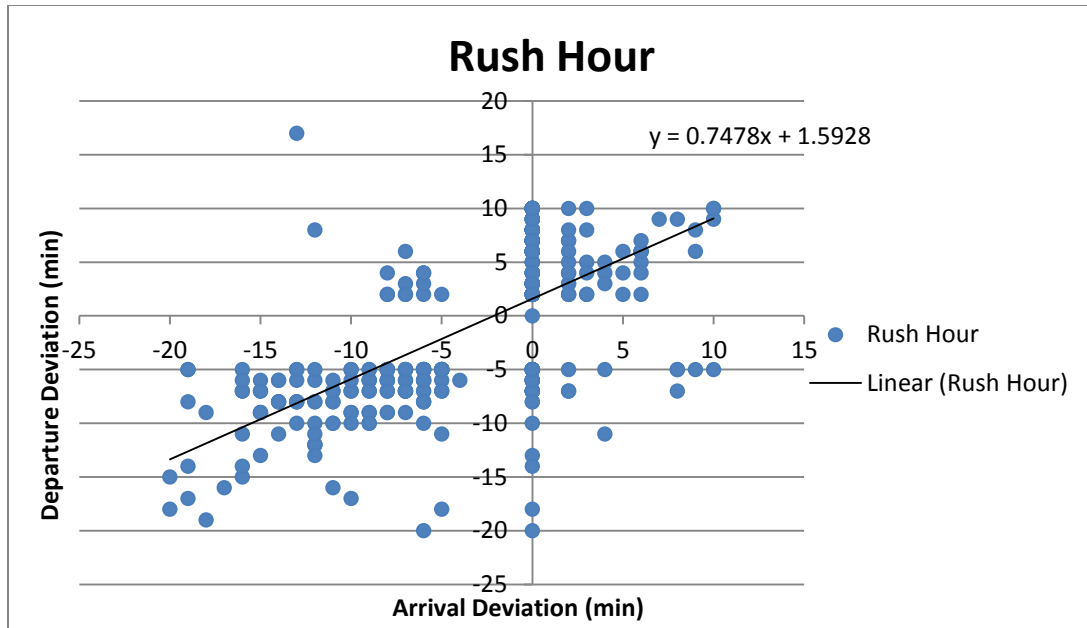
Figure 5.2 Graph of Arrival Deviation against Departure Deviation for all rush hour points

Next data was grouped by layover length and the variables of arrival deviation and departure deviation were graphed against each other. For these purposes the lengths of layovers had to be grouped into different categories. It was decided that a short layover would be classified as three to six minutes, with the few rare cases of a zero minute layover occurrence also grouped into this category. A medium layover would be classified as any layover ranging between seven and ten minutes. A long layover would be classified as all layovers in excess of ten minutes. The rare cases of a half hour layover were not discarded and were placed in the long layover category although they may exhibit unique behavior.

When arrival deviation was graphed against departure deviation for these 3 groups, the r values received were .6742 for small layovers, .6943 for medium layovers, and .5405 for long layovers. The value is highest for medium layovers and almost negligible for long layovers. This implied that bus operators tend to act in a more uniform way with medium layovers and in a more independent way when they had a long layover. From this analysis it was determined that the SLayover algorithm would specifically deal with variables affecting medium layovers and short layovers only, as long layovers were still too unpredictable even after observation.
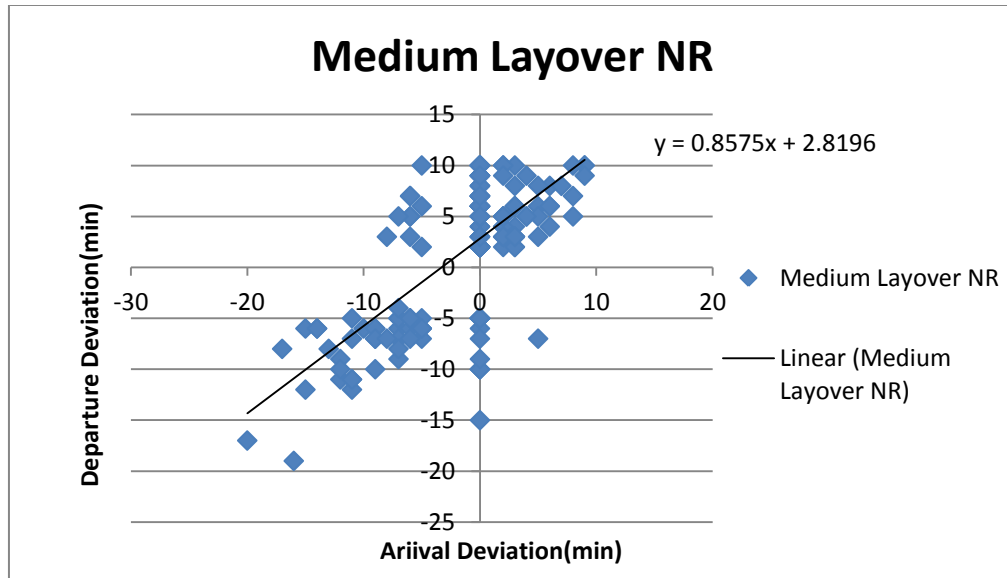
Medium Layover NR

$y = 0.8575x + 2.8196$

Departure Deviation(min)

Ariival Deviation(min)

◆ Medium Layover NR

—— Linear (Medium Layover NR)

Figure 5.3 Graph of Arrival Deviation against Departure Deviation for all non-rush hour medium layover points

Next the data divided by layover lengths was further split into two more categories: rush hour and non-rush hour. This would allow for the study of correlations at an even deeper level. When the points were first graphed, the long layovers for both the rush hour and non rush hour moments of the day had hardly shown any correlation, so in this situation, operators are a bit unpredictable. However the most highly correlated graph was the medium layover during rush hour whose r value was .6955. What this showed is that operators are most likely to take only the allotted time for the layover whether arriving early or late to the layover. Though there are some instances where operators would arrive late and leave early in anticipation of upcoming traffic during rush hour. The other graphs listed also showed high corrrelations, and these are all located in Appendix H.
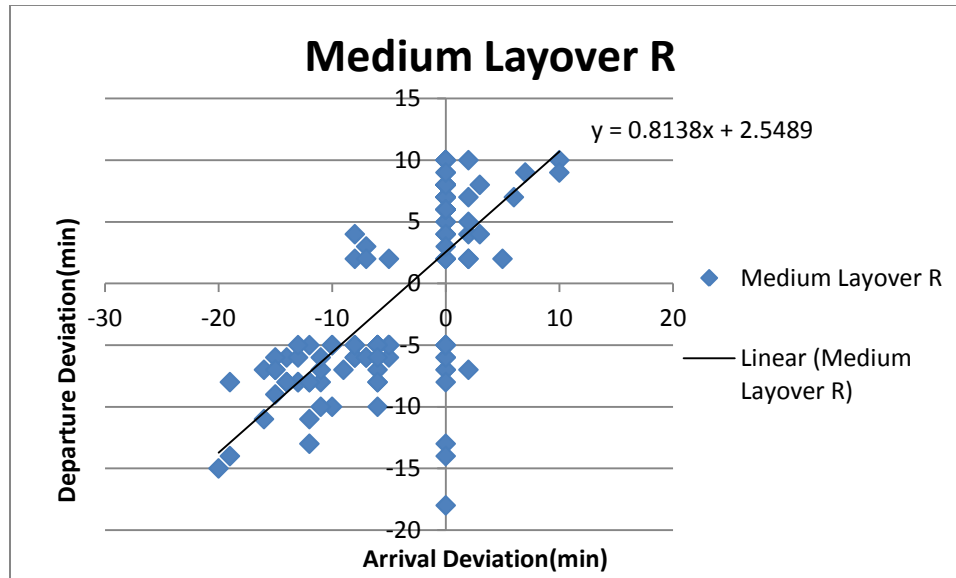
Figure 5.4 Graph of Arrival Deviation against Departure Deviation for all rush hour medium layover points

5.1.2 Layover Location

While working with the data collected, a distinguishable correlation was discovered between two variables: layover location and departure times of buses, especially for locations with restrooms and/or food facilities available for operators. Only locations with a significant amount of both rush hour and non-rush hour layover occurrences were included in this analysis to avoid skewing the data. The same independent and dependent variables were used as before, with the x-axis representing arrival times and the y-axis representing departure time. While some layover locations failed to provide useful information, those locations with restrooms and/or food seemed to have higher correlation values. This showed that operators are more likely to take a bathroom break and/or get something to eat if it is convenient and available for them during their layover, using all the time the scheduler has set for the layover, which in turn causes them to start their next route late. The figure below is a graph of the highest correlated area, the Montgomery Mall layover stop, which was calculated at .8674. This stop has restrooms and food services in the area, although they are not in the immediate vicinity, requiring operators to walk. As shown by the high correlation, it is significantly probable that operators are using the allotted time for the layover to maybe use the restroom and/or get something to eat and thus begin the next route late due to the longer walk.
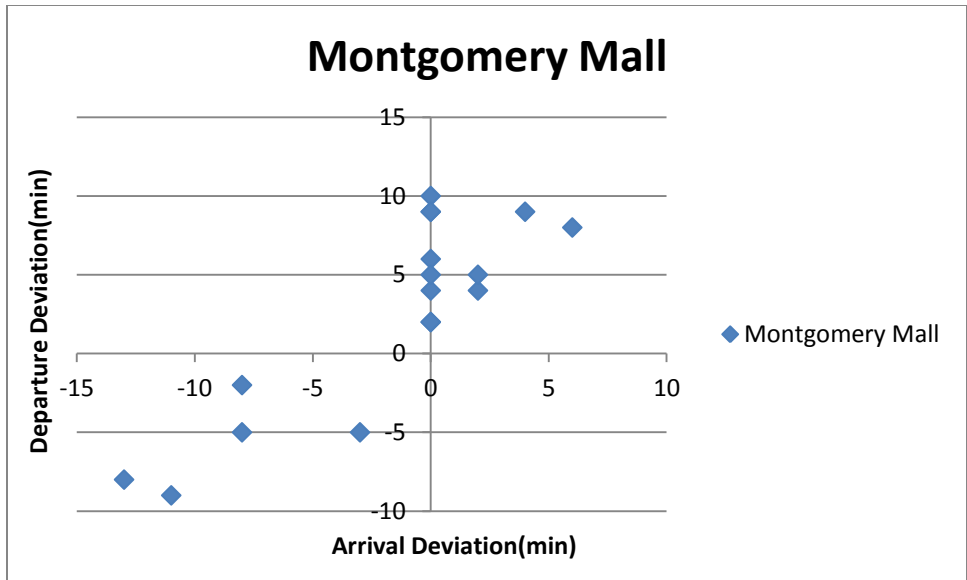
Figure 5.5 Graph of Arrival Deviation against Departure Deviation for all Montgomery Mall layover points

5.1.3 SmartTraveler

To construct an algorithm that could work with the SmartTraveler prediction software, how SmartTraveler already accounted for layover variables needed to be determined. This was accomplished by analyzing a late bus with both OrbCAD and SmartTraveler at the same time. OrbCAD would give the real time location and deviation of the bus in question. Then the predictions returned by Smart Traveler for the same bus after its next layover were recorded.

Bus Number	Stop Number	Refresh Time	Predicted Time (min)	Scheduled Time	OrbCAD Status (min)	Comments
5999	29999	10:00:00 AM	12	10:02:00 AM	-10	
		10:01:00 AM	11		-10	
		10:05:00 AM	5		-8	
		10:07:00 AM	3		-8	
		10:10:00 AM	DUE		LAYOVER	5 minute Layover
	19999	10:01:00 AM	24	10:15:00 AM	-10	5 minute Layover
		10:05:00 AM	18		-8	
		10:07:00 AM	16		-8	
		10:10:00 AM	13		-8	Layover not accounted for

Figure 5.6 Diagram of SmartTraveler Analysis

An example of this process can be seen in the table in Figure 5.6. The first step was to identify the buses that were running late or early from OrbCAD. A late bus was selected from that list and the bus number was recorded under Bus Number. From there, the run that bus was on was identified. From there, the run book was looked at and the route the bus was currently on was identified. A stop that had not yet been serviced by the bus was selected and recorded from SmartTraveler in the Stop Number column. From there, a stop on the next route that bus would

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be servicing was identified and recorded. The Refresh Time and Predicted Time were recorded from SmartTraveler every few minutes. The Scheduled Time was accessed from the Run Book. The OrbCAD Status was the status of the bus (early or late) from OrbCAD. The bus was followed until it reached its layover at the selected stop and then the second stop was looked out. From there the Refresh Time and Predicted Time were added and from that total, the Scheduled Time was subtracted. If that time was equal to the OrbCAD status, then it was determined that SmartTraveler wasn't taking layovers into account.

Much about SmartTraveler's functionality was determined in this way. The software doesn't currently account for layover variables. The most obvious way this impacts SmartTraveler's predictions is with recovery. Currently, SmartTraveler assumes a bus will not use any of it layover for recovery and will continue to take a layover regardless of how late it is. The layover research shows this is not happening. Once a bus operator reaches his layover destination, SmartTraveler re-adjusts its prediction to include the recovery aspect of layover. When it does this calculation, however, it devotes all of the layover to recovery, which the data also shows does not typically occur. A more detailed explanation of methods used, along with all results from this phase can be found in Appendix F.

5.2 SLayover Prediction Algorithm

The algorithm was constructed in multiple phases. All of this was done in Excel as none of the group had any programming experience. The algorithm is constructed based on a series of formulas and gives two outputs: estimated deviation and estimated time of arrival. All phases used run 253. This run was ideal as it was sufficiently long for the purposes of the algorithm and possessed a variety of layover lengths which would make this a better model for testing. This model takes only layover variables into account. The additional variables accounted for by SmartTraveler, such as the real time updates of schedule deviations via OrbCAD, can be added in at a later date by ACS programmers.

Figure 5.7 Logo for SLayover Algorithm

There are some basic features for the model aside from its ability to predict bus arrival times. For one, the model identifies rush hour times and highlights them in red. The algorithm will calculate rush hour and regular times separately so this feature was necessary. The algorithm also identifies all layover time points, calculates the amount of layover time in minutes, highlights this result in yellow, and shifts it over one column so it stands out, as shown in column D of Figure 5.8. This column is normally hidden from the user, but can easily be unhidden. The model also does not assume any deviation until it is entered in by a user.

After accomplishing this, features were developed that were more in line with the specific goals of the project. The estimated deviation column will remain as 0:00 until a known deviation is entered into the appropriate deviation column. In practice this would be supplied from the deviation value of the assigned bus in OrbCAD. Once this value is applied at a time point, the algorithm will assume the deviation will remain the same throughout the rest of the route. This may not be accurate, but in practice, the algorithm can be constantly updated from OrbCAD and such was the intent. The algorithm will assign the estimated deviation as the known deviation for the remaining time point on the route, and then will reevaluate the deviation at each layover point, changing the estimated deviation for each route. The method the algorithm will use to reevaluate these estimated derivations at layover points is the central focus of the project. Before formulas were inserted into the algorithm based off the findings, the formula was first based off of the most ideal possible scenario from the perspectives of the county and consumers, as described in the section below.

	A	B	C	D	L	N	O	P
1	Run 253							
2		Block 2053						
3		Bus Stops	Scheduled Time	Layover Length	Estimated Deviation	Early Deviation	Late Deviation	Arrival Time
5		Mont. College Germantown	5:39		0:00			5:39
6		Milestone Center	5:43		0:00			5:43
7		MD 355 - Middlebrook	5:50		0:00			5:50
8		Watkins Mills-Travis	5:56		0:00			5:56
9		Lakeforest Transit	6:02		0:00			6:02
10		MD 355 - Deer Park	6:10		0:00			6:10
11		MD 355 - Shady Grove	6:13		0:00			6:13
12		Shady Grove Station W	6:17		0:00			6:17
13		Mont. College Rockville	6:25		0:00			6:25
14		Rockville Station E	6:33		0:00			6:33
15		Layover		0:09	0:00			0:00
16		Rockville Station E	6:42		0:00			6:42
17		Mont. College Rockville	6:50		0:00			6:50
18		Shady Grove Station W	6:59		0:00			6:59
19		MD 355 - Shady Grove	7:03		0:00			7:03
20		MD 355 - Deer Park	7:06		0:00			7:06

Figure 5.8 Screen capture of the base case algorithm with no data entered

5.2.1   Base Case

The first task in constructing the model of the algorithm was creating the most basic possible case. This case was created as a first step that could later be built upon with the data to have the model reflect what was actually happening. The base case represents the ideal scenario for Ride On. In this case an operator's layover will always be used solely for recovery. Due to

this a bus operator running 15 minutes late will surrender his/her entire 10 minute layover for the sake of reducing their deviation. While the primary purpose for a layover is recovery and operators are expected to use it as thus, the data has shown that they don't necessarily treat layovers thusly. As seen in figure 5.8, a bus running this route starts off 12 minutes late, and the operator sacrifices his/her layover time accordingly until he/she is completely caught up. However he/she is not immediately caught up after sacrificing the first layover. It takes one full 9 minute layover and part of a second 9 minute layover. The algorithm shifts bus arrival times accordingly.

	A	B	C	D	L	N	O	P
1	Run 253							
2		Block 2053						
3		Bus Stops	Scheduled TIme	Layover Length	Estimated Deviation	Early Deviation	Late Deviation	Arrival Time
21		Lakeforest Transit	7:14		0:00			7:14
22		Watkins Mills-Travis	7:22		0:12		0:12	7:34
23		MD 355 - Middlebrook	7:30		0:12			7:42
24		Milestone Center	7:36		0:12			7:48
25		Mont. College Germantown	7:41		0:12			7:53
26		Germantown Transit	7:47		0:12			7:59
27				0:09	0:12			0:12
28		Germantown Transit	7:56		0:03			7:59
29		Shady Grove Station E	8:16		0:03			8:19
30				0:09	0:03			0:03
31		Shady Groove Station E	8:25		0:00			8:25
32		Shady Grove - MD 355	8:32		0:00			8:32
33		Shady Grove - Research	8:39		0:00			8:39
34		Shady Grove Hospital	8:46		0:00			8:46
35		Traville Transit Center	8:51		0:00			8:51
36				0:04	0:00			0:00
37		Traville Transit Center	8:55		0:00			8:55
38		Shady Grove Hospital	9:01		0:00			9:01

Figure 5.9 Screen capture of the base case algorithm with a deviation of 12 minutes late entered

In the case of a bus running early, the algorithm will again follow the ideal scenario from a management perspective. If a bus arrives early to the layover it will depart on time. The data shows that this is not necessarily the case, however for the sake of creating the base case, this is how early buses were treated.

Figure 5.10 Screen capture of the base case algorithm with a deviation of 10 minutes early entered

5.2.2 Developing formulas

For the next stage of the project, it was necessary to incorporate information from the historical data into the algorithm. This would enable the algorithm to, in theory, make predictions based on what bus operators would do in similar situations. To do this trend lines were developed in the data for each of the scenarios our algorithm would adjust. The data was divided into 8 groups, each of which accounted for a possible scenario. These groups were based on whether the bus was early or late, the time of day, and whether it had a short or medium layover. Once again long layovers showed too much variation to fix a trend to, and will therefore behave as they do in the base case. After grouping the data according to each scenario, a trend line was then fixed to it.

The trend lines are as follows:

Table 1 Table of all Scenarios and their accompanying trend lines

Deviation	Layover Length	Time of Day	Trend lines
Early	Short	Rush	$Y=.0792x+.2343$
Early	Short	Normal	$Y=.773x+.4313$
Early	Medium	Rush	$Y=.8575x+2.8196$
Early	Medium	Normal	$Y=.8138x+2.5489$
Late	Short	Rush	$Y=.0792x+.2343$
Late	Short	Normal	$Y=.4678x-3$
Late	Medium	Rush	$Y=.4864x-2$
Late	Medium	Normal	$Y=.6334x-2$

These trend lines mathematically represent some of the key findings on operator behavior during layovers. These key findings included general trends in operators arriving both late or early for their layover. For example, it was found that operators arriving late to their layover were giving up a fraction of their layover for recovery, as they are supposed to do. In fact,

operators were much more likely to give up a fraction of their layover to ensure an on-time departure for their next route during rush hour. The later they were running, the more of their layover they were willing to give up, especially if it was a medium layover. In the case of a short layover, operators were more likely to run over and start their next route late. The data also showed that operators arriving late to layovers during rush hour tended to leave early from the layover, potentially in anticipation of delays on their next route. For example, one of the trends directly reflected in the algorithm is that during non-rush hour, operators tend to leave half as early as they arrive. When operators arrive to layovers early, they also tend to leave early, especially during rush hour. During non-rush hour, this phenomenon is less pronounced, with operators more likely to leave layovers on time or only one minute early.

5.2.3   Advancements

These trend lines formed the basis of the advancements and were next applied to the algorithm. For a complete explanation of all the steps used in constructing the algorithm, please see Appendix E. After the trend lines were integrated with the algorithm, the predictions returned by it reflected many scenarios described by interviews in the field.

While in the base case, an operator will always use their layover solely for recovery, with these functions in place, this is no longer the case. Operators will now only use a percentage of their layover for recovery. The percentage used depends on which of the scenarios mentioned above is applicable.Also a bus running early during rush hour will also leave somewhat early to try to compensate for the tendency of running late during rush hour. This effect is not nearly so pronounced during non-rush hour times.

6 Conclusions and Recommendations

One of the goals for this project was to design an algorithm that would increase the accuracy of predicted bus arrival times for Montgomery County citizens by accounting for prominent layover variables between bus trips. In the end, this was achieved with the successful completion of an algorithm that was able to account for arrival and departure deviations, layover lengths, and time of day while calculating predicted times for buses throughout the day. The other goal for the project, improving the reliability of the Ride On system by analyzing and providing recommendations for SmartTraveler and layovers in general was also achieved. The findings on general operator behavior during layovers and operator concerns regarding layovers were compiled into a Layover Observations and Recommendations Report, which included conditions that put operators off schedule, a record of routes which were consistently off schedule, and recommendations to improve schedule adherence with respect to layovers. SmartTraveler observations were analyzed and recorded into a separate report. All of the research on the problem presented by Montgomery County Ride On was finalized in this Interactive Qualifying Project report.

6.1 Recommendations

Ride On is already taking great strides to improve their reliability by implementing Ride On Real Time, and this project has provided a multitude of information that can further improve their reliability through future projects, such as working with operators on layover issues and working with ACS to improve SmartTraveler, ideally by incorporating elements of the algorithm designed in this project. Upon completion of the project, three recommendations for future improvements were developed. These included recoding the algorithm in more appropriate software, incorporating layover location into the algorithm, and rebuilding the algorithm to take data input from SmartTraveler rather than OrbCAD to make it more compatible with the system instead of needlessly replacing it.

The first recommendation is to recode the algorithm in more appropriate software. This recommendation was developed based on difficulties encountered when making the algorithm. Microsoft Excel was not designed to handle the complex operations needed to make the algorithm function properly, and so manipulating it to work was a tedious process, particularly getting the program to recognize negative time. In addition, Excel limited the number of operations to seven per cell, limiting the number of layover variables that could be incorporated into the algorithm. Using a different program would expand the algorithm's capabilities.

The second recommendation is to incorporate layover location into the algorithm. This would have been the next variable added to the algorithm if not for the operation limitation with Excel discussed in the recommendation above. Based on interviews with operators, historical data on layover locations with food and bathroom facilities was analyzed in relation to departure deviations at layovers. It was found that these two layover variables were highly correlated, and were in fact the highest correlations found during the historical data analysis. Therefore, incorporating layover location with respect to food and bathroom facilities may make the algorithm's predictions even more accurate.

The final recommendation is to improve the algorithm by incorporating data from SmartTraveler rather than OrbCAD's real time bus deviation. If a contact at ACS, the company that manufactured SmartTraveler, could have been reached, the algorithm could have been designed to better integrate with the system, thus allowing the algorithm to work with

SmartTraveler instead of needlessly replacing it, as SmartTraveler already uses OrbCAD's real time bus deviations. Analysis of SmartTraveler's predictions was conducted in an attempt to reverse engineer the system, but no solid conclusions were gathered on how the predictions were actually being made. Therefore, this information could not be incorporated into the algorithm. Redesigning the algorithm with more information on SmartTraveler's functionality would make it more compatible with this system, into which Ride On has already invested many resources.

These three recommendations for the algorithm produced in this project have the potential to not only greatly improve the accuracy of the predictions made, but also to make it easier to incorporate into the existing system. By improving the algorithm in these ways, it can become an even better tool for Ride On customers, furthering the work Ride On is already doing to increase the reliability and convenience of its services for the citizens of Montgomery County. By completing this work, Ride On has the potential to greatly increase customer satisfaction and in turn ridership, expanding the societal and environmental benefits of public transportation for the county.

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Appendix A Sponsors Description

Montgomery County Government Department of Transportation Division of Transit Services

The Montgomery County Government Department of Transportation is a bustling part of a very busy county. Montgomery County is one of both the most populous and the most affluent counties in Maryland. It contains over 970,000 residents. Four of the five top employers of residents of the district are located in Washington, DC. This makes it imperative that the residents have easy access in and out of DC during peak commute times (Montgomery County Government Department of Finance, 2009).

This is where the Division of Transit Services comes in. Their duty is to deal with all public transit across the County with a special interest on access to major metropolitan areas such as the nation's capital. One of the services they offer is a public transportation bus system known as Ride On. Ride On operates on 76 routes across the county. This allows for easy access throughout the county and into outlying areas of importance. (Montgomery County Government, 2011)

The Division of Transit Services is one of the six divisions of the Department of Transportation, the other five being: the Office of the Director, the Division of Transportation Engineering, the Division of Traffic Engineering and Operations, the Division of Parking Management, and the Division of Highway Services. The entire Department of Transportation is

organized as follows:

MONTGOMERY COUNTY DEPARTMENT OF TRANSPORTATION (MCDOT)
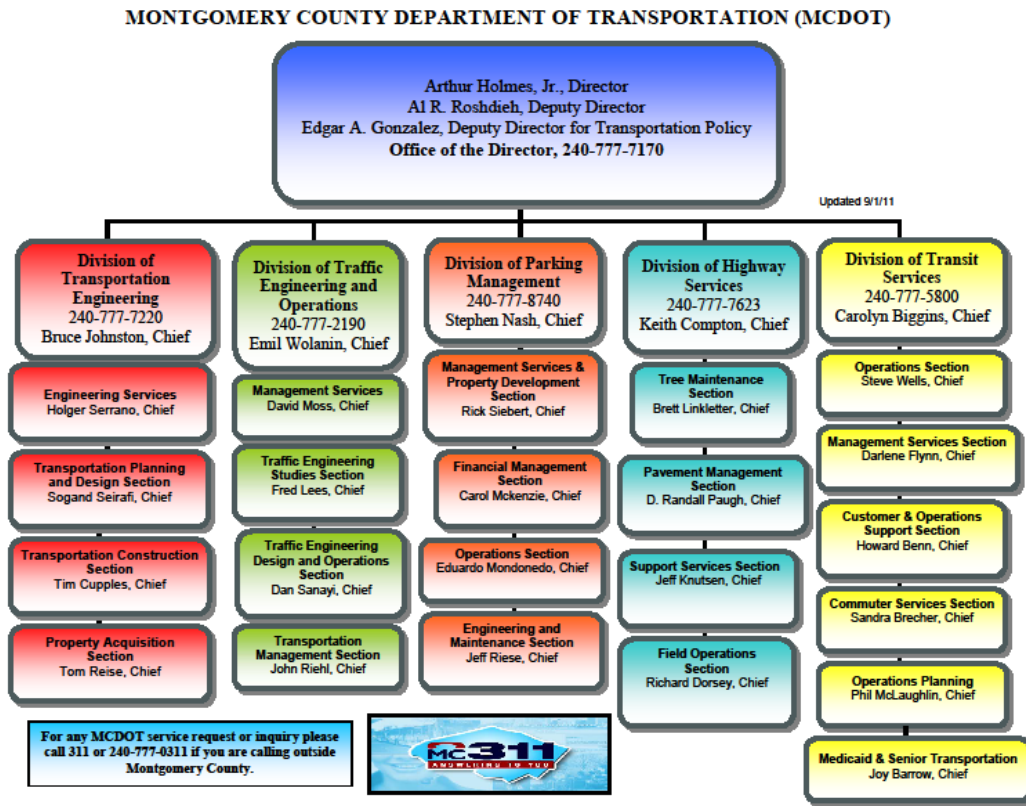
Figure A 1 Flow Chart of the Montgomery County DOT

(Montgomery County Government, 2011)

Montgomery County Government Division of Transit Services can supply many resources to help solve this problem. The current chief of the DTS is Carolyn Biggins. She manages a workforce of approximately 1500 civil servants, including transit engineers, transportation engineers, and operators. The MCDOT received $15 million in funding, which was used for bus, rail, and subway maintenance, paying all employees, and any upgrades to software. The DTS uses an advanced scheduling software that helps them keep route times down and minimize errors (Montgomery County Government, 2011).

Appendix B Societal Impacts

An Interactive Qualifying Project (IQP) is a project that challenges students to solve/address a problem that could affect a society positively which its citizens will benefit from greatly. Generally these projects do not correlate to the majors of the students completing them, however, it does give them a chance to connect with other students and people within the society to work on a problem they would not normally have a chance to tackle. It also gives students an idea of how their future careers may affect the larger society of which they are a part. Students are also allowed to complete their project off campus in order to experience new cultures around the world and experience the life first hand of the people within that culture.

In B term of 2011, we will be working on our project in Washington, DC, trying to help Montgomery County Government and their Ride On bus system increase their reliability for the customers within their society. This means we would like to improve bus arrival times for customers so they do not get to their destinations late. By successfully completing this project Ride On may increase ridership and help the citizens of Montgomery County get to wherever they need to go more efficiently. We will be pushed to think outside the box and may have to create recommendations for an optimization system also known as an algorithm. Within our group, we do not have any members with the experience specifically for this task. However, to completely understand and take on this task we are going to push for many interviews with many of the employees in the agency. We may also have to join the citizens of Montgomery County on bus rides over several days. Even though this project site is within the US, we will still need to adapt to some cultural differences so that we fit into Montgomery County's society and improve the use of technology to help improve a societal need.

Appendix C Interview Protocols

Ride On: Head Scheduler

1. Why did Ride On choose to use interlined routes in their transit system?
2. What are some benefits and disadvantages to interlining for this system?
3. How do interlined routes work in the Ride On system as opposed to other systems?
4. How does Ride On's scheduling software, Trapeze Fixed Route, interface with the scheduler to make the schedules?
5. How does Ride On incorporate layovers into the created schedules?
6. Are there any problems, such as operator complaints, with how the layovers currently are scheduled, such as location, length, time of day?
7. Are there any rules/regulations either state/federal/union regarding when and how long operators' breaks should be? How do they play a role in layover development?

Ride On: Personnel familiar with Software

1. What kind of data does your CAD/AVL system collect?
2. What from the data collected are stored?
3. Of the data collected, how are they currently being used?
4. Have you encountered any problems interfacing your CAD/AVL system with the Trapeze Fixed Route scheduling software? What kinds of problems? Have you found any ways to work around them?
5. How might we navigate efficiently through this historical data?

Ride On: Operators

1. Do you have any concerns on how layovers are currently fit into your schedule? If so, what are they?
2. In your experience, when layovers occur outside of scheduled hours, what are some common causes and how far do they typically put operators off schedule?
3. Are any routes more susceptible to these causes than others?
4. Are there any human elements that cause unscheduled or long layovers, if so, what are some common cases(operators, pedestrians, etc.)?
5. Are there consistent delays on some routes, if so which ones?
6. What do you think makes these routes more susceptible to delays than others?
7. Are there certain conditions that make some delays longer than others? If so, what are they?
8. How do the differences in time between projected and actual layovers times affect your route?

Appendix D Analysis Methods

In section 4, the correlation coefficient r, is a measure of correlation between two variables. The numerical value for r is calculated by performing Pearson product-moment correlation coefficient analysis. This analysis quantifies the amount one variable varies in accordance with another. The numerical value r is given by:

$$r = corr(x,y) = \frac{E[(X - u_x)(Y - u_y)]}{\sigma_x \sigma_y}$$

Figure D 1 Equation for Pearson Correlation

A value for r close to positive 1 suggests that the correlation between two variables is very strong and positive. This mean as one variable increases, the other variable increases proportionately. An r coefficient close to -1 suggests the correlation is very strong and negative. This means that as one variable increases, the other decreases proportionately. An r correlation close to 0 suggests the two variables in question have no correlation. This means as one variable increases, the other has no consistent trend in changes.
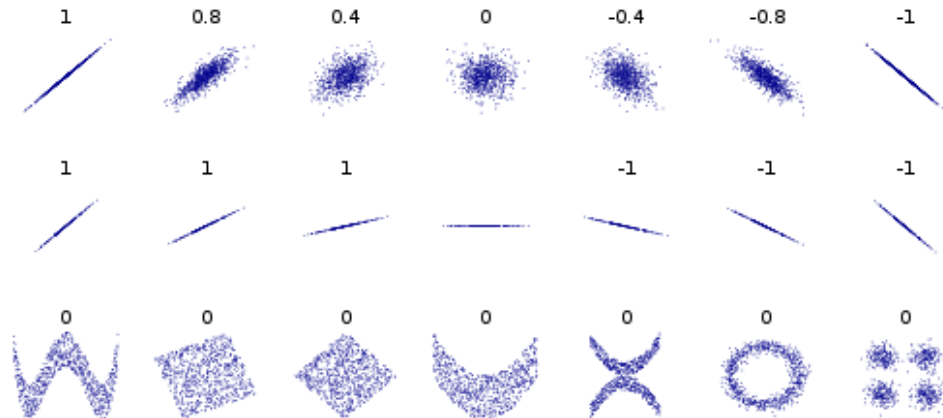

Figure D 2 Example of r values for different distributions

Appendix E Algorithm Guide

This guide details the construction and operations behind the final algorithm. Many of the cells displayed are usually hidden, but are displayed here for better understanding. For the purposes of the discussion, the section letters do not match the column letters.

	A	B	C	D	G	J	K	L	M	N	O	P	R	S	T
1	Run 253														
2		Block 2053													
3												Est. Deviation	Early Deviation	Late Deivation	Arrival Time
4		Germantown Transit	5:35									0:00			5:35
5		Mont. College Germantown	5:39									0:00			5:39
6		Milestone Center	5:43									0:00			5:43
7		MD 355 - Middlebrook	5:50									0:00			5:50
8		Watkins Mills-Travis	5:56									0:00			5:56
9		Lakeforest Transit	6:02									0:00			6:02
10		MD 355 - Deer Park	6:10									0:00			6:10
11		MD 355 - Shady Grove	6:13									0:00			6:13
12		Shady Grove Station W	6:17									0:00			6:17
13		Mont. College Rockville	6:25									0:00			6:25
14		Rockville Station E	6:33									0:00			6:33
15		Layover		0:09	ML	R	MLR	0:00	0:00	0:00	0:00	0:00			0:00
16		Rockville Station E	6:42									0:00			6:42
17		Mont. College Rockville	6:50									0:00			6:50
18		Shady Grove Station W	6:59									0:00			6:59
19		MD 355 - Shady Grove	7:03									0:00			7:03

Figure E 1 Screen capture of recommended algorithm identifying first three sections

A: This is a list of all the time points for a run. These are taken straight from a run book. For the purpose of integrating such an algorithm with OrbCAD, it may be best to use the abbreviations used by the system. Ex. Lakeforest Transit - LFTRANS

B: This is a list of all scheduled arrival times for the bus. These are taken straight from the run book. In our algorithm all rush hour time points are formatted to be shown in red. However this coloring is purely for the sake of making the concept more understandable and is not necessary.

C: This is the amount of layover time given at one specific layover time point. This number is given by subtracting the arrival times at the point after the layover, from the arrival time before the layover. In the picture above the operation is =C16 − C14. In this algorithm, these cells are highlighted yellow; this is once again purely cosmetic.

	A	B	C	D	G	J	K	L	M	N	O	P	R	S	T
1	Run 253														
2		Block 2053													
3												Est. Deviation	Early Deviation	Late Deivation	Arrival Time
4		Germantown Transit	5:35									0:00			5:35
5		Mont. College Germantown	5:39									0:00			5:39
6		Milestone Center	5:43									0:00			5:43
7		MD 355 - Middlebrook	5:50									0:00			5:50
8		Watkins Mills-Travis	5:56									0:00			5:56
9		Lakeforest Transit	6:02									0:00			6:02
10		MD 355 - Deer Park	6:10									0:00			6:10
11		MD 355 - Shady Grove	6:13									0:00			6:13
12		Shady Grove Station W	6:17		D							0:00			6:17
13		Mont. College Rockville	6:25									0:00			6:25
14		Rockville Station E	6:33									0:00			6:33
15		Layover		0:09 ML	R	MLR	0:00	0:00	0:00	0:00		0:00			0:00
16		Rockville Station E	6:42									0:00			6:42
17		Mont. College Rockville	6:50									0:00			6:50
18		Shady Grove Station W	6:59									0:00			6:59
19		MD 355 - Shady Grove	7:03									0:00			7:03

Figure E 2 Screen capture of recommended algorithm identifying the layover classification cells.

D: These three cells are used to characterize the layovers according to the variables examined. SL stands for short layover, defined as a layover ranging between three and six minutes. ML stands for medium layover, ranging between seven and ten minutes. There are layovers over 10 minutes classified as long layovers, or LL, in our report. These were not included as there was no strong correlation found with them. In the case of a long layover, this algorithm assumes the operator will use his layover time solely for recovery, completely using it up if necessary. N stands for Normal, or non-rush hour times. R stands for rush hour times, defined by Ride On as being from 6:30AM to 9:30AM for the morning commute.

The first cell determines the length category of the layover. The formula used is:

=IF(D15<E15,"SL",IF(D15<F15,"ML","LL"))

Cell D15 is a cell with a layover value. Cells E15 and F15 contain the values 0:06 and 0:10, respectively. This formula returns "SL" if the layover cell in question contains a value lower than or equal to 0:06. If the cell does not contain a value lower than 0:06, but does contain a value lower than 0:10, the formula returns "ML". If the cell does not contain a value lower than 0:10, the formula returns LL.

The next cell determines the time of day category of the layover. The formula used is:

=IF(C14<H15,"N",IF(C14<I15,"R","N"))

This formula references cell C14, the cell with the arrival time for the start of the layover. Evaluated in this order, if the time listed in cell C14 is earlier than 6:30AM this formula will return "N", if the formula is not earlier than 6:30AM but is earlier than 9:30AM, this formula returns "R". If neither of these conditions is true, the formula returns "N".

The final cell in this set combines the text results of the first two cells in the set. The formula is:

=CONCATENATE(G15,J15)

For example, if the results of the first two cells were "ML" and "R" respectively, this formula would return "MLR", or a medium layover in rush hour. The purpose of this operation is to make one cell that can be referenced which contains information about both variables.

E: This section determines the predicted arrival time for the bus based off the trend lines the group developed from old OrbCAD data. There are four formulas in this phase, one for each of the combinations of layover length and time of day the group observed. The formulas are as follows:

- =IF(AND($K15="MLR",$P14>0),MAX(0.4678*$P14-(2/24/60),0),IF(AND($K15="MLR",$P14<0),MIN(0.8138*$P14+(0.25489/24/60),0),0))
- =IF(AND($K15="MLN",$P14>0),MAX(0.6334*$P14-(2/24/60),0),IF(AND($K15="MLN",$P14<0),MIN(0.8575*$P14+(2.8196/24/60),0),0))
- =IF(AND($K15="SLR",$P14>0),MAX(0.7902*$P14+(0.2343/24/60),0),IF(AND($K15="SLR",$P14<0),MIN(0.7902*$P14+(0.2343/24/60),0),0))
- =IF(AND($K15="SLN",$P14>0),MAX(0.4678*$P14-(3/24/60),0),IF(AND($K15="SLN",$P14<0),MIN(0.773*$P14+(0.4313/24/60),0),0))

Each of these works in the same way, and operates simultaneously on the same cell, the estimated deviation cell. First the command IF(AND($XXX,$P14>0), determines if the bus is late, and if the bus is of the proper characteristics for its equation. XXX represents the characteristics SLR, SLN, MLR, MLN. Some layovers will be classified as LLN and LLR, but will not be handled by the algorithm as stated above, but will be treated the same as the base case. Based on which three digit code a layover has, the appropriate equation will compute a value and the other equations will return 0:00. If the bus is late the next command in the formula, MAX(0.7902*$P14+(0.2343/24/60),0), will return the proper prediction for the bus arrival time from the layover based on the trend lines developed by the group. The trend line in the command just given is y=.7902x+.2343. The y intercept of the trend line is divided by 24 and then by 60. This is because Excel will interpret a number value not in the form hh:mm as a number of days, so to have the y intercept interpreted as a number of minutes, the division is necessary. This

command will return the higher of either the predicted value with the trend line or zero. This is to stop the predictions from changing endlessly due to the fact that a trend line is infinite if it models a distribution with a real finite limit. If the bus is early instead of late, the remainder of the command goes though the same process as it goes through for late buses, only with a different trend line and returning the lower of either the predicted arrival time or zero.

As stated above, all four functions work in tandem. Since a layover can only have one classification, only one of the formulas will return a value, that value is then substituted as the next estimated deviation.

	A	B	C	D	G	J	K	L	M	N	O	P	R	S	T
1	Run 253														
2		Block 2053													
3												Est. Deviation	Early Deviation	Late Deivation	Arrival Time
4		Germantown Transit	5:35									0:00			5:35
5		Mont. College Germantown	5:39									0:00			5:39
6		Milestone Center	5:43									0:00			5:43
7		MD 355 - Middlebrook	5:50									0:00			5:50
8		Watkins Mills-Travis	5:56									0:00			5:56
9		Lakeforest Transit	6:02									0:00			6:02
10		MD 355 - Deer Park	6:10									**F** 0:00			6:10
11		MD 355 - Shady Grove	6:13									0:00			6:13
12		Shady Grove Station W	6:17									0:00			6:17
13		Mont. College Rockville	6:25									0:00			6:25
14		Rockville Station E	6:33									0:00			6:33
15		Layover		0:09	ML	R	MLR	0:00	0:00	0:00	0:00	0:00			0:00
16		Rockville Station E	6:42									0:00			6:42
17		Mont. College Rockville	6:50									0:00			6:50
18		Shady Grove Station W	6:59									0:00			6:59
19		MD 355 - Shady Grove	7:03									0:00			7:03

Figure E 4 Screen capture of recommended algorithm identifying the estimated deviation cells.

F: This cell is meant to be the culmination of all other steps in this algorithm. This estimated deviation is a prediction of how early or late a bus will be based on how early or late it was earlier and how it is predicted to behave during layovers. The formula for this cell is:

=IF(D15>0, MAX(L15:O15),IF(Q15=0,MAX(P14-D15+S15,0),MAX(P14-D15-Q15,-Q15)))

The formula carries out the following calculations in the order they are presented here. If cell D15 is greater 0, that row represents a layover time. If that is the case, and the bus is late, this equation takes the highest value of the four equations mentioned above. Since only the correct one will produce a number greater than zero, the correct value of the four will always be taken. In the case of an early bus, no work is done in the cell and the all the work is done in the adjacent cell in the hidden column Q. This is a necessary step to work around having negative time in excel. The formula for the cells in Q is:

=IF(D15=0,MAX(R15,Q14),ABS(MIN(L15:O15)))

The formula carries out the following calculations in the order they are presented here. If the cell D15 equals zero, that row is not a layover row. If this is the case, this cell takes the maximum=m of the cell above it and the cell to the left of it (Early Deviation). This is so if a deviation is entered, the cell will take on that value, in all other cases the cell will simply repeat the deviation above. If the cell D15 is not 0, the row in question is a layover row and the formula will take on

the value of the minimum value of the four cells with trend lines. Since only one of the cells returns a value, and that value is negative in the case of an early bus, the correct value will always be taken.

	A	B	C	D	G	J	K	L	M	N	O	P	R	S	T
1	Run 253														
2		Block 2053													
3												Est. Deviation	Early Deviation	Late Deivation	Arrival Time
4		Germantown Transit	5:35									0:00			5:35
5		Mont. College Germantown	5:39									0:00			5:39
6		Milestone Center	5:43									0:00			5:43
7		MD 355 - Middlebrook	5:50									0:00			5:50
8		Watkins Mills-Travis	5:56									0:00		G	H 5:56
9		Lakeforest Transit	6:02									0:00			6:02
10		MD 355 - Deer Park	6:10									0:00			6:10
11		MD 355 - Shady Grove	6:13									0:00			6:13
12		Shady Grove Station W	6:17									0:00			6:17
13		Mont. College Rockville	6:25									0:00			6:25
14		Rockville Station E	6:33									0:00			6:33
15		Layover		0:09	ML	R	MLR	0:00	0:00	0:00	0:00	0:00			0:00
16		Rockville Station E	6:42									0:00			6:42
17		Mont. College Rockville	6:50									0:00			6:50
18		Shady Grove Station W	6:59									0:00			6:59
19		MD 355 - Shady Grove	7:03									0:00			7:03

Figure E 5 Screen capture of recommended algorithm identifying the deviation entry and arrival time cells.

G: These columns provide the only means of data entry into the system. In the late deviation column, the amount of minutes the bus is late is entered in the form h:mm. In the early column, the amount of minutes the bus is early is entered in the same format. Excel does not accept negative times as both a cell that can be referenced for further calculations and an input. To get around this, one column is hidden, Q. This column will take the value of either the cell directly to the left it or, if that cell is zero, the cell directly above it. By having this extra column that repeats whatever is entered into the early deviation column, but is not directly input by the user, there is now a cell that excel can reference and turn negative so it can be used in calculation of early buses.

H: This cell contains the final calculation done by this algorithm and computes predicted bus arrival times. It simply takes the scheduled bus arrival times, adds the estimated deviation calculated in column P, and returns the new prediction for the bus arrival. The formula is:

$$=P15+C15$$

Appendix F SmartTraveler Data

     The purpose of evaluating SmartTraveler was to provide an understanding of what SmartTraveler does exactly. The table below has all the data collected sorted and listed in separate columns to show exactly what data was collected. The first column is the stop number, which is the number assigned to a specific stop. Every bus stop in Montgomery County has a stop number. The second column is Refresh Time, which was collected off of the SmartTraveler webpage and is the time when the SmartTraveler system last refreshed. The third column is Predicted Time (in minutes) which was also recorded off of the SmartTraveler webpage. The predicted time is the time until the next bus will arrive at a specific bus stop. The fourth column is the Scheduled Time of which a particular bus will arrive at a specific bus stop. The scheduled time was recorded out of the run books. The fifth column is the OrbCAD Status. This information is provided by the OrbCAD system, which was run simultaneously with SmartTraveler and provides the status (in minutes) of how late or early a particular bus is running in real time.

     In order to figure out if SmartTraveler was taking layovers into account, we had to do a little math. We took the Refresh Time, added the Predicted Time, and subtracted out the Scheduled time. If that answer was the same as the OrbCAD status, it was concluded that SmartTraveler was not taking layovers into account.

Table 2 SmartTraveler Observations

Stop Number	Refresh Time	Predicted Time (min)	Scheduled Time	OrbCAD Status (min)	Comments
	11:09:36 AM	30	11:32:00 AM	-8	
	11:17:37 AM	23		-11	
	11:23:42 AM	8		-11	
	11:25:47 AM	6		0	
	11:27:47 AM	6		-2	
	11:34:48 AM	DUE	11:41:00 AM	6	
25654	11:36:22 AM	25	12:07:00 PM	5	
	11:39:49 AM	23		4	
	11:49:58 AM	16		1	
28526	11:53:01 AM	4	12:05:00 PM	7	

27996	11:54:50 AM	12:37	12:38:00 PM	6	8 minute layover
14753	11:56:14 AM	22	12:25:00 PM	5	8 minute layover
	11:58:47 AM	21		6	8 minute layover
	12:06:49 PM	14		4	
	12:09:49 PM	8		7	
	12:11:49 PM	8		5	Early, didn't take layover into account, schedule predicted on time
	12:21:20 PM	3		ON TIME	
	12:23:19 PM	DUE		LAYOVER	
	12:24:19 PM			-1	Didn't show up predicted
22252	12:28:58 PM	13	12:33:00 PM	-9	
14392	12:30:25 PM	1:09	12:51:00 PM	-9	
	12:38:19 PM	1:09		-10	
	12:42:19 PM	26		-10	
	12:45:19 PM	24		-10	
	12:49:18 PM	20		-10	
	12:50:18 PM	10		-1	
	12:51:18 PM	8		LAYOVER	
	12:52:17 PM	7		ON TIME	
26586	12:57:38 PM	1:33	1:30:00 PM	-7	??
25644	12:59:11 PM	5		-6	
	1:00:53	24	1:19:00	-5	8 minute layover

	AM		PM		
	1:03:40 AM	19		-3	
	1:04:40 AM	17		-3	Says 3 minutes late when on layover
	1:05:39 AM	16		-3	
	1:06:39 AM	12		LAYOVER	
	1:08:40 AM	10		LAYOVER	
	1:11:46 AM	8		-2	
	1:12:46 AM	8		-2	
	1:14:47 AM	6		-2	
	1:15:47 AM	3		ON TIME	

Appendix G Layover Observations and Recommendations

In this project, many elements of research were required to develop the parameters for the algorithm, One of these elements was semi-structured interviews with bus operators from the three bus depots in Montgomery County: Silver Spring, Nicholson Court, and Gaithersburg/Rockville . The purpose of these interviews was to gather operator opinions on their layovers: if they got their layovers, how did they use them? If they were not getting their layovers, why not? (See Appendix C for interview protocol.) No personal information that could be used to identify the operators was gathered, but general information from the interviews was in part used to determine the layover variables to be considered in the algorithm, particularly layover locations with respect to food/restroom facilities. Not all of the information obtained could be used in the algorithm. Some of this information was still considered useful to Montgomery County Ride On, however, so a summary of these findings is provided below, The topics covered include restroom facilities, early departures, and specific difficult routes.

Facilities

One topic that consistently came up in the discussion of layovers was restroom facilities. Operators are very concerned about both layover length and layover location with respect to bathroom accessibility. Several operators were concerned that their layovers were not long enough for them to use the restroom, citing that the routes were scheduled too tight. . For example, if an operator arrived late to their layover due to delays enroute , he/she would not always have enough time to use the restroom without leaving his/her layover late as well. Operators feel that adequate time should be scheduled for restroom breaks during layovers throughout their runs, especially because it can be a health concern. On the topic of health concerns, some operators also referenced not having enough time to stretch between trips, citing doctor's orders for hourly stretching.

Other operators voiced concerns about layover locations, stating that there are many routes that reoccur consecutively throughout their runs which do not have accessible restrooms at the layover. Two locations operators raised concerns about were Germantown and Montgomery mall. Germantown does not even have restrooms available for the public, and the facilities at Montgomery mall are too far of a walk for operators to leave their layover on time. Additionally, operators were concerned about early morning routes, because sometimes there are no restrooms available, since stores are not usually open that early. As a potential solution to this problem, one of the operators suggested the installation of porta-potties at locations where there are no restrooms available. These facilities could be kept locked, with keys given only to operators. Preventing public access to these facilities would ensure that operators could use them whenever necessary as quickly as possible, helping to alleviate health concerns and reduce late departures caused by restroom breaks. In addition, limiting the usage of these facilities to operators only may reduce the maintenance necessary for their upkeep.

Early Departures

While many operators raised very similar concerns about restroom availability, their reasons for leaving a layover off-schedule, particularly leaving early, differed greatly. All operators know that leaving early is out of the question, since it is taboo in the public transit industry, as it can cause customers to miss their bus even if they arrive to the stop on time. However, some operators, more often the experienced ones, do leave early for certain reasons. Incidentally, the delays that some operators try to avoid by leaving early were also the most common reasons for why operators were arriving late.

One of the reasons operators decide to leave early from layovers is because they feel that they can anticipate delays along the route, believing that, in the end, this will help their customers get where they need to go on time. Some operators believe that leaving as little as one minute early can make a difference for their passengers. On many routes, during rush hour most significantly, operators must maneuver through heavy traffic and try to avoid red lights in order to keep up with the schedule. Operators have even claimed that during rush hour, they may have to wait as long as five minutes at a stop light before proceeding to the next intersection. Some operators that are very familiar with their route may leave early in anticipation of avoiding these red lights.

Typical passenger characteristics specific to certain routes are another delay that operators can anticipate and therefore try to avoid by leaving early. Once an operator becomes familiar with a route, he/she can begin to anticipate the number of handicapped, elderly, or young passengers they may have. As operators will often wait until these passengers are seated before continuing their trip, some operators may leave early to account for the extra waiting time at stops. This is also true of the extra time needed to operate the hydraulic lift to load handicapped passengers onto the bus, especially if it fails to work properly the first time. Another factor operators may anticipate is the load of passengers at certain stops. Operators may leave early if they will be stopping at an area with a typically heavy passenger load, such as areas near schools.

However, it is also important to note that some operators do leave their layovers early solely to get the whole time for their next layover. These operators will anticipate a late route based on past experience. Many operators feel that layovers are their time and that they deserve to have the whole time for themselves, but say that they often do not get their layovers due to delays on the route.

The recommendation that operators provided to stop early departures due to delays was to increase the run time for certain routes. They want schedulers to not only account for the length of the route, but also the delays that could happen along the route, such as traffic congestion. Traffic congestion does not only occur during rush hour but also in locations where construction is taking place and detours are implemented on the streets. Operators also want schedulers to account for passenger delays as well, such as high passenger loads on stops or routes that typically have many elderly and handicapped passengers. However, it is also

important to note that several operators incorrectly believe that runtimes are determined by car, not by bus.

Routes

Along with the operator's general thoughts on layovers, they provided a list of specific routes which they believe have reoccurring problems. Two routes that were frequently mentioned were the 55 and 43. Many operators said that it is very difficult to complete the 55 on time, as it is very long, and typically has heavy passenger loads. Operators said that that there are typically many elderly and handicapped passengers on this route, leading to longer times at stops. There are also numerous college students, who are eligible to ride for free, which may cause the over capacity of passengers typical to this route. The 43 was said to be an easy route to run, however, even without heavy passenger loads and hardly any heavy traffic, there is still not enough time in this route to complete it on time safely. Other routes operators listed with heavy traffic congestion problems in general were the 26, 34, 38 and 47.

Areas under construction are specific areas where operators feel that run time should be adjusted. Operators are particularly concerned about the construction that will occur when work on the Purple Line begins, as it will run along many metro stops. These stops are important destinations for many Ride On routes. Operators are concerned that the construction will cause major traffic congestion in these areas, making it harder to stay on time. Another area that operators believe should be altered is Walter Reed hospital. There is a lot of traffic in this area and the infrastructure can't support larger volumes of people, which may require an increase in run time.

Appendix H Complete List of Graphs

This appendix has all graphs and correalations generated during the course of this report. The ones significant enough to use were mentioned in the results and incorporated into the final deliverables in some way. This first set of graphs is the correlations of Arrival Deviation against Departure Deviation for layover locations. It was stated earlier that Montgomery County should investigate incorporating layover location into the algorithm, the data collection for that has already been completed.
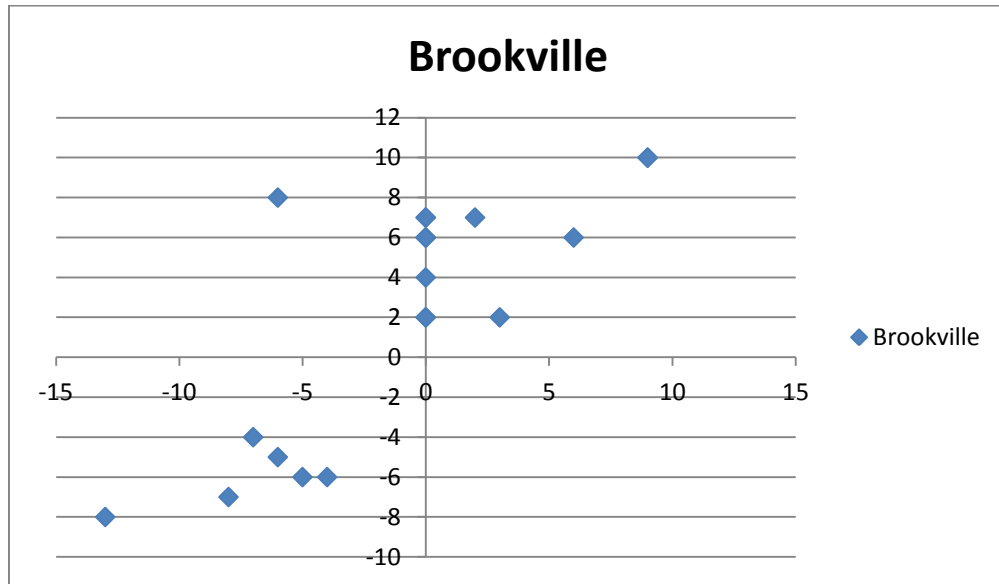
Figure H 1 Graph of Arrival Deviation against Departure Deviation for all Brookville layover points.

The Brookville layover stop only provides restrooms in the area. The Pearson value that was calculated for this specific location was .79242, which results in a high correlation. This means that operators are likely to take most of the allotted time on the layover to maybe use the restroom and begin the next route late.
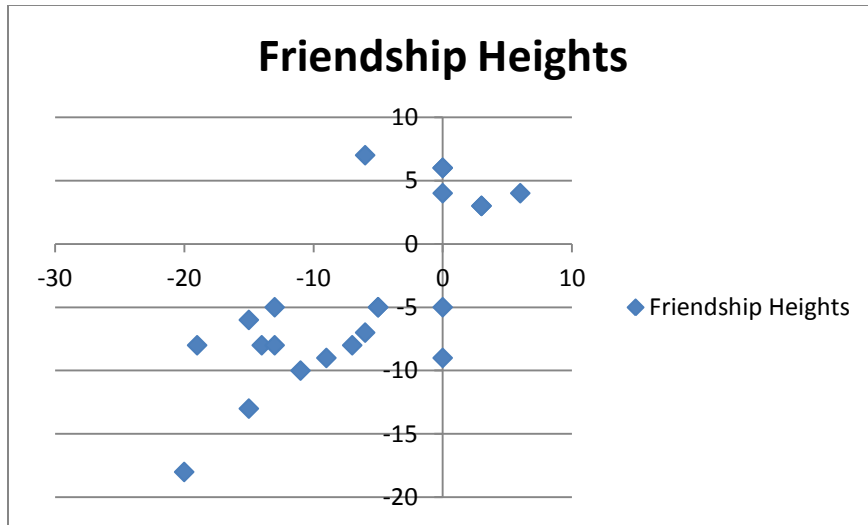
Figure H 2 Graph of Arrival Deviation against Departure Deviation for all Friendship Heights layover points.

The Friendship Heights layover stop provides restrooms and food services in the area. The Pearson value that was calculated for this specific location was .7448, which results in a high correlation. This means that there is a significant relation with operators using the allotted time for the layover to maybe use the restroom and/or get something to eat and begin the next route late.
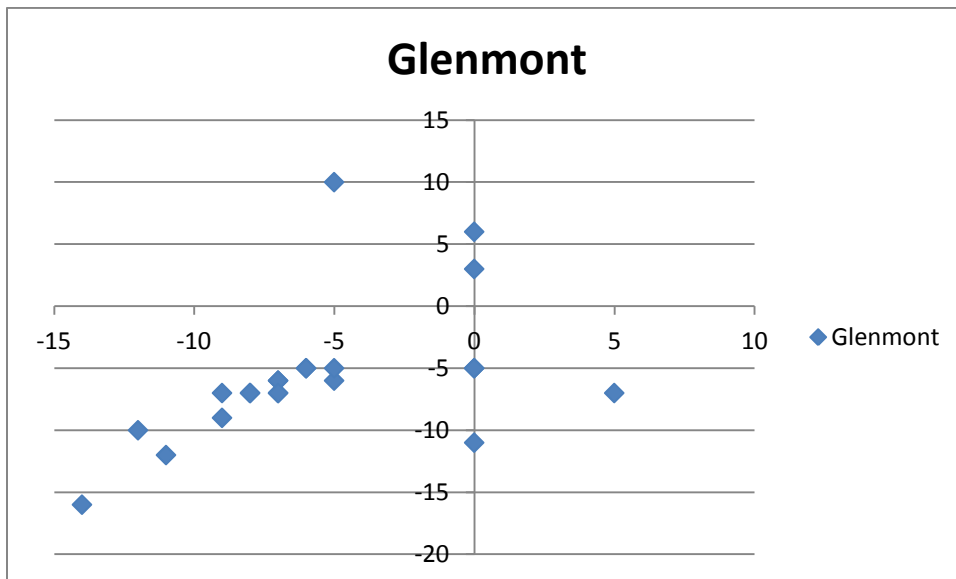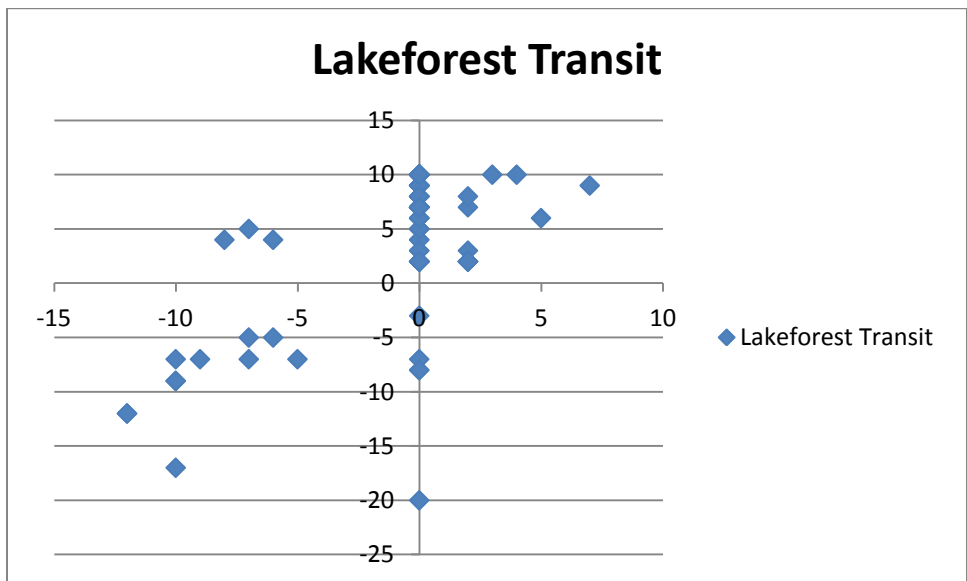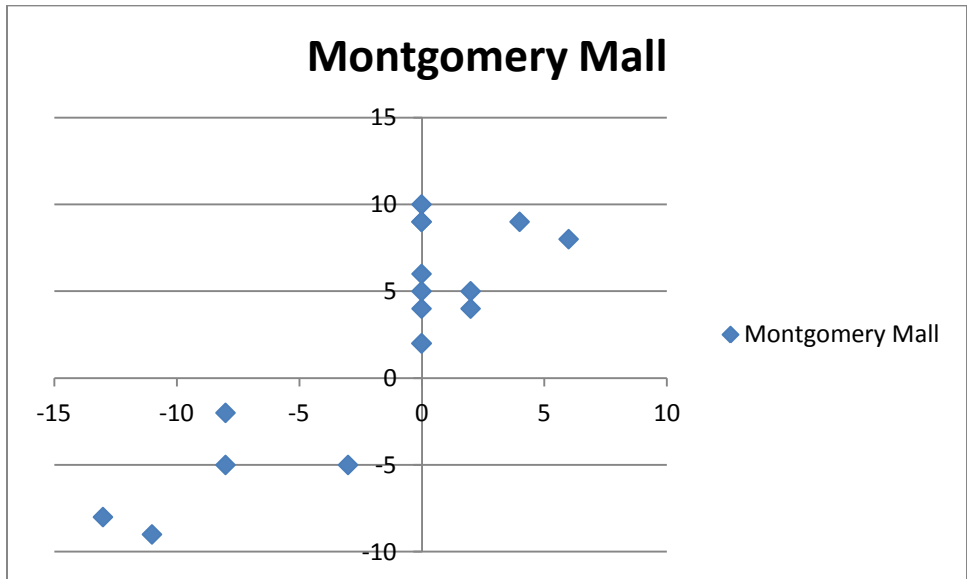

Figure H 3 Graph of Arrival Deviation against Departure Deviation for all Glenmont layover points.

The Glenmont transit layover stop only provides restrooms in the area. The Pearson value that was calculated for this specific location was .4735, which results in a medium correlation. This means that there may be a relation of operators taking most of the allotted time for the layover to use the restroom and begin the next route late.

Figure H 4 Graph of Arrival Deviation against Departure Deviation for all Germantown layover points.

The Germantown layover stop only contains food services in the area. The Pearson value that was calculated for this specific location was .5602, which results in a medium correlation. This means that there may be a relation of operators taking most of the allotted time for the layover to maybe get something to eat and begin the next route late.
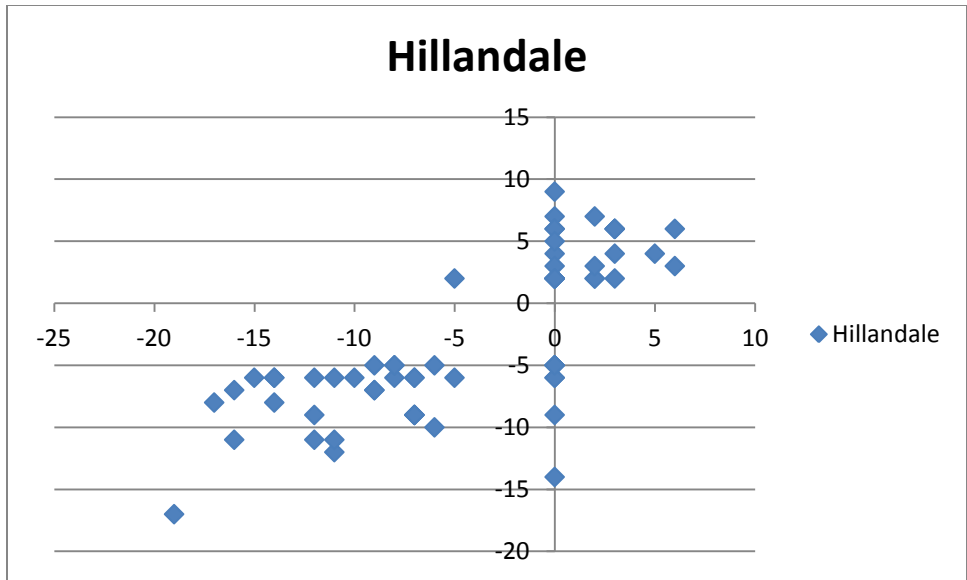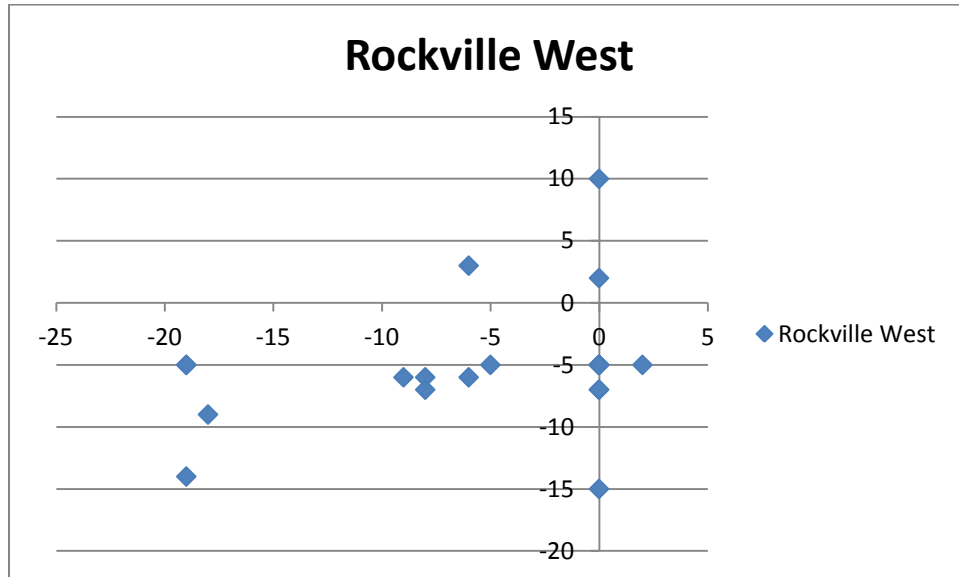
Figure H 5 Graph of Arrival Deviation against Departure Deviation for all Hillandale layover points.

The Hillandale layover stop only provides restrooms in the area. The Pearson value that was calculated for this specific location was .7474, which results in a high correlation. This means that there is a significant relation with operators using the allotted time on the layover to maybe use the restroom and begin the next route late.

Figure H 6 Graph of Arrival Deviation against Departure Deviation for all Lakeforest Transit layover points

The Lakeforest transit layover stop only contains food services in the area. The Pearson value that was calculated for this specific location was .6418, which results in a medium correlation.

This means that there may be a relation of operators taking most of the allotted time for the layover to maybe get something to eat and begin the next route late.
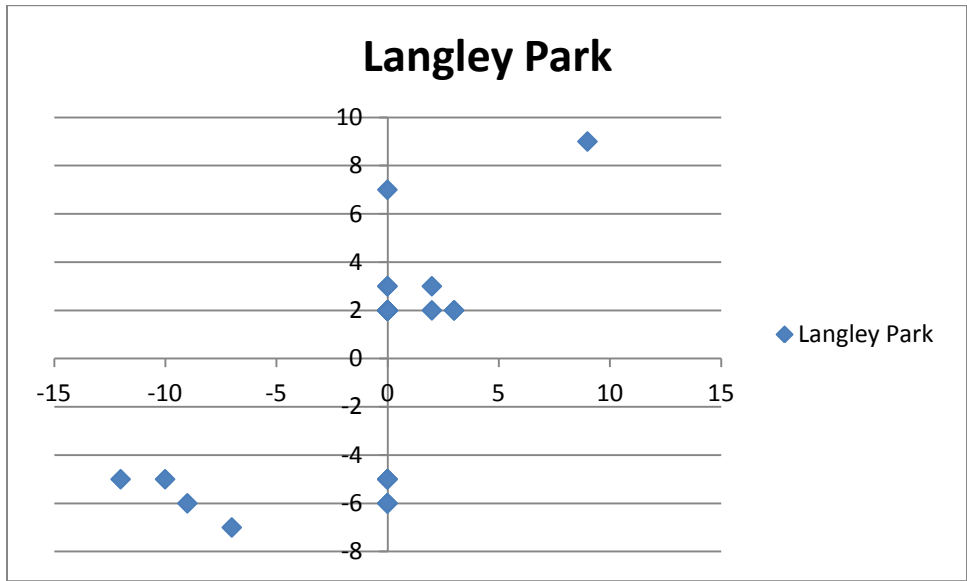
Figure H 7 Graph of Arrival Deviation against Departure Deviation for all Langley Park layover points.

The Langley Park layover stop does not provide restrooms and food services for the operators. The Pearson value that was calculated for this specific location was .6084, which results in a medium correlation. This means that there may be a relation of operators taking most of the allotted time for the layover for the layover and begin the next route late. However we do not know the reason for taking the whole layover.

Figure H 8 Graph of Arrival Deviation against Departure Deviation for all Montgomery Mall layover points.

The Montgomery Mall layover stop provides restrooms and food services in the area. The Pearson value that was calculated for this specific location was .8674, which results in a high correlation. This means that there is a significant relation with operators using the allotted time for the layover to maybe use the restroom and/or get something to eat and begin the next route late, especially due to the longer walk to these facilities.
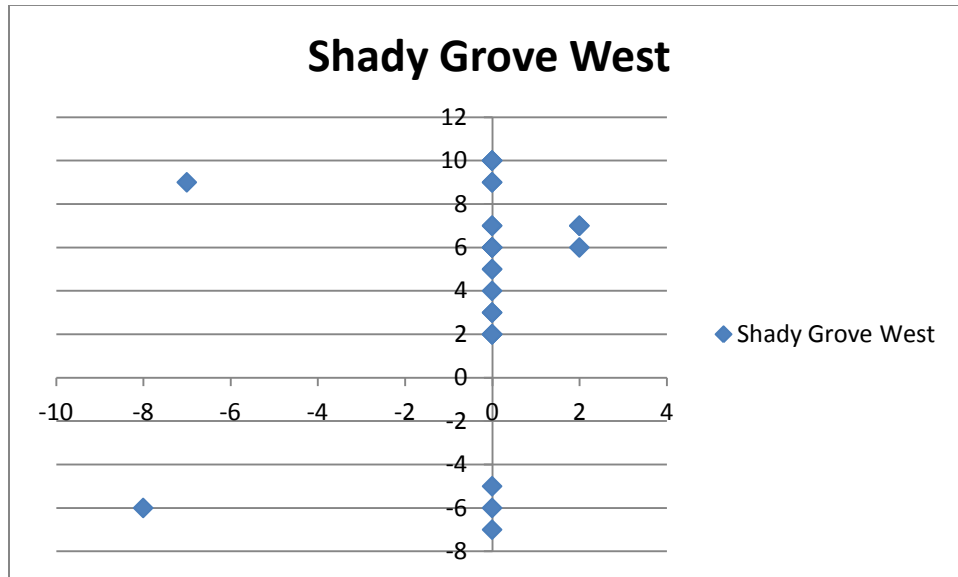

Figure H 9 Graph of Arrival Deviation against Departure Deviation for all Rockville West layover points.

The Rockville West layover stop provides restrooms and food services in the area. The Pearson value that was calculated for this specific location was .2885, which result with no correlation. This means that the operators actions are sporadic at their layover and the information is not able to be recorded in an organized way. We also cannot tell if the restrooms and food services in the area have an effect.
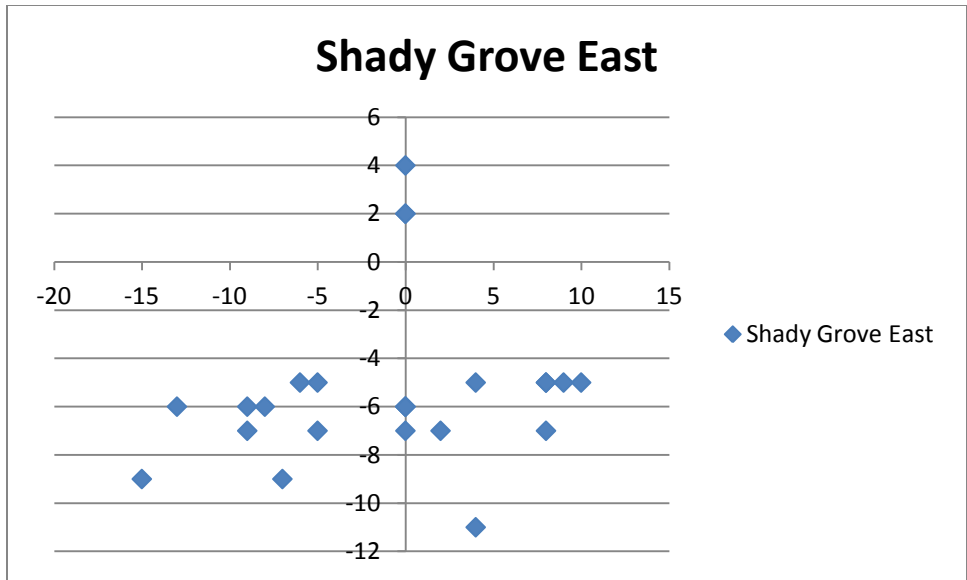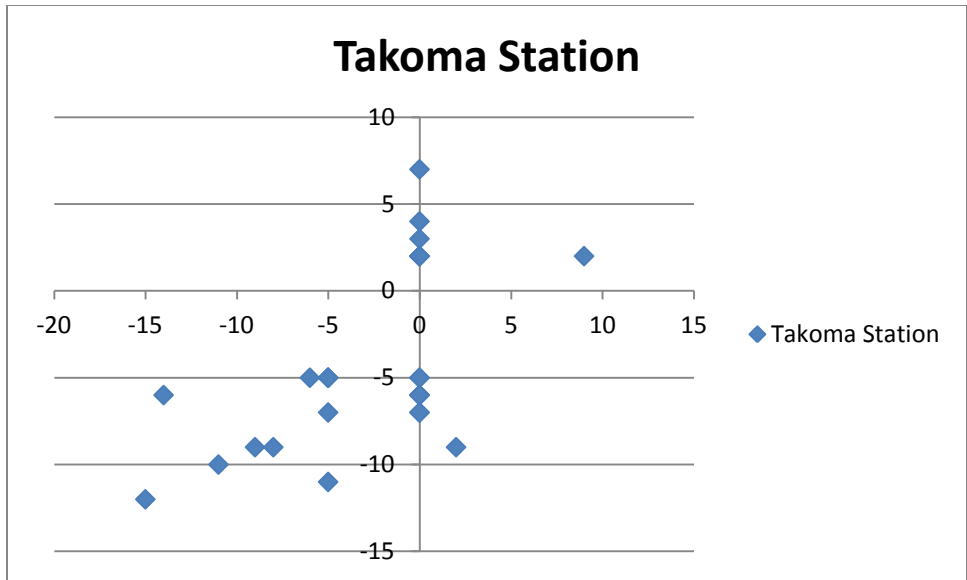
Figure H 10 Graph of Arrival Deviation against Departure Deviation for all Shady Grove East layover points.

The Rockville West layover stop only provides restrooms in the area. The Pearson value that was calculated for this specific location was .1709, which result with no correlation. This means that the operators actions are sporadic at their layover and the information is not able to be recorded in an organized way. We also cannot tell if the restrooms in the area have an effect.
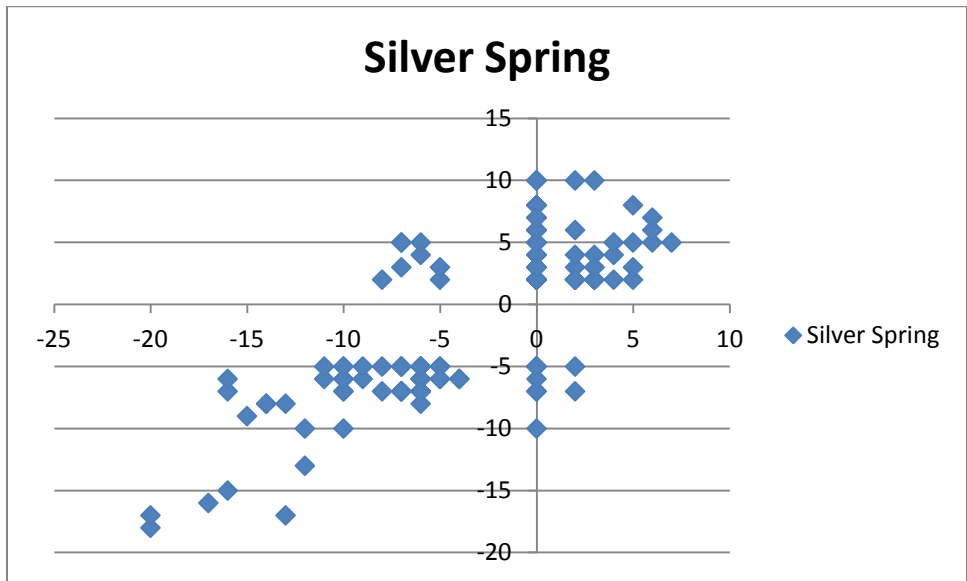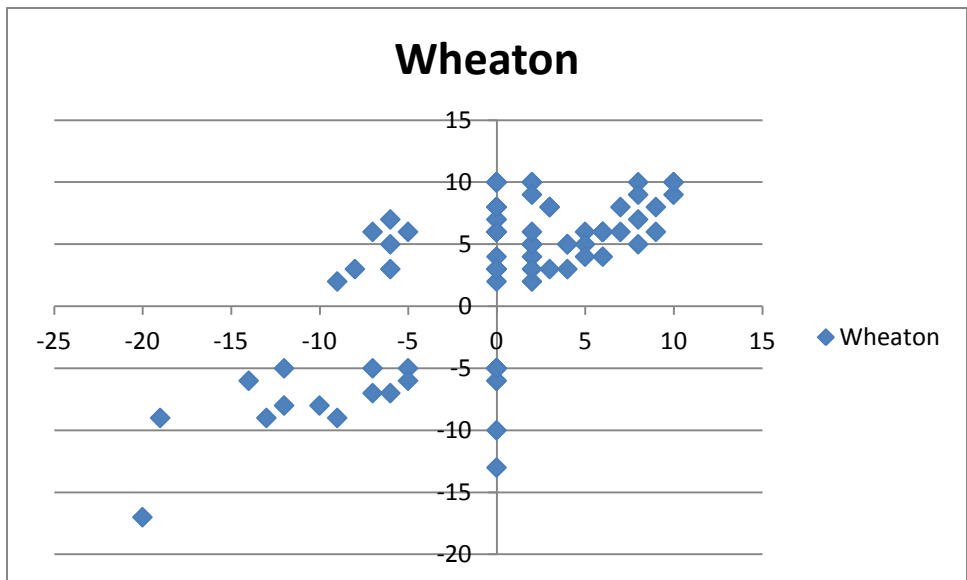

Figure H 11 Graph of Arrival Deviation against Departure Deviation for all Silver Spring layover points

The Silver Spring layover stop provides restrooms and food services in the area. The Pearson value that was calculated for this specific location was .7544, which results in a high correlation.

This means that there is a significant relation with operators using the allotted time for the layover to maybe use the restroom and/or get something to eat and begin the next route late.

Figure H 12 Graph of Arrival Deviation against Departure Deviation for all Shady Grove West layover points

The Shady Grove West layover stop only provides restrooms in the area. The Pearson value that was calculated for this specific location was .2266, which result with no correlation. This means that the operators actions are sporadic at their layover and the information is not able to be recorded in an organized way. We also cannot tell if the restrooms in the area have an effect.

Figure H 13 Graph of Arrival Deviation against Departure Deviation for all Takoma layover points

The Takoma Station layover stop only provides restrooms in the area. The Pearson value that was calculated for this specific location was .5680, which results in a medium correlation. This means that there may be a relation of operators taking most of the allotted time for the layover to use the restroom and begin the next route late.

Figure H 14 Graph of Arrival Deviation against Departure Deviation for all Wheaton layover points

The Wheaton Station layover stop only provides restrooms in the area. The Pearson value that was calculated for this specific location was .6560, which results in a medium correlation. This

means that there may be a relation of operators taking most of the allotted time for the layover to use the restroom and begin the next route late.

The following set of graphs were all generated for the sake of determining which correlations were strong enough to be used in the algorithm. The ones chosen were mentioned in Section 4.
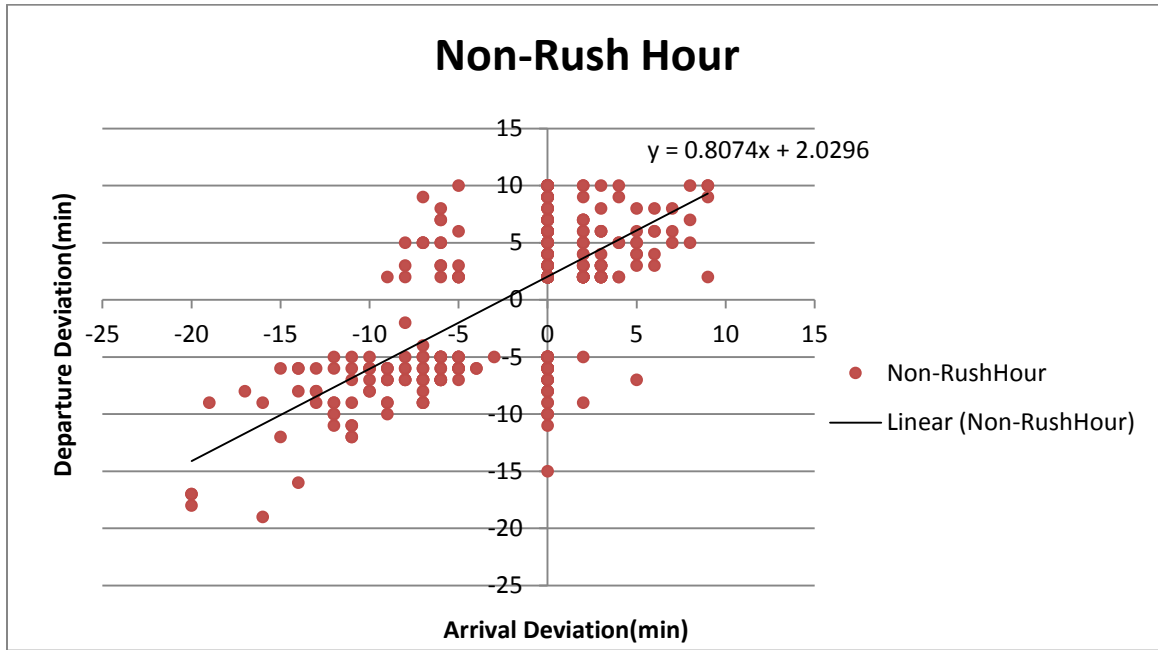
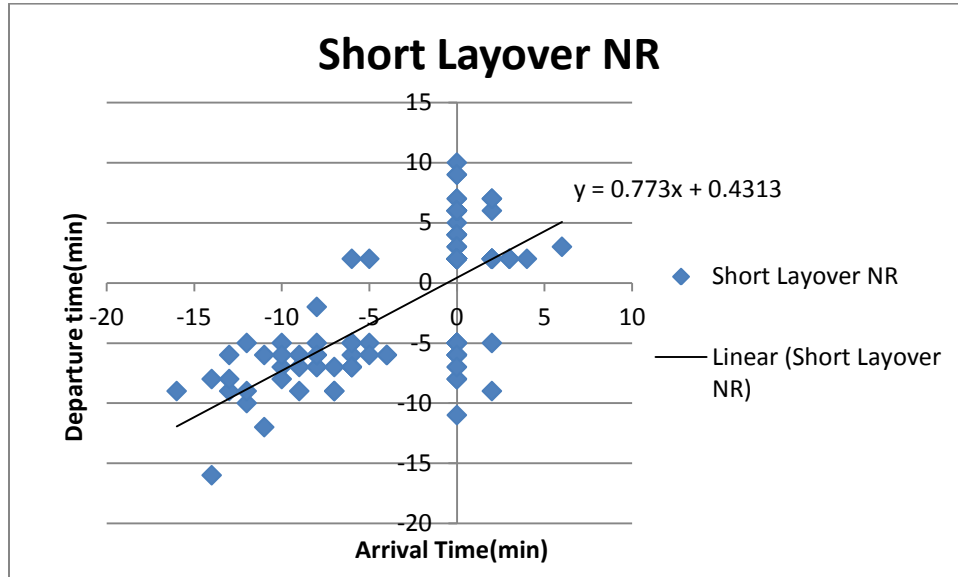**Figure H 15 Graph of Arrival Deviation against Departure Deviation for all non-rush hour points.**

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the condition of non-rush hour. The Pearson Correlation Coefficient for this graph is r=.633, which is considered a significant correlation.
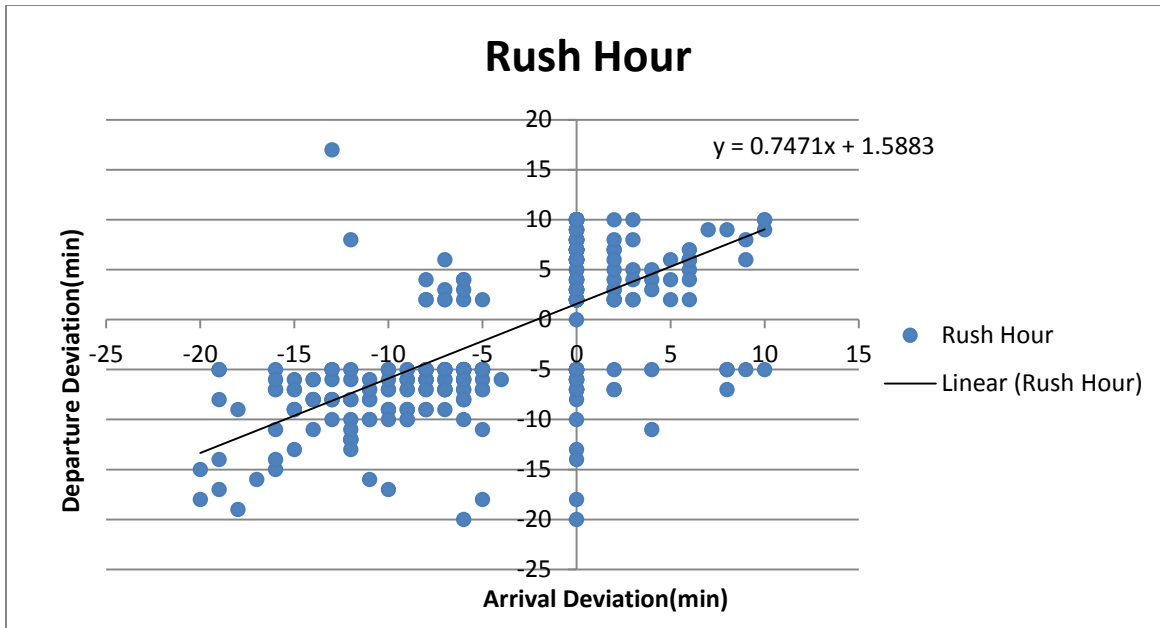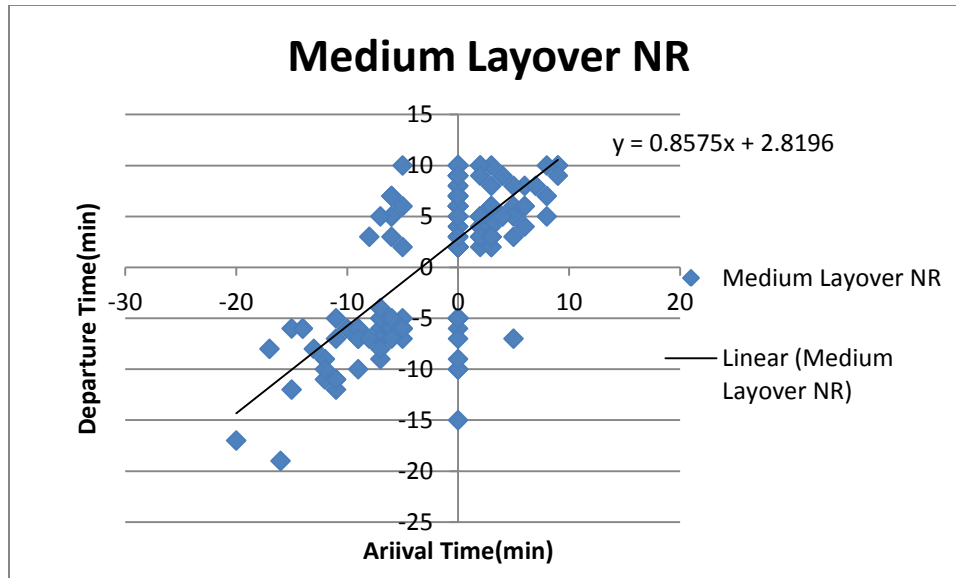
Figure H 16 Graph of Arrival Deviation against Departure Deviation for all rush hour points.

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the condition of rush hour. The Pearson Correlation Coefficient for this graph is r=.635, which is considered a significant correlation.
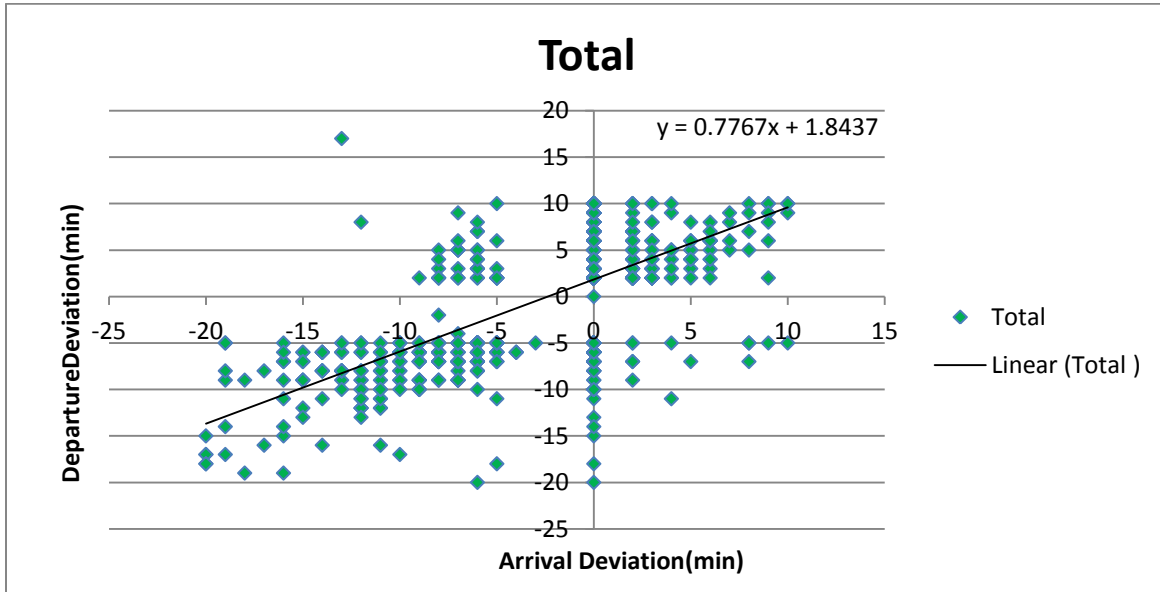
Figure H 17 Graph of Arrival Deviation against Departure Deviation for all points

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of rush hour and non-rush hour. The Pearson Correlation Coefficient for this graph is r=.639, which is considered a significant correlation.

Figure H 18 Graph of Arrival Deviation against Departure Deviation for all non-rush hour short layover points.

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a short layover during non-rush hour. The Pearson Correlation Coefficient for this graph is r=.652, which is considered a significant correlation.

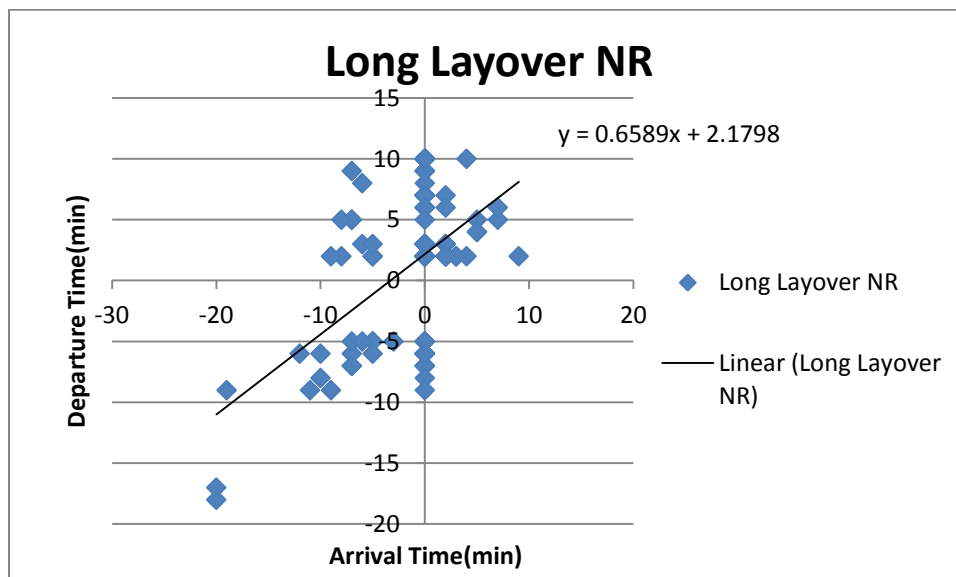**Figure H 19 Graph of Arrival Deviation against Departure Deviation for all non-rush hour medium layover points**

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a medium layover during non-rush hour. The Pearson Correlation Coefficient for this graph is r=.676, which is considered a significant correlation.

Figure H 20 Graph of Arrival Deviation against Departure Deviation for all non-rush hour long layover points

71

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a long layover during non-rush hour. The Pearson Correlation Coefficient for this graph is r=.510, which is considered an indeterminate correlation.
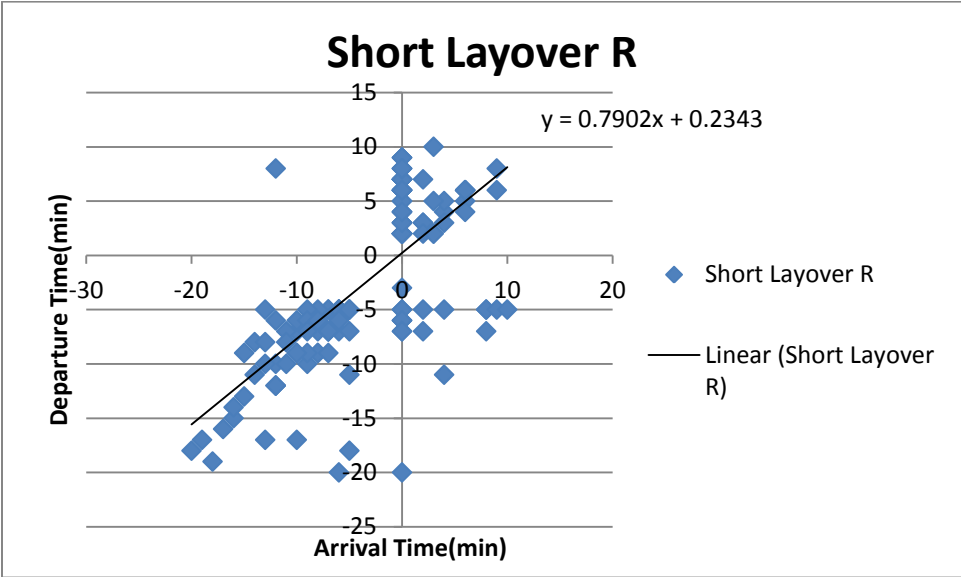

Short Layover R

$y = 0.7902x + 0.2343$

Departure Time(min)

Arrival Time(min)

◆ Short Layover R

—— Linear (Short Layover R)

Figure H 21 Graph of Arrival Deviation against Departure Deviation for all rush hour short layover points

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a short layover during rush hour. The Pearson Correlation Coefficient for this graph is r=.683, which is considered a significant correlation.
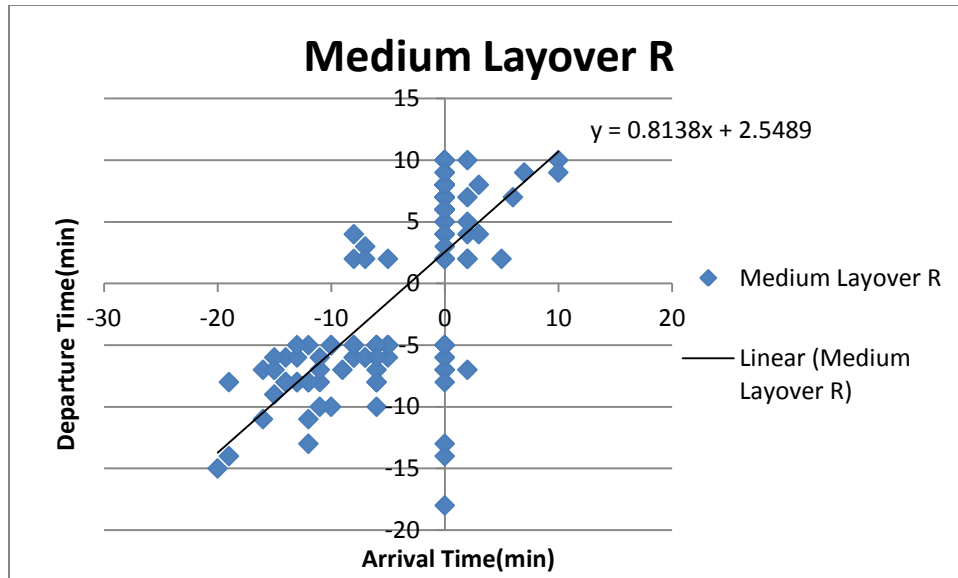
Figure H 22 Graph of Arrival Deviation against Departure Deviation for all rush hour medium layover points

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a medium layover during rush hour. The Pearson Correlation Coefficient for this graph is r=.696, which is considered a significant correlation.
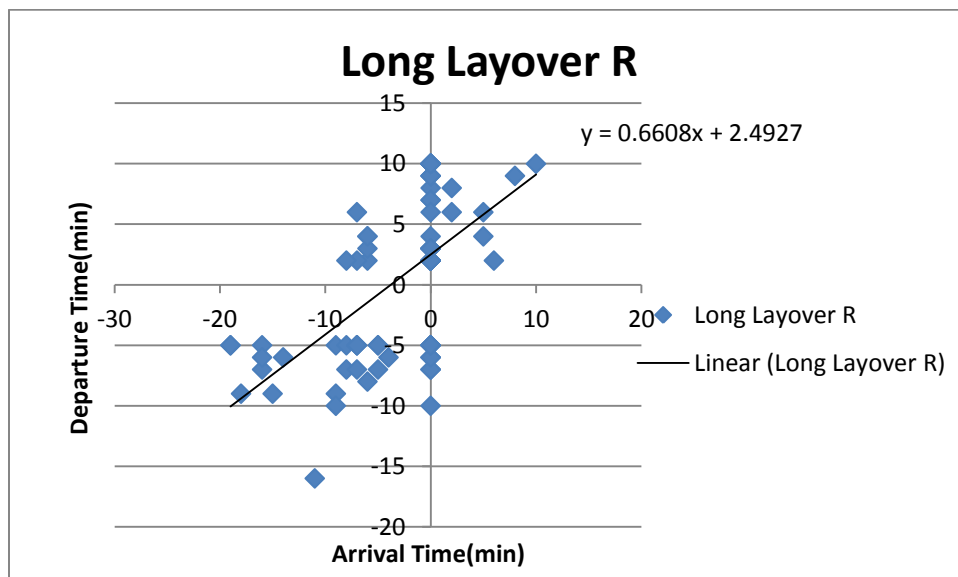

Figure H 23 Graph of Arrival Deviation against Departure Deviation for all rush hour long layover points.

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a long layover during rush hour. The Pearson Correlation Coefficient for this graph is r=.571, which is considered an indeterminate correlation.
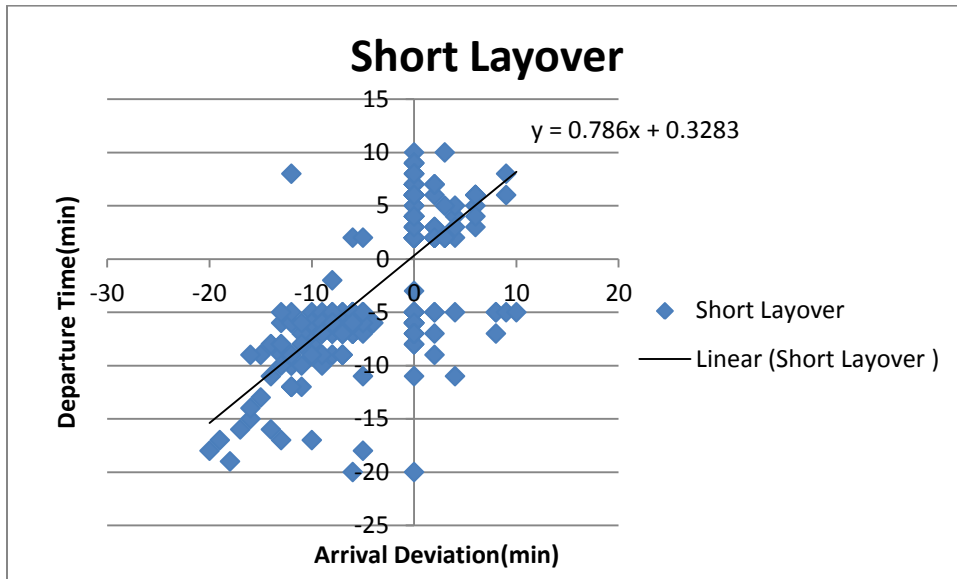

Figure H 24 Graph of Arrival Deviation against Departure Deviation for all short layover points

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a short layover in both rush hour and non-rush hour. The Pearson Correlation Coefficient for this graph is r=.674, which is considered a significant correlation.
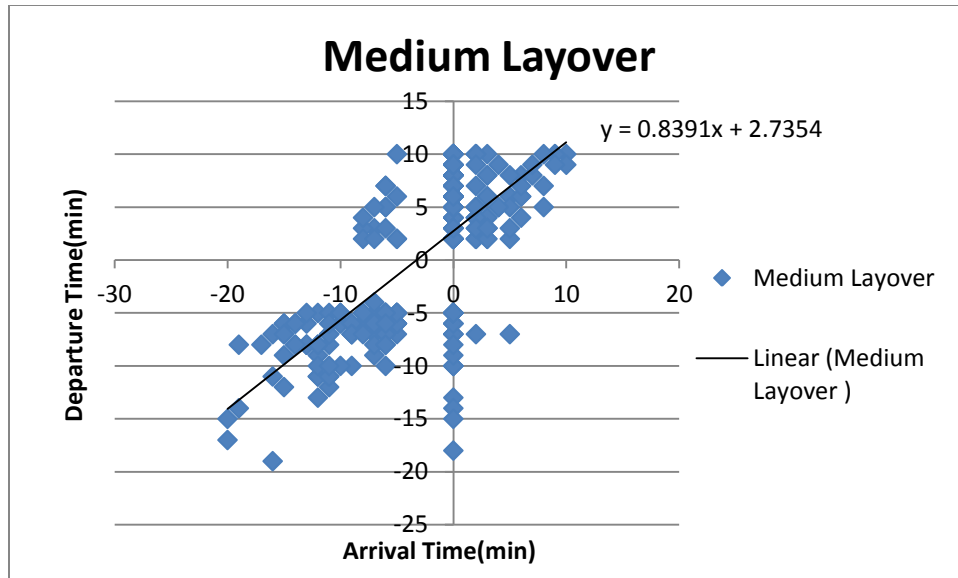
Figure H 25 Graph of Arrival Deviation against Departure Deviation for all medium layover points

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a medium layover in both rush hour and non-rush hour. The Pearson Correlation Coefficient for this graph is r=.694, which is considered a significant correlation.
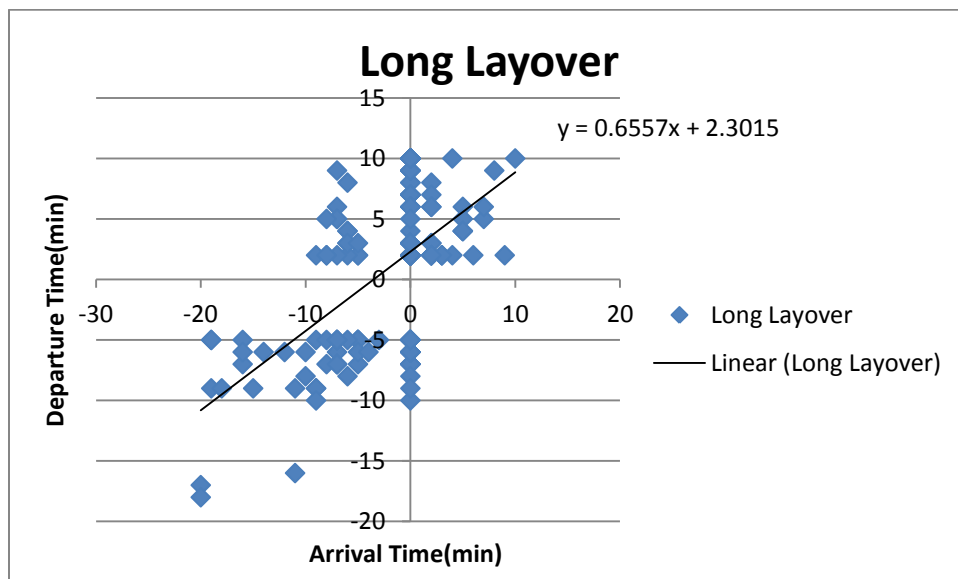

Figure H 26 Graph of Arrival Deviation against Departure Deviation for all long layover points.

This graph represents Arrival Deviation (in minutes) versus Departure Deviation (in minutes) under the conditions of a long layover during both rush hour and non-rush hour. The Pearson Correlation Coefficient for this graph is r=.540, which is considered an indeterminate correlation.