BUS ANALYSIS IN MONTGOMERY COUNTY

An Interactive Qualifying Project Report
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By

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Abstract

Optimizing public transit is an important issue in the 21st century. This research project was focused on the run time performance of the Ride On bus system in Montgomery County, MD. Through a focus group, field observations, and interviews we were able to create a set of comprehensive recommendations targeting addressable issues such as bus boarding, traffic signal idle time, and scheduling. Besides recommending common solutions, such as smart cards and transit signal prioritization, we developed a new, innovative scheduling paradigm.

Acknowledgements

About the Authors

Ryan Foley ('10)

Ryan is a Junior of Worcester Polytechnic Institute studying Mechanical Engineering. He plans to obtain a Masters Degree in Fire Protection Engineering following his graduation from WPI. His principle contributions to this project focus on bus boarding and related solutions. He investigated other cities' fare payment systems, comparing them to Montgomery County. He constructed the customer survey, distributed the survey, and performed subsequent analysis on the survey's results. His contributions to this report include any section related to bus boarding and subsequent analysis.

Scott MacDonald ('10)

Scott is a Junior of Worcester Polytechnic Institute studying Civil Engineering. He has a concentration in project management. Scott's contributions to the project focused on transit signal priority. He researched other cities' transit signal priority implementations, gathered related metrics in Montgomery County, and led an interview with traffic engineers to see how applicable transit signal priority would be for Montgomery County. His contributions to this report include any section related to transit signal priority.

Brian Tate ('10)

Brian is a Junior of Worcester Polytechnic Institute studying Computer Science. Using his previous studies, he developed the idea of analyzing a bus route like a finite state machine. While in Montgomery County, he moderated a focus group of bus operators. After analyzing the results of the focus group, he introduced the idea of a bus network to solve some of Ride On's runtime performance issues. While a bus network has many applications, he focused on one particular application of dynamic scheduling. He further developed this idea of dynamic scheduling to provide the County with a long-term goal for scheduling improvements. His contributions to this report include any section related to dynamic scheduling. He also was the principle author of the Executive Summary.

Project Roles and Responsibilities

Despite the fact each author had a primary focus in this research, everyone contributed to editing and revising duties. General sections, like the Introduction and Background were redrafted and revised enough such that no individual author can be attributed to it.

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Executive Summary

Optimizing public transit is vital for a modern America. As energy costs continue to be unstable, more and more people are depending on public transit as a method of transportation. This project's goal focused on improving the runtime performance and schedule adherence of the Ride On bus system in Montgomery County, Maryland. By using proven analytical methods, including observation, interviews, and surveys, we created a comprehensive set of recommendations to aide Montgomery County. We looked at a bus route in terms of the processes involved, such as boarding, idling at traffic signals, and scheduling. By looking at each process, we were able to focus on the addressable issues, and effectively create realistic, concrete recommendations.

The main problem related to bus boarding is the variability in the method of fare payment among customers. By observing bus loading we learned that payment methods vary from the very fast, like SmarTrip or flash-passes, to the very slowest method, cash. According to county documents, about one quarter of the ridership uses cash to pay the fare. The fare payment problem will soon be exacerbated by the upcoming phase out of paper transfers. The county must ensure passengers, who currently use paper transfers, transition to SmarTrip or flash-passes in order to maintain reliable boarding times. Increasing SmarTrip adoption is a vital step in this effort. From our survey and subsequent analysis, we believe the best way to accomplish this goal is for the county to increase the fare discount for SmarTrip users.

Crowded intersections are a detriment to a successful transit network. Busses spend considerable amounts of time waiting at traffic intersections, and this causes bus routes to run late. To overcome this, some cities have implemented transit signal prioritization (TSP) systems. TSP grants priority to busses, allowing them to pass through intersections cleanly and efficiently. From field research, we have discovered Rockville Pike is a candidate for a TSP implementation. From interviews, we have learned the transportation division of the county government is in the process of upgrading its traffic signal network. These upgrades are compatible with TSP systems. Thus, we recommend further investigation of implementing TSP along Rockville Pike.

The Ride On static bus schedule can not account for day to day variability in traffic flow. Using a focus group with bus operators, interviews with transit officials, and field observations, we developed an innovative enhancement for Ride On bus scheduling. Instead of scheduling busses based on predictions, dynamic scheduling would be calculated using real-time bus arrivals. By scheduling busses dynamically, Ride On could absorb some of these traffic variances while providing a stable route schedule to its customers. Dynamic scheduling would be accomplished by using new technologies to form a bus network. Implementing such a network would put Montgomery County on the forefront of new transit technologies and open up many doors for future enhancements. Bus service viability is dependent on customer satisfaction. Because one of the most important factors for customers is schedule reliability, we recommend Montgomery County further investigate dynamic scheduling to achieve better schedule adherence.

This comprehensive set of recommendations is based on three distinct problem areas; together they will address the larger issue of runtime performance. These recommendations will help Ride On as it strives to provide quality service to its customers. Furthermore, these recommendations will move Ride On into the modern transit age and will make Montgomery County a model for other transit agencies to follow.

1. Introduction

As we continue into the 21st century, public transit is becoming increasingly popular. This increased interest can be traced in part to the unstable cost of energy. Negatively affecting this new found interest in public transit, specifically bus transit, is its susceptibility to delays in heavy traffic. These delays make potential users less likely to adopt a public transit lifestyle. Cities are attempting to combat congestion by improving traffic infrastructure, but this is often a losing battle. Congestion continues to occur and even worsens. When public transit systems cannot stay on schedule, it creates a sentiment among customers that it is better to just use private transit (Zhao, 2006). This increases congestion because there are more private vehicles on the road, which makes the public transit systems even more inefficient. The Montgomery County Ride On System is a public bus system suffering from this problem.

Montgomery County is part of the Washington, D.C., metropolitan area. This region is home to many government agencies and businesses and is the third most visited tourist destination in America (Travelerszone, 2008). Therefore, there are many people moving in, out and around Montgomery County every day. According to the Reason Foundation and the Texas Transit Institute, Washington, D.C., is the third most congested metropolitan area in America (Hartgen, 2006; Schrank, 2007). By 2030 it is expected that it will take 75% longer to make a trip into densely populated areas during peak hours than off-peak hours (Hartgen, 2006). Putting this into real numbers, a bus route that is supposed to take 30 minutes would end up taking over 52 minutes. In a perfect world, there wouldn't be a difference in run time between peak and off-peak hours. This is unrealistic because traffic flow is inherently variable. A more realistic solution is to have more consistent runtimes despite traffic variability.

The major challenge for Montgomery County's Ride On system is to stabilize runtimes for its bus routes. Each bus route has a scheduled runtime which is used to assemble the network of busses into a reliable system. If a bus does not run on time, it creates delays for future routes. Ultimately these delays

leave customers unsatisfied. When a bus doesn't run on time, it creates a chain reaction that affects the rest of its run. Thus, a series of small delays add up to a significant delay by the end of a run. Considerable research has gone into optimizing bus runtimes. Across the globe, transit authorities are using new technologies to improve bus service. Many agencies are beginning to implement rapid boarding techniques. Proximity cards are increasing in popularity as they are a significantly faster fare payment system than cash. Other technologies such as traffic signal prioritization offer buses the right-of-way in crowded intersections. Transit officials also verify that bus schedules are up to date with changing populations and ridership patterns.

A notable gap in bus transit research is the cumulative effect of a set of individual enhancements to a system. There is room for a study on the collective effect of different technologies, such as rapid boarding, transit signal prioritization, and advanced scheduling on a bus system. Montgomery County is a diverse county, containing rural, suburban, and urban areas (Montgomery County, 2008). Hence, its transit problems cannot be solved with any singular solution.

It was the goal of this project to find ways to improve the efficiency of the Montgomery County Ride On system in congested areas. To accomplish this, we looked at a bus route like a state machine. As a bus completes a route, it transitions between a number of states, or stages. Each stage has a finite duration. We objectively examined each stage and investigated measures to lower the time in each stage. The focus of this project is becoming increasingly important as energy concerns continue to plague the world. It is our hope that our recommendations will not only help Ride On schedule adherence but also put Montgomery County at the forefront of transit technologies.

2. Background

Traffic congestion is a growing problem; in 2007 alone it cost urban Americans 78 billion dollars (Schrank, 2007). As energy costs remain uncertain, more people are looking towards public transit to commute and travel. This trend alleviates some congestion on the roads, but increases strain on transit systems. Because there are competing forces involved as people transition to using public transit over private transit, a stabilization point is reached in which no more people transition. At the stabilization point the transit system is sufficiently stressed such that mass transit "holdouts" would rather drive themselves than be inconvenienced with public transit. People are less likely to use mass transit if it takes them longer to get to work or are otherwise inconvenienced by using the public transit system. Due to these holdouts, there is still a significant presence of privately owned vehicles on the streets. These privately owned vehicles create traffic congestion, which slows down bus routes and makes it harder for public transit to meet the demands of its customer base. If a particular area is continually growing, the situation is exacerbated, because only some of the new population is able or willing to use public transit. Thus more holdouts hit the road, creating more congestion and dissatisfaction with public transit.

Significant research has been done to recognize and fight traffic congestion in America's cities. This research includes annual reports on the state of traffic congestion and observing its growth over time (Schrank, 2007). In this chapter we will cover a variety of topics useful for understanding the impact of our results and recommendations. These topics include an overview of Montgomery County, factors that contribute to traffic congestion, factors that contribute to bus tardiness, and other cities' solutions to a stressed bus system.

2.1 Montgomery County Transit Authority

The Montgomery County Government has its own transit authority to complement other transit providers operating in the Washington, D.C., Metropolitan Area (Montgomery County Government,

2007). They have their own public bus system called "Ride On". Montgomery County owns a fleet of buses that operate on almost 80 routes throughout the county as well as select areas of surrounding counties. Ride On operates all 80 routes during weekdays but only 30 routes operate on weekends. The Ride On system is one of the largest public bus systems in the nation, serving Montgomery County's population of about one million. According to Howard Benn of the Montgomery County Transit Authority, the entire Ride On system transports about 95,000 passengers each day through an average of about 5,000 trips.

Interlining

Scheduling is at the base of any bus network. In typical systems, like Boston, one would see busses scheduled to complete the same route throughout the day (Chris Garnier, Personal Communication, 11/03/2008). In these systems when a bus finishes a route it waits at the final stop until it is required to leave for the returning route. This is a simple technique that allows for a multiple busses to run periodically along the same route. A more complex technique of scheduling, known as interlining, is used by Montgomery County.

Unlike systems like Boston, an interlined system has busses scheduled to run different routes throughout the day (Chris Garnier, Personal Communication, 11/03/2008). When a bus reaches the end of its route, it may take an entirely different route out of that station. A major advantage of this approach is the better allocation of resources. In a non-interlined bus network, a bus needs to wait for the entire frequency of the bus route in order to start the next sequence. That is if a route runs every 15 minutes, a bus will wait 15 minutes before starting up again in the opposite direction. For smaller layover times, savings are not as apparent, but for layover times as large as 30 minutes interlining saves significant resources. A negative effect of interlining is the potential chain reaction of delays. If a bus early on in the day is delayed, the next route that bus takes will start late. As more delays occur, the total delay grows, resulting in significant delays by the end of the day.

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Rockville Pike

Route 355 in Maryland is one of the main traffic corridors located in Montgomery County. It is a main access road from Washington, D.C., into the county. It stretches from the border of Washington, D.C., all the way through Montgomery County into neighboring Frederick County. Route 355 changes name a number of times throughout the county with large sections including Wisconsin Ave, Rockville Pike and Frederick Rd. This stretch of road carries one of the highest volumes of commuters in Montgomery County.

All eight Metro stations off the red line from Shady Grove to Friendship Heights are located on route 355. Five of these Metro stations, Shady grove, Grosvenor-Strathmore, Twinbrook, Rockville and White Flint have parking available at the station with spaces ranging from 524 in Rockville to 5,745 in Shady Grove. Despite the amount of parking available, they usually fill early in the morning. This results in many people using Ride On to get to and from the metro stations, creating high demand for routes that travel to the red line Metro stations.

The 10 Year Plan

In 2005 Montgomery County released a 10 year transportation plan. The multi-billion dollar plan is intended to address increasing traffic congestion throughout Montgomery County. This plan is the largest transportation initiative by a county in the Washington Metropolitan area. Projects under this plan include new roadways, road improvements, intersection upgrades and increased rail availability. Many of these projects have already been completed or are currently underway. A major component of this plan specifically addresses the Ride On bus system.

The plan calls for the expansion of Metrobus and Ride On in the county by 50 percent by the year 2015 (Montgomery County, 2007). Under this transportation plan it is expected that transit ridership will increase by more than 75 percent during rush hour; from 34,000 users to nearly 60,000 users. Methods to accommodate these new riders include adding more routes and increasing service

hours. Within the next seven years routes will run about every 15 minutes, but some may run as often as every 10 minutes, depending on ridership.

Projections show that Montgomery County's 10 year transportation plan will make significant strides against traffic congestion. These projects, together with expanding transit services will reduce the duration of afternoon work trips by 18% and increase total transit use by 45% (Montgomery County, 2007). By performing these projects Montgomery County is hoping to reduce traffic congestion and improve mobility by 2015. Montgomery County acknowledges the fact that fighting traffic congestion is not an easy task nor inexpensive, however they realize it is necessary to improve the quality of life in Montgomery County. A complete list of the projects can be found in Appendix B.

2.2 Factors that contribute to traffic congestion

The principle cause of traffic congestion is a large population with "many people moving around at the same time" (Schrank, 2007, p.7). Montgomery County traffic patterns follow this trend. With a population of almost one million people as well as neighboring the nation's capital, there are many people moving on the roadways throughout the county. People move using a variety of means; driving personal vehicles, riding public transportation, or even walking. Regardless of the particular form of transportation used, there is always some contribution to traffic congestion.

The most visible cause of traffic congestion is too many vehicles on the road at any given time. This is what the average commuter considers traffic congestion. As commuters we know it's draining to seem to be always going where everyone else is going. Roads are only designed for so much traffic; when these limits are reached, drivers are negatively affected.

Infrastructure problems and resulting construction also contribute to congestion. Sometimes, old cities have roadways that are outdated and not sufficient to handle the amount of traffic that roadways are seeing (Tennyson, 2007). For example, picture a road constructed in a small Kansas farm

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town. Back in the 1950s, the road may have been constructed primarily for farm equipment transit, but today it may be a connector to a major metropolis. Clearly one can imagine the road's original design may not be suitable for its current usage. Roads like these are inevitably going to have to be repaired. When the repairs are performed, sections of the road may need to be shut down (Tennyson, 2007). These road closures create temporary delays that negatively impact traffic flow.

Pedestrian traffic is also a contributor to traffic congestion. Transportation hubs like park and rides, Metro stations, or major bus stations are prone to heavy foot traffic. Pedestrians are known to frequently ignore signals at a timed intersection and J-walk. Unpredictable pedestrian movement causes vehicles to be backlogged as they might miss their opportunity to pass through the intersection. Pedestrians, though not vehicles on the road, have a serious impact on traffic flow.

2.3 Montgomery County Transit Services and Traffic Congestion

Montgomery County has been consistently rated the third most congested region of the United States, the first being Los Angeles (Schrank, 2007). From the transit authority's own estimate, Ride On bus routes are on time 80 percent of the time (Howard Benn, Personal Communication, 9/12/08). This is undesirable because often times, commuters have specific work schedules and cannot be late. Currently there has been an effort to alleviate the burden faced by passengers in congested areas. The Ride On website includes the use of online tools and information to help to reduce the wait time for passengers (Montgomery County, 2008). Specifically these tools alert a commuter to the location of lane closures and roadwork. With this information a commuter can avoid these areas or schedule more time for his or her commute. Other useful tools on the commuter website include an updates page to notify users if a bus is running late. These tools help commuters deal with the problem of traffic congestion, but more direct steps need to be made in improving efficiency in congestion.

2.4 Factors that Contribute to Bus Tardiness

Traffic congestion is not the only cause of a bus being late. Other factors contribute to a bus not finishing its route as scheduled. Red lights can be a major factor in whether or not a bus is on time. Depending on how the bus approaches a light, it may spend a significant amount of time at an intersection. Every time a bus is stopped at a red light, not only is it wasting time waiting at the light itself, it also looses time accelerating back up to speed. A bus is not like a normal car, it takes a lot more time and energy to get a bus up to speed. In more urban area of the county, where you have a number of lights in a row, bus runtimes can be significantly increased.

We have discovered, through an interview with Mr. Tim McCormick, that a major factor contributing to bus tardiness is the payment type of passengers. Mr. McCormick, a transit official from Providence, Rhode Island, did his own independent study to find the effectiveness of the Providence Smartcard system. He found the average time for someone with a Smartcard, whether it's a proximity card or one with a magnetic strip that you swipe, was somewhere between three to five seconds. Those paying with cash, however, averaged a fare payment time of about twenty-two seconds. This may not seem like a significant difference, but extrapolate that over an entire bus run, those seconds add up to many minutes of time.

2.5 Other Cities' Solutions to a Stressed Bus System

Many cities have had to deal with similar problems to the ones that Montgomery County is now facing. Increasing energy costs have caused more interest in public transit. It is not uncommon for other cities to deal with increased usage in a system with transit issues related to crowded streets. Because many cities have had to deal with this problem, there are a lot of unique ideas to increase efficiency of a bus system despite traffic congestion.

Smart Cards

Smart cards are an increasingly popular way to optimize bus boarding. Cities such as Boston, Hong Kong, and Washington, D.C., have all invested in smart card technology. Hong Kong implemented a smart card called the "Octopus Card" (Octopus Cards Unlimited, 2008). This proximity Smartcard is used to transfer electronic payments to collect fares for the city's public transit system. Making a payment using the card can be done by holding the card against or waving it over an Octopus card reader, even if it is in a wallet or purse. One can imagine how this is more useful than a swipe card, as it does not require users to remove them from a container. The octopus card has tremendous popularity in Hong Kong, boasting a 95% user rate.

Smart cards provide effective, flexible and secure business transactions with minimal human intervention (Octopus Cards Unlimited, 2008). The standard transaction time for readers is 0.3 seconds. Smart cards allow for more advanced handling of fares. In the Hong Kong implementation, when riding the transit system, the entry point of commuters is noted when they first get on. This allows for different fares for different lengths of travel.

Bus Size Options

A unique solution seen in Boston is longer busses. By connecting a second body to the end of a normal bus one bus can carry twice as many people at a time. This solution has benefits and drawbacks. The only time that a route will benefit from a larger bus is when it is at full or near-full capacity. Also, the bus may be able to carry significantly more people, but it is much harder to maneuver. Depending on how a city is designed it may be more practical to extend the bus in a different dimension. For example, England wanted more capacity in each bus, so they have a second story on top of some of their busses. Roadways were not designed to accommodate extra long buses, so they made them taller.

Transit Signal Priority

Some transit agencies have started to combat congestion by implementing transit signal prioritization (TSP) (Davol, 2001). The objective of TSP is to improve schedule adherence and improve transit travel time efficiency while minimizing impacts to normal traffic operations. Traffic signals are typically timed to minimize the total delay to all vehicles at the intersection. However, minimizing vehicle delay may not be optimal for passengers if the passenger load of the vehicles is considered. For example, a 30-second delay to a crowded bus is not equivalent to a 30-second delay to a single-occupancy vehicle on a per passenger level. Thus a valid metric to use is the total delay caused to all passengers in a vehicle rather than just look at the vehicle as one indivisible object. This metric represents the impact of delays imposed on the users of the transportation network instead of on the vehicles of the transportation network. Thus, using this metric grants priority to public transit vehicles and minimizes the average delay per person.

Transit Signal Prioritization strategies attempt to reduce delays in two ways, by reducing the probability of a transit vehicle encountering a red signal, and if this does occur, by reducing the wait time for the green signal (Davol, 2001). One implementation of TSP is made up of four components (Smith, Hemily, Ivanovic, 2005). There is a detection system that lets the TSP system know where the transit vehicle requesting priority is located. The detection system communicates with a priority request generator that alerts the traffic control system that the transit vehicle would like to receive priority. There is software that processes the request and decides whether to grant priority based on the programmed priority control strategies. Then there is also software that manages the system, collects data, and generates reports.

Traffic Signal Priority systems are divided into two distinct types; passive and active (Corby, Stewart; 2006). Active priority strategies are more commonly used than passive priority systems. Active systems alter signal settings dynamically and only when necessary; making adjustments in real-time to the signal timing in order to minimize delay for an approaching public transit vehicle. Passive systems do not

dynamically alter the light due to the presence of a bus. This includes signal light timing, special lanes for a bus at an intersection, or other measures that don't dynamically alter due to the presence of a bus. The application of passive or active transit priority can be disruptive to competing traffic movements depending on the situation.

Active priority strategies are divided into three classes, unconditional, conditional and adaptive (Davol, 2001). An unconditional strategy is one which gives priority to every transit vehicle detected. The disadvantage to this is that priority may be granted unnecessarily; for example, a vehicle that is ahead of schedule, or worse, a bus that is currently not even in service. Unconditional priority requires no further information other than the presence of the vehicle to be transmitted to the signal controller. This makes it a viable option for transit systems with limited funding or communications capabilities.

Conditional strategies grant priority status based on certain criteria (Davol, 2001). The criteria are the current properties of the specific transit vehicle. Common criteria for conditional priority are the tardiness of the vehicle relative to its schedule, the number of passengers on the bus, or simply the time of day. By making the signal prioritization based on multiple conditions the system is more robust. By being robust the system can be more flexible in optimizing traffic flow for public transit while minimizing unnecessary delay for other types of vehicles.

Adaptive transit priority strategies are those which use optimization-based control schemes to determine if and how to grant priority (Davol, 2001). In such schemes, the delay of the transit vehicle is considered along with the delay faced by all other vehicles. The controller then calculates the optimal solution for how to allocate time between the competing approaches. This type of active signal prioritization is the most dynamic.

Expected benefits of traffic signal prioritization vary depending on the applications, but include improved schedule adherence, reliability and reduced travel time for busses (Smith, Hemily, and Ivanovic, 2005). This leads to increased quality of service for busses. Potential negative impacts of

implementing a system include delays for private vehicles. However, logically, delays for private

vehicles can be proven to be minimal. This is because for every private vehicle delayed by the

prioritization of a bus there is an opposite private vehicle that benefits from a longer green signal.

For design and development of TSP strategies, however, field tests are often infeasible (Davol,

2001). Microscopic traffic simulation is usually the most practicable alternative for testing designs

before implementation. The most common metric used for such evaluations is travel time through the

network, as this is the most direct measure of the impact to the control strategy. The impact on transit

vehicles is usually separated from the impact on traffic as a whole in evaluation studies. This allows the

benefits of the transit vehicles to be directly contrasted with the negatively impacted vehicles.

Conclusion

The background research was an excellent foundation for the rest of the project. Understanding

Montgomery County, traffic congestion, bus tardiness, and others' solutions, was vital for a successful

project outcome. As we began to perform our project objectives, the background served as an

instrument of knowledge in our quest to further understand Montgomery County.

3. Methodology

The Montgomery County bus transit system, Ride On, has been experiencing time performance issues due to increasing congestion throughout the Washington, D.C., Metropolitan area. The goal of this project was to provide multiple recommendations for the Montgomery County Government to help improve time performance and schedule adherence for Ride On. To do so we focused on three main objectives: identify current problems with Ride On as related to time performance, identify other transit authorities' solutions to these problems and examine their applicability to Ride On and develop an analytical framework for bus loading performance and signal delay in order to support our recommendations. To complete these three objectives we had to use several different methods of research: observation, interviews, focus groups and the use of a survey. Using these methods allowed us to complete our project objectives efficiently and effectively.

3.1 Identify current problems with Ride On as related to time performance

We discovered that a crucial objective to completing our project was to understand the fundamental shortcomings of Ride On. While in Montgomery County, we used methods of both direct and participatory observation to identify current problems. The best way for us to understand how Ride On functions was to use it. Participatory observation of riding the busses allowed us to be a customer and go through exactly what every other passenger has to go through on a daily commute. We expected to face traffic congestion, poorly timed lights, long waiting times, and late arrivals. Riding the busses was very important to us, because we needed an understanding of how Ride On operates.

Route Determination

The first milestone we needed to reach for this project was to determine which routes our study should focus on. During weeks one and two we chose to ride a variety of routes throughout Montgomery County. The first route we rode was the 55 from Rockville Station to Germantown; this was selected because of high ridership and the amount of stops on the route. We were able to

determine what other routes to ride by discussing the topic with County officials, in addition to looking at ridership data ourselves. We ended up observing a variety of routes originating from the Rockville and Silver Spring Metro stations. These routes included the 55, 46, 59, 47, 15, 16 and 20. Only a subset of these routes was focused on for our study. The subset we finalized on was the 55, 46, 16 and 20. These four were selected because of their locations on major congested traffic corridors. Descriptions of the routes can be seen in Appendix C.

Observation Practices

While we were traveling on each of these routes, we engaged in conversation with other passengers. This allowed us to gain "insider information" on how customers felt about Ride On. We did our best to make these encounters as natural as possible; in fact, occasionally riders would spark conversations with us. Oftentimes the conversation led to information that helped us understand the system better. However, this was not always the case, and we had to consider different aspects of the conversations to determine whether to take them seriously. Through these casual encounters we found out what it is like to ride the bus everyday and what problems people face. This method allowed us to get firsthand information on customer attitudes towards Ride On.

From our background research and investigation, we learned that in completing a route, a bus transitions through a variety of stages. Such stages include loading and unloading passengers, en-route on the road and stopped at traffic signals. The bus spends a certain amount of time in each stage. While out in the field we gathered quantitative data on all stages but focused our study on stages that are easiest to improve. Through discussion with our project liaisons and our engineering judgment, we determined bus loading and traffic signals were the easiest stages to alter. Our study consisted of gathering actual time a bus spent in each stage on the chosen routes, at peak and non-peak hours. By gathering these data, we were able to see how much of a difference changing one stage would affect the entire system. Additionally we discovered that scheduling was also an important part of the bus

system.

Fare Payment Systems

From our background research we learned there is a gap in research on fare payment systems. There has been no conclusive research in the United States about the efficiencies of different fare payment systems (Tim McCormick, Personal Communication, October 6, 2008). Thus, while planning to observe a bus in all stages, we knew we wanted to specifically observe the length of time a bus needs to load its passengers. This observation meant recording what payment type people used, and how long it took them to pay their fare. To make these observations we rode on a variety of buses with a stopwatch and recorded the amount of time it took people to pay for the fare. We started timing when the passenger reached the top step of the bus and stopped timing when they walked by the bus driver. It was important to collect the data the same way every time to get consistent results, we recorded about 100 trials. Once these quantitative data were gathered, we were able to find an average time that it takes a passenger to pay using each payment method. This was valuable information because changing bus loading times is one of the easier stages to alter for Ride On.

Traffic Signal Delay

From background literature we found that delays at traffic signals are sometimes directly related to bus schedule adherence. We performed a study on where and how much signal delay affected Ride On routes. In completing this study we collected data on how much time buses spent at red lights. We did this by timing the bus from the point the bus started to decelerate for a red light to the time the bus started to accelerate again. Once these data were collected we were able to determine the percentage of time spent at traffic signals compared to the total bus route. By completing this study we had hoped to find a connection between signal delay and schedule adherence.

Operational Standpoint

Besides riding buses, we also organized a focus group of Ride On bus operators. A focus group is a small group of people taking part in a guided discussion. Important preparatory steps were taken in order to make the focus group successful. First, a definitive set of topics and questions had to be constructed. A final version of this is located in Appendix D. We had six bus operators participating in the discussion, one of us served as the moderator, while the other two were observers. During this focus group we gathered data pertinent for meeting our objective of learning about Ride On and were able to gather constructive feedback on the bus system. We wanted the participants to feel comfortable talking to us, so we held the focus group at the bus depot in Gaithersburg, Maryland. The bus drivers were reserve drivers, so they had no set schedule of routes at that time. This allowed them to be free for the entire 90 minute duration of the focus group. Because there were reserve drivers, they knew most of the routes, allowing us to get insight on routes all around the county. The specific topics we discussed included the drivers' views on traffic congestion, ways to enhance bus loading and unloading, and general observations about Ride On. The discussion included, but was not limited to, each of these pre-determined topics. In fact, this specific method of information gathering was chosen specifically for the open-ended nature of the conversation. While other methods such as interviews or surveys can gather similar information on known variables, the focus group uncovered fresh ideas about problems Ride On is facing.

After holding the focus group we explored the validity of the observations and validated suggestions that were made by the operators. This included traveling to sites where operators reported frequent traffic congestion. We followed up on their suggestions to see whether they were feasible or applicable to improving the Ride On system. We talked to our liaisons to gain a management perspective on the operators' feedback. We compiled the results of the focus group into a summary report which can be found in Appendix E.

3.2 Identify other transit authorities' solutions to these problems

Through our background research we discovered numerous solutions that other public transit systems have used to increase time performance. Such technologies include Hong Kong's Octopus card, Boston's Charlie card or Chicago's and Los Angeles' transit signal priority systems. Besides identifying these potential solutions we investigated how applicable they would be for Ride On. This involved interviewing bus users as well as County officials.

Identify benefits and feasibility of increasing usage of SmarTrip

The fare payment study discussed in Section 3.1 focused on bus loading time. We wanted to investigate this topic from multiple angles. We wanted to look both into the plausibility of increasing SmarTrip usage and the benefits it would bring to Ride On. We discovered the time metrics related to SmarTrip in the fare payment study. Because we also wanted to discover the users' opinion of SmarTrip we conducted a survey. Interviews with transit officials were conducted to gather their opinions as well.

We developed a brief questionnaire to gauge user opinion about Ride On. This evolved into choosing the survey topic to be about SmarTrip. Because users would not be inclined to answer complex questions, we chose to use a Guttman Scale model. The Guttman scaling model is best to analyze simple yes or no questions in a short questionnaire. The survey questionnaire can be found in Appendix F. The objective of the survey was to find out a participant's knowledge and opinion of SmarTrip. It was used to gauge the customers' interest in increasing the usage of SmarTrip throughout the County. The questionnaire was distributed at various Metro stations across the county. This included Rockville, Shady Grove, and Silver Spring. By passing out the questionnaire at these stations we were able to maximize the number of responses per unit time. This is because the population of bus riders at a Metro station is much higher than on a single bus.

To determine the feasibility of increasing SmarTrip usage, we had numerous discussions with county officials. We discussed the feasibility with Chris Garnier, a route scheduler at Montgomery

County Transit, and Phil McLaughlin, manager of transit scheduling and planning. Knowing what the

future goals for the SmarTrip were for the county, as well as understanding previous related efforts

helped us to determine the feasibility of increasing SmarTrip usage on Ride On buses.

Transit Signal Prioritization Applicability

We have learned from background research that many public transit agencies have

implemented transit signal prioritization (TSP) systems to combat signal delays. The study mentioned in

Section 3.1 was focused along Rockville Pike on routes 46 and 55. Rockville Pike is a heavily traveled,

large retail corridor carrying many bus routes. The Rockville Pike corridor was specifically chosen for

applicability analysis because a TSP system would be implemented along a major corridor like Rockville

Pike. We also spoke with traffic engineers to discuss TSP feasibility. Specific topics focused on the

compatibility of current software and hardware with TSP. The data we gathered were useful in

determining whether a TSP system would be beneficial to Ride On.

Development of Dynamic Scheduling

After completing some analysis, we developed an idea that would be beneficial to Ride On bus

scheduling. This unique idea materialized as dynamic scheduling and was drawn from connections with

other fields of study. While dynamic scheduling is a powerful idea, we needed to see how applicable it

was for the Ride On system. Thus, we held meetings discussing the topic with Chris Garnier and Phil

McLaughlin. Using Ride On's own On-Time performance data, we were able to see how various

scenarios would work using dynamic scheduling. Lastly, we hypothesized how dynamic scheduling could

be implemented. Using all the data gathered in this phase, we were able to create a sound engineering

proposal for dynamic scheduling for the Montgomery County government.

3.3 Develop Analytical Framework

Throughout the project, it was our hope to create or utilize some sort of traffic analysis. This was

an objective in itself, as it would help us create much better solutions for the county. By being able to

test our solutions, it made us more confident in our recommendations. The analysis focused on boarding

times on select routes. Using the data we gathered from our study on fare payment methods we were

able to develop an analytical framework of Ride On operation. We were able to calculate the

quantitative time differences between bus routes with varying percentages of SmarTrip passengers.

With these data we were able to calculate different scenarios for the bus boarding times. By

demonstrating different scenarios, it allowed us to demonstrate the potential problems with boarding in

the future.

4. Results and Analysis

The goal of this research project was to optimize time performance for Montgomery County's bus system, Ride On. Upon completing field observations, we have learned that many factors contribute to this problem. Many of these factors are variable, such as accidents, loading times, encountering red lights or road repairs. We focused our project's results on boarding, traffic lights, and bus scheduling. We analyzed fare payment methods and their effect on loading time, traffic signal wait time, and traffic congestion's effects on schedule reliability. In the course of analyzing the data we collected, we discovered new results that did not match our project's focus. These unrelated results and data could benefit Montgomery County, so we have included Information on these results in Appendix G.

4.1 Payment Methods and SmarTrip

When we first began our project, we theorized that the method of fare payment was an important factor that contributes to bus running times. Our theory was shared by Tim McCormick, the Manager of the planning department at the Rhode Island Public Transportation Authority. After hearing about a small study he had performed on the subject, we were convinced that this would be one of the areas where improvements could be made in Montgomery County. By riding on a variety of bus routes in the Rockville and Silver Spring areas, we collected data on the time needed for paying with different fare media. The list of routes we observed can be seen in Table 4.1.

Table 4.1- List of routes ridden to collect payment type data

Route Number	Destination
55	Rockville-Germantown
47	Rockville-Montgomery Mall-Bethesda
46	Rockville-Medical Metro Station
20	Silver Spring-Hillandale
16	Takoma-Silver Spring

Payment Methods in the Ride On System

In the current Ride On bus system there are a variety of payment methods a passenger can use to ride the bus. Figure 4.1 displays the current payment breakdown for Ride On users. Transfer and cash payment users make up almost half of the total ridership, while one of the fastest methods of payment, SmarTrip, is used by only 14% of customers. Other payment methods make up the remaining 39% and include monthly passes, 20-trip tickets, Metrobus passes, Montgomery College ID's and a variety of others.
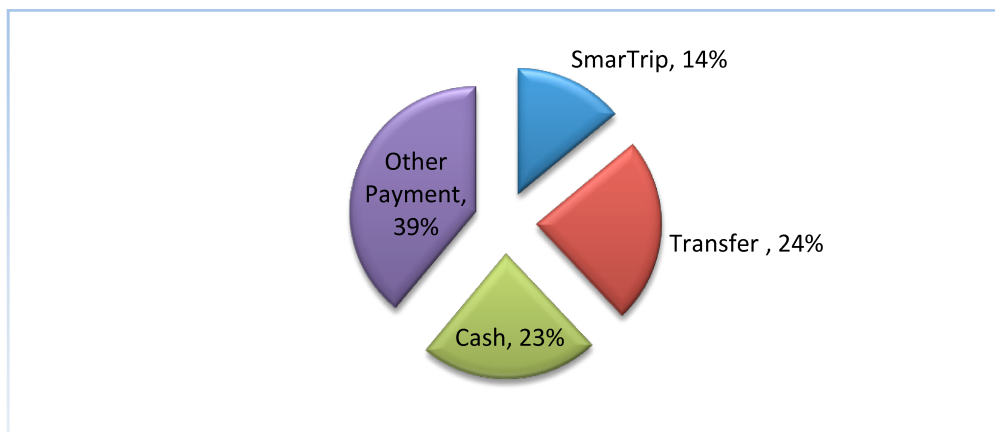
Figure 4.1- Current Ride On Ridership Breakdown

Future Ride On System with no Paper Transfers

The Washington, D.C, Metro system has decided to retire paper transfers. Ride On is planning to do the same in early 2009. This could cause problems for Ride On users as 24% use paper transfers. Retiring paper transfers means that transfer users will have to find another means of paying to ride the bus, whether this is cash, purchasing a monthly pass or a SmarTrip card. We project a good portion of these users will still pay with cash for multiple reasons. One reason is that some of these users may not be everyday commuters, so purchasing a SmarTrip card might not seem beneficial. Another reason is that paper transfers can result in fraudulent riders. Fraud methods include the use of expired transfers, users passing transfers on to other users and the theft of transfer rolls. Because of this fraudulent use of

transfers, a portion of Ride On riders should be considered illegitimate. Thus, some riders cannot or will not pay to legitimately ride the bus. Therefore, the belief that everyone will switch to SmarTrip once transfers are retired is an overly optimistic statement. Figure 4.2 displays the future payment breakdown assuming all paper transfers become cash payments.
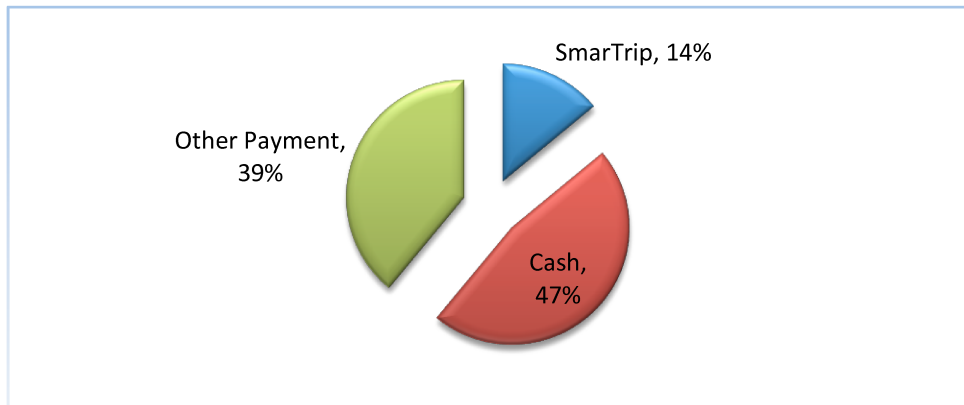
Figure 4.2- Future payment breakdown assuming all paper transfers become cash payments

Current System vs. Future System

From our data collection using the methods described in Section 3.1, we found that it takes a cash user an average of 9.3 seconds to pay his or her fare and board a bus. It only takes an average of 1.8 seconds for a SmarTrip, flash pass or transfer slip user. Specific metrics weren't gathered on the other types of payments, but they are comparable to a transfer slip or SmarTrip. The majority of them are considered flash passes; they only need visual confirmation and take the same amount of time to use as a transfer. These extra seven seconds to pay with cash may seem minimal but when accumulated over a whole day, it can add considerable length to the total bus run time. Table 4.2 shows the estimated amount of time busses on route 55 spend in the passenger loading stage. This table also shows the comparison of loading time in the current system with paper transfers to a system where there are no paper transfers. For a worst case analysis, we assumed that all paper transfers would become cash payments. Boarding times will increase by an estimated 158% if these former paper

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transfer users don't switch over to a non-cash payment method. Thus, it is important for Ride On to promote flash passes or SmarTrip cards.

Table 4.2- Loading Times- Paper vs. Non Paper

With Paper Transfers

% SmarTrip/transfer/other type	77%
% users using cash	23%
Estimated time spent loading bus throughout the day- min	486.4
Estimated time spent loading bus throughout the day-hours	4.4

Without Paper Transfers

% SmarTrip/transfer/other type	53%
% users using cash	47%
Estimated time spent loading bus throughout the day- min	721.8
Estimated time spent loading bus throughout the day-hours	6.4

The equation we used to determine bus loading time was the following:

$$T_L = p \cdot c \cdot T_c + p \cdot N_c \cdot T_n$$

Where parameters in the equation are defined as:
T_L: Time spent loading bus throughout the day
p: number of passengers
c: Percent of users using cash

T_c: Average loading time using cash

N_c: Percent of users using non-cash payment

T_n: Average loading time using non-cash fare

4.1.4 User Opinion of SmarTrip

To gather public opinion about the SmarTrip card, we distributed a questionnaire to the users of Ride On. We attempted to pass out an estimated 300 questionnaires, but only received 55 legitimate ones back. The voluntary survey's sample was not random but rather, it was opportunistic. The questionnaires were only handed out at a few locations. Therefore, we cannot claim the results as a true representation of all of Montgomery County. We kept this problem of survey validity in mind and only considered the results as a suggestion of how some of the riders feel about SmarTrip.

The results of these surveys were for the most part expected. There were a few categories, however, where the results were surprising to us. Despite the fact most Ride On passengers were found to be frequent users, only 77% of them were aware of SmarTrip. Nineteen percent of respondents claimed they did not know that SmarTrip existed, as seen in Figure 4.3. This is important because it means that there may be room for improvement with respect to SmarTrip awareness. The 18% of Ride On users who said they did not know that SmarTrip exists is a large group of people to target for future SmarTrip marketing campaigns.

Through discussions with our sponsors, we hypothesized that a part of the reason SmarTrip usage is low is because of a perceived customer inconvenience associated with purchasing and loading the card. Despite our hypothesis, the majority of bus users felt that obtaining and maintaining SmarTrip was convenient. As shown in Figure 4.4, about 30% of respondents noted an inconvenience about SmarTrip. This is a sizable population to think a service is inconvenient. Despite the fact that most people have no inconvenience with the card, there should be more research done to find out where the inconveniences are for the minority of users.
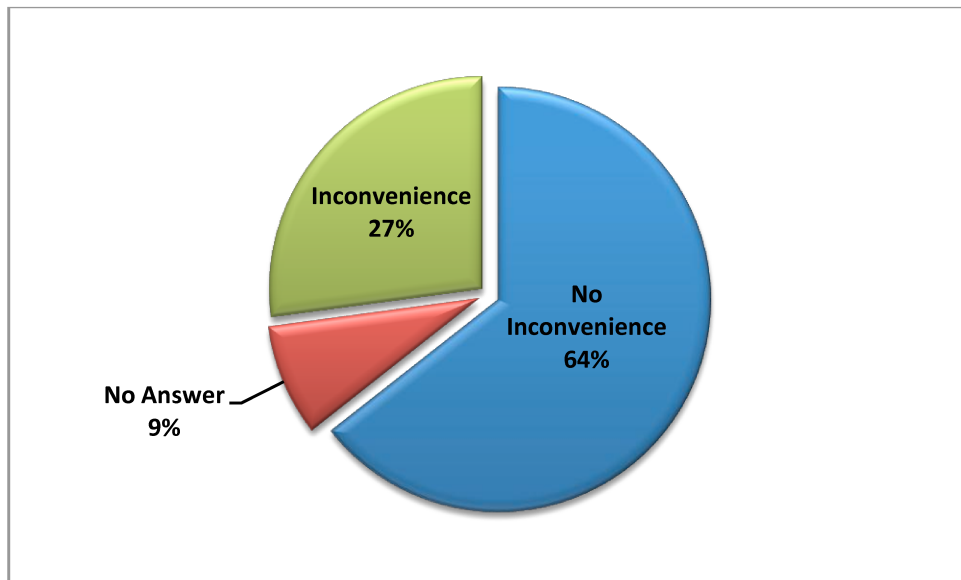
Figure 4.4 – Convenience of Purchasing/Loading SmarTrip Cards

One series of questions tried to gather what size, if any, a discount would need to be in order to entice users to obtain a SmarTrip card. We gave the option of 20, 30, 40 or 50 cent discount per trip. We did not ask about a 10 cent discount because there is already one that exists. We expected almost all of the responses to call for a 50 cent discount. While most of them did, the second-most popular choice was a 20 cent discount. Figure 4.5 shows the distribution of the discount choices of the respondents. Of the 55 respondents, 32 said they did not have a SmarTrip card. Eighty-seven percent of those would be more inclined to purchase a SmarTrip card if there were a greater discount offered to card users. This is

a large group of people who could potentially be converted to SmarTrip users. If these people bought

and used the SmarTrip card, boarding time on the busses would be reduced, therefore reducing bus

runtime.
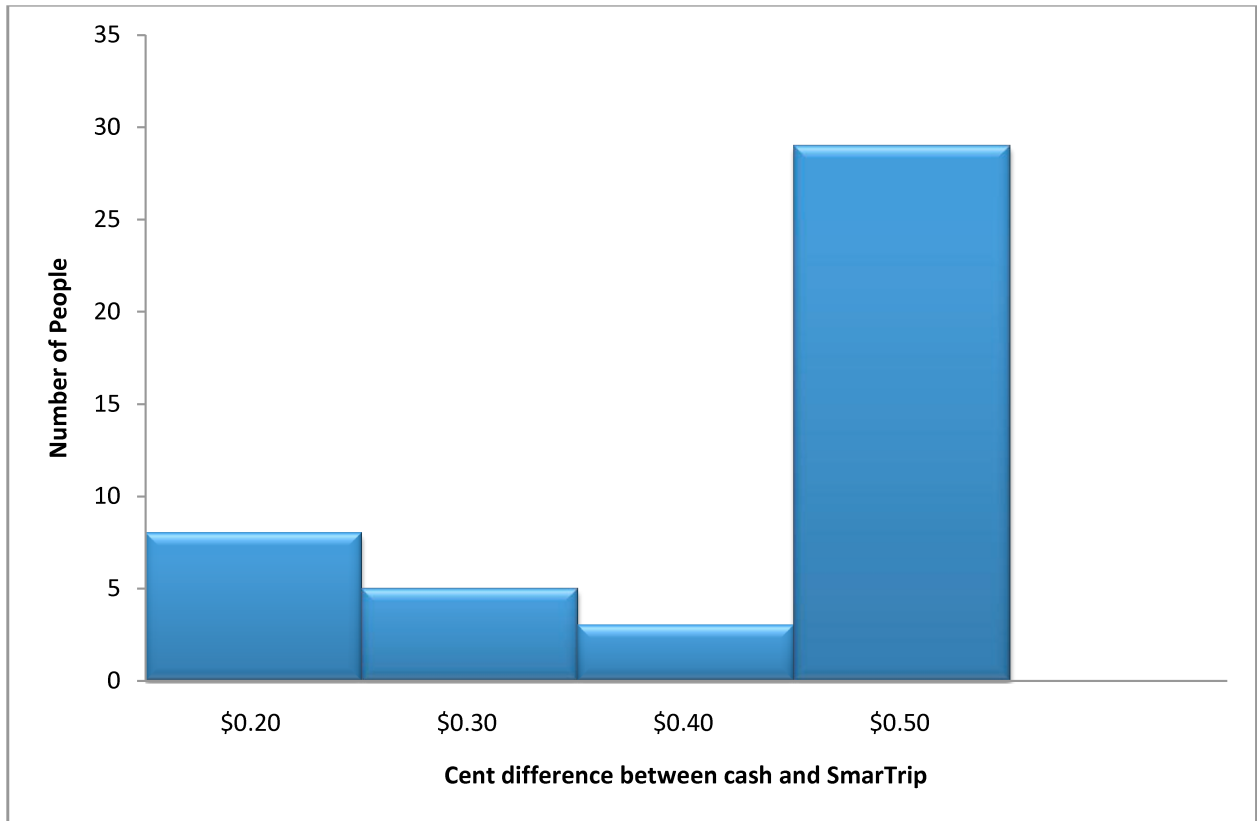
Figure 4.5 – Price Choices for Ride On Customers

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4.2 Analysis of Traffic Signal Delay

Our initial assessment of traffic signal delay and its impact on transit travel times consisted of taking field measurements. We collected data throughout our eight week stay about traffic signal delay along two major traffic corridors in Montgomery County: Rockville Pike and New Hampshire Avenue. After analyzing the initial data on these two corridors we found that Rockville Pike was a better candidate for a transit signal prioritization (TSP) system. The corridor of Rockville Pike was determined to be a better candidate for TSP because of the number of Metro stations and the number of routes operating along the corridor. We gathered our data on the segment of Rockville Pike from the Medical Metro Center up to Lake Forest Transit Center. Six Metro stations are located along this corridor with a total of 48 Ride On routes entering or exiting the Metro stations. Figure 4.6 highlights both routes 46 and 55. Route 46 is highlighted in the dark blue, while route 55 is highlighted in light blue. We collected our traffic signal data on the section of Rockville Pike from Medical Center Metro Station to Lakeforest Transit Center.

Figure 4.6- Rockville Pike- Medical Center Metro Station to Lakeforest Transit Center

Traffic Signal Delay along Rockville Pike

The data collected along Rockville Pike was only taken when the bus was stopped at red lights
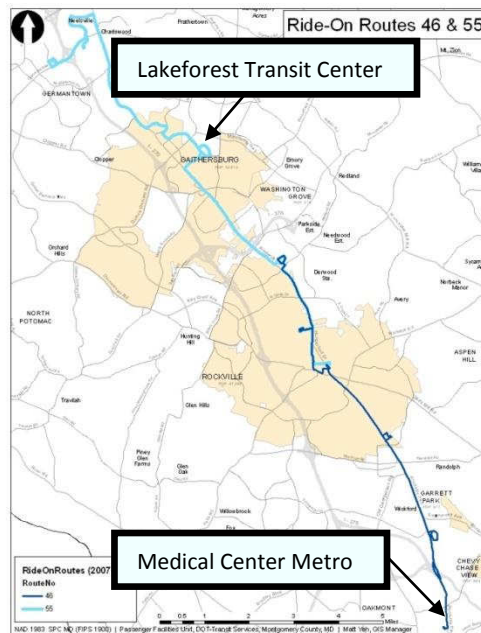
on Rockville Pike. Figures 4.7 and 4.8 compare the red light time spent to the other stages of the bus

route along Rockville Pike. A TSP system would only be implemented along a major corridor with heavy

transit movement. Thus, we felt it was important to capture the specific corridor-based data, not route-

based data. Comparisons exist for both peak and non-peak hours.

Time in other Stages, 80%

Time at Red, 20%

Figure 4.7- Time at Red lights vs. Other Stages: Non-Peak

Shown in Figure 4.7 is the time stopped at red lights compared to the time it spent in other

stages during non-peak hours. We observed routes 46 and 55 ten times during both AM and PM non-

peak hours. During these hours busses spent an average of 21% of their route stopped at red lights. We

found that there was a significant correlation between wait time at traffic signals and bus route

unreliability. If a bus spent more than 20% of the time at red lights it was an average of nearly nine

minutes late on the whole route. Consequently, when a bus spent less than 20% of the time at red lights

it was usually on time. Route 46 spent considerably more time at red lights than route 55.This can be

attributed to route 46 passing through nine more traffic signals and stopping at three extra Metro

stations than route 55. At the five Metro stops located from Rockville to Medical Center, the bus took

an average of 6 minutes to stop at a red light waiting for a left turn signal; this was on average 15% of
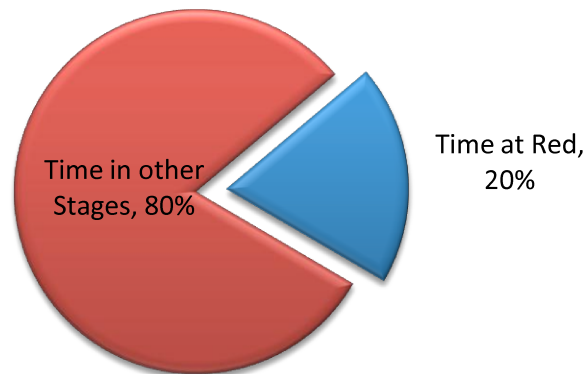
the total time.
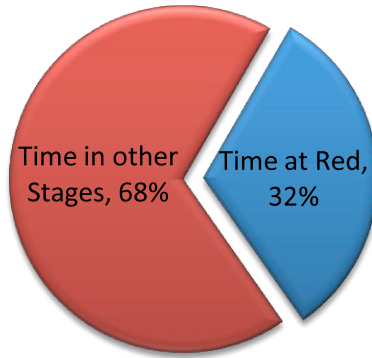
Figure 4.8- Time at Red lights vs. Other Stages: Peak

Shown in Figure 4.8 is the time stopped at red lights compared to time in other stages during

peak hours. The average time spent at red lights was considerably more than during non-peak hours. On

average, a Ride On bus spent 32% of its time sitting at a traffic light while traveling along Rockville Pike.

This is 10% more than during non-peak hours and was expected as there are more cars traveling during

peak hours when congestion is at its worst. Similar to non-peak hours, in peak hours we saw the

correlation of time spent at red lights to schedule adherence. When a bus spent more than 30% of the

time at red lights, it was an average of more than six minutes late on the whole route.

While observing Rockville Pike, a notable bus disadvantage that was magnified was its

maneuverability. A bus consumes significant time slowing down and accelerating at traffic signals. Buses

also have trouble at yielding left-hand turns. At many yielding left-hand turns the bus would have to

wait for the left turn green signal before it could proceed. As a result, a considerable amount of time

was spent waiting for the left turn signals. This is an area for major improvement for Montgomery

County. If these intersections were installed with TSP, it would recognize a bus waiting and grant priority for a left turn green signal.

A noteworthy intersection where we saw considerable delays was the Medical Center Metro station. During peak hours buses spent an average of nearly two minutes waiting for the left turn signal. These data were collected on busses exiting the Medical Center and busses traveling Northbound attempting to enter the station. A birds-eye view of this intersection is displayed in Figure 4.9. The orange arrows in this picture show the routes where buses see considerable delay waiting for a left green signal. It can also be seen in this picture that the avenue entering the station is extremely narrow. In fact, a bus needing to turn right does not have enough room to get by if there is a bus waiting for a left green signal. A TSP implementation at this intersection would also have to result in a widening of the street to create better traffic flow. We found widening the street would allow more than two buses to exit the station at once and would result in smoother traffic flow exiting the intersection. This is a common theme with TSP implementation, things such as widening streets and relocation of bus stops would have to be researched and executed concurrent with TSP implementation.
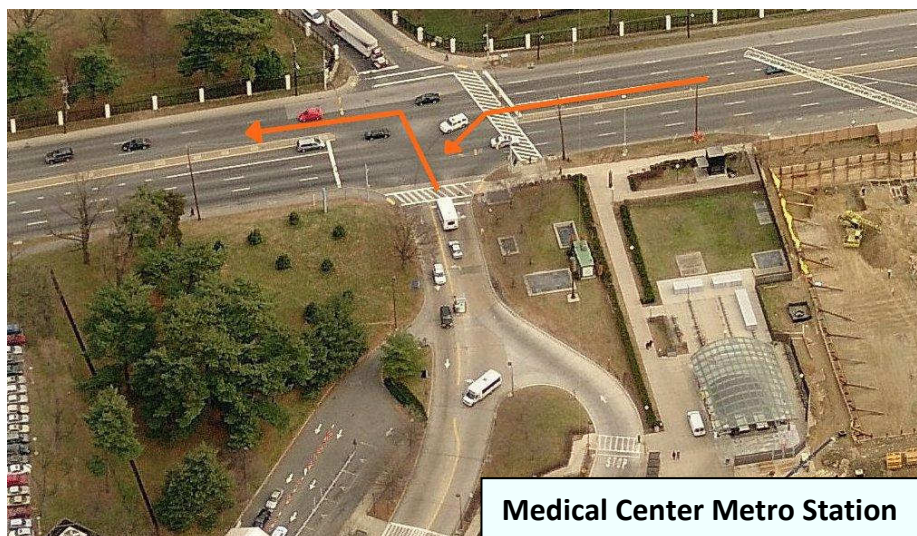

Medical Center Metro Station

Figure 4.9-Medical Center Metro Station Intersection

Effects of Traffic Signal Prioritization

Upon learning there was a relationship between traffic signals and bus unreliability the next step in our research was to look at the cost and potential benefits of TSP. From talking with county officials we learned Ride On is set up similarly to Chicago's bus system, PACE and the MTA in Los Angeles, CA (Smith, Hemily, and Ivanovic, 2005). Both transit authorities have implemented TSP systems and both have observed benefits.

In Chicago, 15 intersections were equipped with TSP along Cermak Road, a major traffic corridor within Chicago (Smith, Hemily, and Ivanovic, 2005). Cermak Road is a high volume traffic corridor very similar to Rockville Pike in Montgomery County. The total cost of the implementation was $732,000. Included in this cost was the removal of existing conduit cable and replacement with fiber optic cable, replacement of all controllers and cabinets and installation of advance detector loops and check out loops. The Department of Transportation in Montgomery County is currently implementing an Advanced Transportation Management System. This project includes updating all central traffic software, replacing all copper wire with fiber optic cable and installing new controllers and cabinets at traffic signals. By already heading in the direction of upgrading its infrastructure, Montgomery County is dramatically decreasing the potential cost of TSP. Implementing TSP with compatible software and hardware already installed drops the cost of implementing to $5,000 to $20,000 per traffic light. The costs vary depending on the type of detection software used.

Both Chicago and Los Angeles' transit authorities saw an average time savings of 17% on routes implemented with TSP (Smith, Hemily, and Ivanovic, 2005). In addition to time savings, both agencies observed increased ridership throughout their respective regions. The detection technology used in both Chicago and LA is out of date; there is more sophisticated detection software available now that has been proven to show even better results and is more reliable. Agencies that use the more

sophisticated new software have seen greater route time savings, time saving ranging from 20%- 30% (Smith, Hemily, and Ivanovic, 2005).

There are 29 intersections along Rockville Pike from Medical Metro Station to Lake Forest Transit Center that could be considered as candidates for a TSP implementation. Of these 29 intersections, five are excellent candidates. These five are excellent candidates because of the high volume of routes passing through them each day. Table 4.3 lists these intersections and the number of routes passing through.

Table 4.3- Excellent TSP Candidates

Name of Intersection	Number of Routes
King Farm Rd - Rockville Pike	8
Redland Rd- Rockville Pike	8
High St- Rockville Pike	7
Park Rd- Rockville Pike	6
Med Center- Rockville Pike	6

Some traffic engineers have a priority for single occupancy vehicles and believe granting priority to busses has a negative effect on street networks. If enough research is done and if the proper preparatory steps are taken, TSP is a very viable solution to public transit time performance issues. There have been cases in numerous cities where TSP implementation has worked with minimal effects on the street network. Appendix H shows other transit agencies' implementations and their findings on the benefits of TSP and its impact on personal vehicles. There has been and continues to be a lot of research going into transit signal prioritization, and we have no doubt that TSP is the wave of the future for public transit.

4.3 Scheduling Systems

A successful bus network requires a quality scheduling system. The scheduling of a bus system affects both customers and county officials. Customers interface with the bus system through the schedule; riders base their day around it. A bus system that does not take riders when they want to go is underperforming just as much as a system that does not take riders where they want to go. County officials depend on the schedule to allocate resources properly. Ride On only has a finite number of busses and operators; they need to be allocated properly in order to create the best system possible.

4.3.1 Current Scheduling System: Static Interlining

Montgomery County uses an innovative technique for scheduling known as interlining. A bus has two forms of identification, a physical bus number, and a virtual route number. Interlining calls for the route identification to change as a bus completes a route. By allowing the bus to transition between different routes throughout its run, the Montgomery County Ride On system is more robust. Interlining has an operations level effect and does not directly affect customers. In static interlining, the schedule set by county officials determines the route transitions for different busses. Further background information on interlining can be found in Section 2.1.

Disadvantages of Static Interlining

A recurring theme we found from our data was variability. When observing bus routes we recognized there was no regularity to delays. While specific routes could be identified as problem routes as described in Section 3.1, there was no guarantee a route would always be late. Furthermore, scheduled events at schools, college class variations, and other inevitable events vary traffic patterns day-to-day during the week. Being able to handle this variability would be a major improvement for public transit. It is difficult for static scheduling to accommodate these types of variations.

Because of the variation of weekday traffic flow, we hypothesized that for every bus that runs very late, there is a bus running either not as late, on time, or even early. This was largely confirmed by

the County's on-time performance data. Unfortunately the on-time performance data represents only a subset of the total data. Thus, analysis can only be done on this snapshot. The data showed it was clear there was irregularity in bus arrival times. For instance, one example shows that at Grosvenor Metro Station a bus arriving late is paired with another bus arriving early. In one extreme case, a bus was so late it arrived only one minute ahead of the next bus running that route. Because the data are only a snapshot, it is impossible to see exactly what happened immediately after this incident. However, from our focus group with bus operators we learned that in these situations operators are supposed to follow their routes. That is, the busses continued to run too closely together with no schedule adjustment. This means the resource misallocation stayed in the system throughout the rest of the day. Static bus schedules have the weakness that regardless of the actual bus runtimes, busses need to stay running as scheduled.

Misallocated resources cost the Ride On significant amount of money. We discovered from personal dialog with county officials, the capital cost of a bus was discovered to vary from 325,000 to 500,000 dollars. More important than the capital cost is the usage cost. Because of maintenance issues, Ride On currently faces a bus shortage. Due to labor restrictions, busses are only able to be serviced during normal business hours, when they are supposed to be in service. When busses begin to break down, a bus shortage occurs. If an unneeded bus were to be freed up from a route, it could be used elsewhere more effectively.
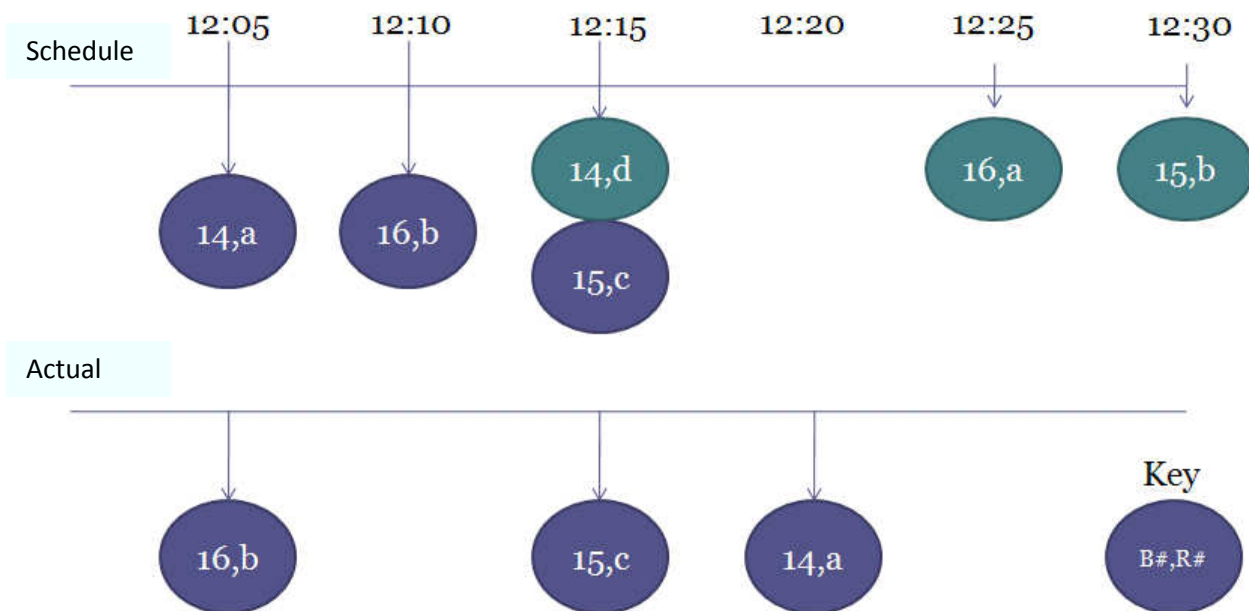
Figure 4.10 Diagram of a simplified static interlined schedule. Numbers represent bus numbers (B#), where as letters represent route numbers (R#). The purple ovals represent bus arrivals; the teal ovals represent bus departures. Actual departures are not shown because it is superfluous information.

Figure 4.10 shows a simplified version of busses' arrivals and departures. In this case, bus 14 arrives critically late, which causes it to start its next route, route d, late. This late arrival/departure pair causes bus 14 to be late for the rest of the day, or until it can catch up. Because the static schedule doesn't change frequently, situations like this may occur regularly until the schedules are updated. While this is a simplified example, it shows the inefficiencies with a static bus scheduling system.

In the static Ride On schedule the scheduled departures are based on the scheduled arrivals. From our focus group and personal communication with county officials we learned about the layover time associated with each route. There is a scheduled layover time after each route; the driver expects this time to be for him or her to recover. After each route the driver expects a minimum of 10% of the route time to prepare for the next route. If a bus arrives early, it takes a longer layover before departing on the next route. However, if the bus arrives late, there is no recourse; the bus starts its next route late. Operators are expected to give up part or all of their layovers if the bus is running late.

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Quality schedules that meet both customer and operational demands are essential for a successful bus system. From analysis of the current system, we gathered that overly relying on static scheduling is a weakness for Ride On. Static schedules can not account for seemingly random variations in traffic patterns. To increase the effectiveness of Ride On schedules, a non-static bus scheduling system needs be investigated.

4.3.2 A Scheduling Alternative: Dynamic Scheduling

Dynamic scheduling calls for the departures to be based on the actual bus arrival times, rather than predicted values in static scheduling. The priority for the scheduling becomes getting the next route started as close to on time as possible. By focusing on the actual bus arrival time this scheduling paradigm attempts to overcome the random variations in traffic flow. Static Interlining already allows a bus to change route identification throughout its run; dynamic interlined scheduling simply changes how a bus changes its identification. By using recent innovations in computer networking to its advantage, dynamic scheduling is a unique solution to scheduling that addresses variable traffic patterns. If a bus is late because of heavy traffic, its next route won't be severely affected as another bus would cover that route.

Dynamic scheduling would only differ from the static scheduling when something drastic occurs to the transit network. If all goes according to plan, dynamic scheduling decisions wouldn't differ from the preset static schedule. The benefits of dynamic scheduling come into play when the static schedule can not longer be met. Traffic patterns vary on a day-to-day basis; dynamic scheduling would allow the schedules to adjust to the swings in traffic flow. Similar to an emergency auto-pilot on an aircraft or a backup parachute to a skydiver, dynamic scheduling would be a safety net for Montgomery County's Ride On.

Advantages of Dynamic Scheduling
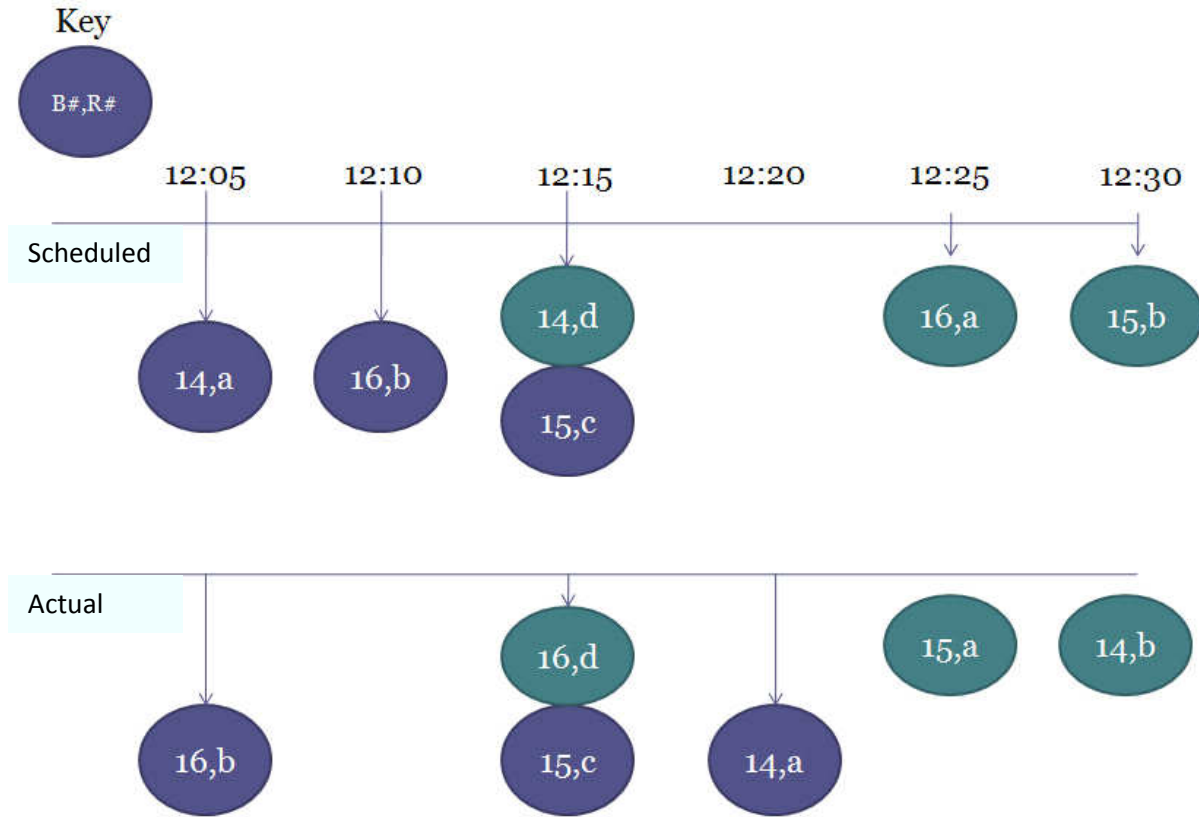
Combining dynamic scheduling with the concept of interlining would create a powerful tool for Ride On. Figure 4.11 shows the same situation described in Section 4.3.2. Bus 14 arrives late, yet route d leaves as scheduled. This demonstrates the emphasis on actual bus arrival times. The busses arrive in the same order they leave. In this example each layover is normalized to 10 minutes. Each route, a, b and d, leave as scheduled. The customer has no knowledge anything occurred, as customers have no knowledge or concern for the physical bus numbers. From an operations standpoint, all the resources are being used effectively, and routes remain on time.
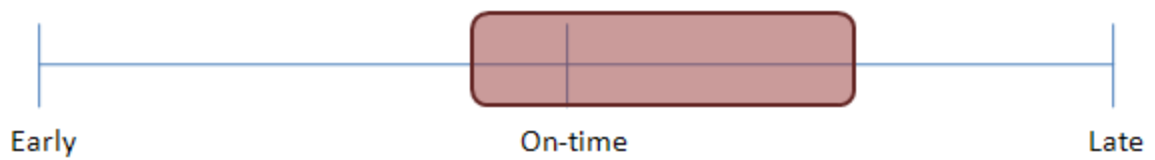
Figure 4.12 Window of "On-time" tolerance

According to the County, a bus is on time if it is inside a certain window of tolerance of the schedule. Specifically, this is one minute early and no more than 5 minutes late. A graphical representation of this window of tolerance is shown in Figure 4.12. Dynamic scheduling normalizes bus tardiness into this window. Busses running excessively late would get covered by busses running on time or early. Layover times would normalize because late busses would gain layover time and early busses would lose layover time. Operators that lose layover time may resent dynamic scheduling; however operators that gain layover time will appreciate it. Ultimately, having a more consistent, dependable layover time is a value to operators. While the next route may not always start exactly on time, analysis predicts more busses would be able to leave within the window of being on time. Overall, dynamic scheduling would allow Ride On to have better schedule coherence.

Design of a Dynamic Interlining Scheduler

The engineering effort behind implementing a dynamic scheduler would be a moderate investment for the County government. A definitive requirement for a dynamic scheduler is the construction of a bus network. Another important aspect is the algorithm used for dynamic scheduling. These requirements are linked as depending on the data required for the algorithm, requirements for the network change.

Scheduling Algorithms

The dynamic scheduler needs an algorithm to determine how to schedule routes. By default the scheduler would follow the static schedule unless a bus started to run very late. The system could use a

scheduling algorithm as simple as a first-in, first-out stack to a complex location based system. This problem is analogous to computer process scheduling; depending on the requirements of the target system there is no right or wrong answer.

The simplest algorithm, first-in, first-out (FIFO), was used in the example in Section 4.3.4. In this algorithm, all that is considered is the arrival time of the bus. No consideration to the location of another bus is considered. This algorithm is simple, and the requirements for data collection and network resources are minimal. There is no mechanism using FIFO to determine how late another bus may be. This knowledge is important when considering whether the dynamic scheduler should override the static schedule. FIFO is simple to implement, but simplicity is not necessarily versatility.

Another algorithm is based on bus location. If the algorithm took the location of a bus into consideration, the scheduler could preemptively decide that the next route of the bus will start late and needs to be covered. This algorithm would require more data than the FIFO model. Thus, it requires more advanced networking than FIFO. This algorithm could run in tandem with FIFO; the location-based algorithm could trigger the system to start using FIFO dynamic scheduling.

The scheduling algorithm would contain advanced software written to dynamically manage Ride On resources including busses and operators. Many use cases and conditions need to be considered in constructing this software package. For instance, if an operator is only scheduled to work for another half hour, the system can not schedule him to work another hour. Writing the scheduling algorithm to take account of human factors is important to be a realistic solution.

While we have looked into various scheduling algorithms, there is more work to be done in the field of dynamic scheduling. While both location and FIFO-based algorithms have their strengths, a hybrid solution should not be overlooked. Finding the best algorithm for dynamic scheduling would allow it to vastly increase the consistency of Ride On runtimes.

Bus Network Design

Depending on the scheduling algorithm chosen, network requirements vary. Simple algorithms require a simple network, whereas complex algorithms require a more versatile network. There are different models for a network depending on these requirements. Ideally, a cost effective solution could be used to allow the county to implement dynamic scheduling at an acceptable price point. A bus network would be a powerful utility for Montgomery County with many potential uses. Besides dynamic scheduling, the county could implement other services that require communication. These services are described in Appendix I.
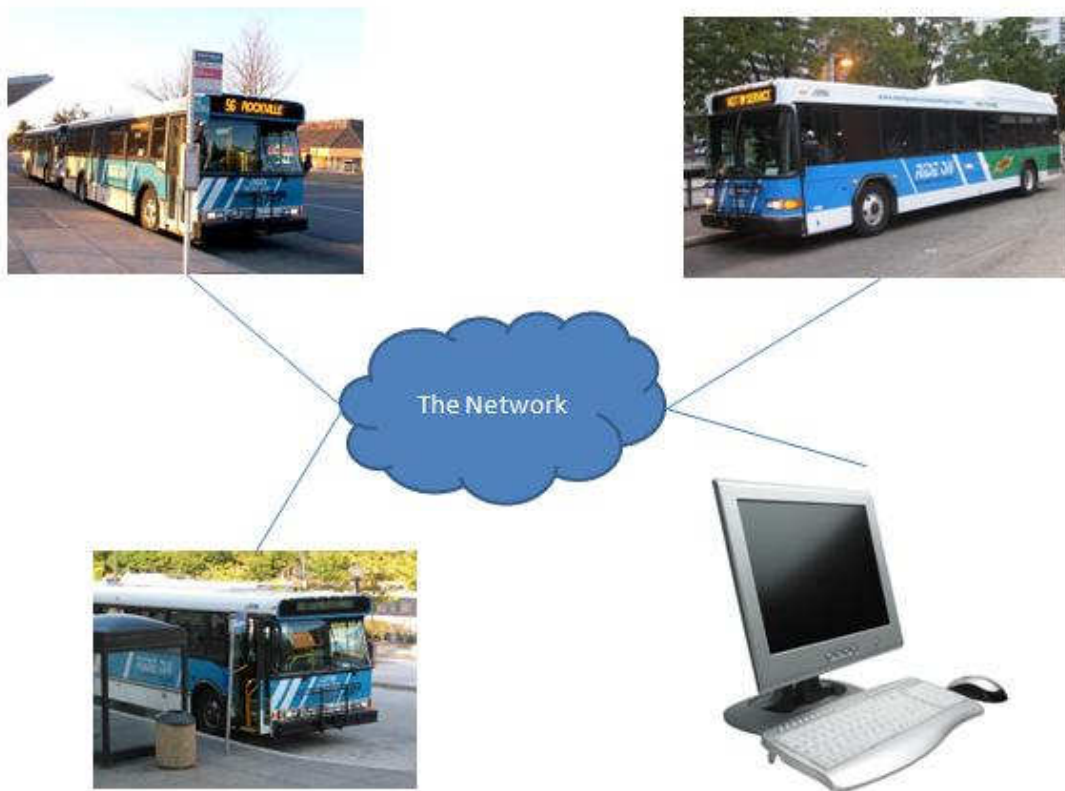

Figure 4.13 Bus Network Diagram

Figure 4.13 shows a theoretical representation of a bus network. The network would be the transport layer connecting all the busses and a scheduling server. Bandwidth requirements of the network are minimal, despite the low latency requirements. The network would use standard TCP/IP

communication to communicate scheduling data. This is the standard protocol for the kind of network needed for dynamic scheduling. Each bus would be represented by an IP address on the network, similar to how each computer has an IP address on a LAN. A global server would keep track of the status of each bus and be responsible for executing the scheduling algorithm.

Ideally, the server would be able to query each bus about its status in real-time, be able to make decisions based on that data, and send out route roles to busses. This kind of network could be created based off a cellular network. This network would be expensive as it would require a contract with a cellular provider to provide network access for each bus in the system.

If a real-time bus network was not possible to implement, an alternative could be devised using existing traffic network. Montgomery County is currently upgrading its traffic signal network to a fiber-optic network. This network uses TCP/IP communication and would be compatible with the bus network (Bill Corder, personal communication, 12/8/2008). Thus, the bus network could piggy-back off the traffic signal network. Wi-Fi hotspots could be created at key traffic signals, allowing a bus network to have a handshake connection as it passes through. During this handshake process, the scheduling server would get updated on that route's performance data. At this time, the server could also send data back to the bus. This would allow the scheduler to make a scheduling decision and relay that decision as the bus reaches its final destination.

If a location-based algorithm was chosen, each bus would need a device to interface the existing vehicle location system with the bus network. Currently Ride On busses have a vehicle location system, but the data can only be retrieved at the end of the day, not on-demand. The software on the bus could be written to interface the vehicle locator to the network accessible to the scheduling server. The bus software would also interface with the operator notification console. Upon arriving at the station the notification console would be used to inform the operator about his or her next assigned route. Ideally the software should be as lightweight as possible to minimize hardware requirements for the bus.

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Dynamic Scheduling Sequence

The dynamic interlining scheduler follows a predictable sequence to accomplish its scheduling goals. First, a bus notifies the scheduler to its imminent arrival on its final stop in the form of a schedule request. The scheduler gets this request and computes the best route for that bus to take. It considers the amount of time left in the operators shift. It has a preference for making the next route leave on time, but considers that operators need layover time. As described previously in Section 4.3.6, it could query the location of other busses in order to make a more in-depth analysis before making a scheduling decision. After computing the optimal scheduling decision, it sends a response to the schedule request. The response is relayed to the operator by way of the notification console on the bus. The notification console would output both the route number and time of departure to the operator. The time of departure is important, because the route may not always be able to leave exactly on time.

Further Research

Dynamic scheduling is an exciting opportunity for Montgomery County. Dynamic scheduling is a new philosophy for transit scheduling; therefore there is plenty of additional research to be done. Dynamic scheduling would affect a bus operator's day. While it is our hope operators would appreciate consistent layover times, they may be disconcerted by the fluid nature of dynamic scheduling. While still covering the same shifts, the routes being covered could vary day-to-day for operators. The County would need to investigate how the operators' union would react to this plan.

4.4 Summary

Our project successfully broke down a bus route into addressable issues of bus boarding, traffic signal wait time, and scheduling. We collected a fair amount of data on the metrics of bus boarding time and traffic signal wait time, while also delving into the human factor through a survey. We also developed a detailed analysis of our innovative idea of dynamic scheduling. These results and subsequent analysis allowed us to create our recommendations for Montgomery County.

5. Conclusions & Recommendations

There is no magic bullet to solving traffic problems. The only way to increase performance in congested areas is to implement a comprehensive set of improvements to the system. Making enhancements across the system will increase time performance and schedule adherence. By implementing these recommendations customer satisfaction will increase in addition to putting Montgomery County on the forefront of new transit technologies.

Fare Payments

Currently, a small percentage of Ride On passengers use the SmarTrip system. Because paper transfers are being phased out on regional transit systems, including Ride On, county officials should take active measures to increase SmarTrip usage. We have found riders would be more interested in using SmarTrip if there was a larger SmarTrip discount. Thus, we recommend fares should be adjusted to entice users to obtain SmarTrip cards.

Transit Signal Priority

Transit Signal Prioritization (TSP) has been known to have positive effect on transit systems. Chicago and Los Angeles, as well as other transit authorities have seen benefits with TSP as well as having low impact on non-priority street traffic. Our results showed in Montgomery County there is a relationship between traffic signal delay and schedule adherence. Poor schedule reliability is poor customer service. In order to address the problem, we recommend that Montgomery County perform deeper research into Transit Signal Prioritization, specifically looking at implementing TSP at 29 intersections along Rockville Pike as a pilot program.

Scheduling System

Random traffic fluctuations negatively affect the Ride On bus system. Day-to-day variations in traffic patterns cannot be absorbed by the current static interlining system. Because of interlining, delays are cumulative throughout the day. By combining modern computer technology with the concept of interlining Montgomery County could pioneer a new way of thinking about bus scheduling. This scheduling innovation will absorb some of the day-to-day variances in traffic flow. Montgomery County should begin further research into implementing a Dynamic Interlining Scheduler like the one described in Section 4.3.

Conclusion

Together, these three recommendations will greatly enhance Montgomery County's Ride On bus system. These recommendations scale from now and into the future. SmarTrip usage needs to be increased, likely by increasing the SmarTrip discount, in order to maintain reliable boarding times as paper transfers are phased out. In the near future, in order to maintain schedule adherence along Rockville Pike, Montgomery County should investigate and implement a pilot program of transit signal prioritization. Lastly, in the further future, Montgomery County should investigate implementing new technologies to facilitate dynamic scheduling.

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Appendix A - Sponsor Description

Montgomery County is located north of Washington, D.C. and southwest of Baltimore

Maryland. Montgomery County has three major locations: Gaithersburg, Rockville and Silver

Spring. The county consists of 3 cities, 12 towns and 4 villages (Montgomery County Government,

2008). Most of the residents of Montgomery County live in unincorporated areas, the largest being

Silver Springs. Unincorporated areas have no form of local government so they are not recognized

by the federal government as unique, individual districts. As a result there are no definitive

boundaries of these areas so many of them overlap with one another in Virginia and Maryland.

The Division of Transit Services manages the transit system in Montgomery County

(Montgomery County, 2008). The Divisions goal is to "provide an effective mix of public

transportation services in Montgomery County", as stated in their mission statement on the county

website. The division of Transit Services is composed of four sections; three focused on the

operations of the Ride on system, and the fourth handling alternate transportation matters.

The division plans, schedules and manages the Ride On bus system that consists of 243 county-

owned that operate on over 80 routes (Montgomery County Government, 2008).

The Ride On system is highly integrated with other transit providers in the area, including

the WMTA (Washington Metropolitan Area Transit Authority) and the Maryland Mass Transit

system's MARC commuter rail and MTA commuter bus systems(Montgomery County Government,

2008).

Appendix B- MCG 10-Year Plan

MONTGOMERY COUNTY'S
10-YEAR TRANSPORTATION PLAN
A blueprint to make a difference now for Montgomery families...

Dear Neighbor,

Many issues have a great impact on the lives of residents in Montgomery County. However, the issue that affects most people on a daily basis is traffic congestion on our major arteries and in our local communities.

This brochure describes the projects, programs and policies that the Montgomery County Council hopes to implement as part of a 10-Year Plan already underway to address our transportation crisis. It is the largest transportation initiative adopted by a County in the Washington metropolitan region. This multi-billion-dollar plan is designed to address traffic congestion with new roads, road improvements, intersection upgrades, more buses and increased rail availability and improved pedestrian safety. Future decisions in land use also will impact the degree to which we are able to help ease congestion.

Many of the projects you will see listed elsewhere in this plan have already been completed or are underway. For example, we have already completed 17 of 20 planned intersection improvements and have finished six of eight planned parking garages and parking lots. We are adding new buses and bus routes, and we are committed to doing this through energy-efficient, lower emission vehicles that are better for our environment.

Upkeep of infrastructure is a topic on everyone's mind. Three years ago the Council began a major initiative to improve the maintenance of existing infrastructure. We can report that seven of 11 bridge replacements targeted in the original plan are already complete. We also have stepped up our annual effort to resurface roads, replace deteriorating sidewalks and curbs, prune street trees and upgrade streetlights.

The 10-Year Plan also calls for:
- Building 345 lane miles of additional roadway capacity
- Building 18 grade-separated interchanges
- Adding High Occupancy Vehicle (HOV) lanes on I-270 from the I-270 West Spur south to Virginia and on I-270 north from Shady Grove to Frederick County
- Adding express bus service
- Creating six new transit centers

The Montgomery County Council. Standing, from left to right: Marc Elrich, Valerie Ervin, Roger Berliner, Duchy Trachtenberg, Nancy Floreen and Mike Knapp. Seated, left to right: George Leventhal, Marilyn Praisner and Phil Andrews.

There are a number of major projects that are part of this plan. The new Montrose Parkway, which will soon be completed, will relieve congestion in the North Bethesda / South Rockville area. The proposed Purple Line of Metrorail would be a light rail service linking Bethesda and Silver Spring with Langley Park, the University of Maryland at College Park and the Amtrak Station at New Carrollton. The Corridor Cities Transitway would connect Clarksburg, Germantown and Gaithersburg to Shady Grove. The State's proposed construction of the Intercounty Connector is aimed at helping ease east-west congestion.

However, relief from traffic congestion does not come easily or cheaply. We need more County money, but we particularly need much more transportation investment in the County by the State. We will work closely with the County Executive to identify more local revenue and with Montgomery County's delegation to the General Assembly to generate more State funding for transportation. The Council also has established a working group to suggest additional options to help finance infrastructure improvements, including transportation.

There is no easy answer to our traffic congestion problem. We must expand mass transit, better manage transportation demand, build more and better roads, and re-examine land use policies. And we must do so while also protecting our environment.

Marilyn J. Praisner, President
Montgomery County Council
Fall 2007

MONTGOMERY COUNTY COUNCIL
100 Maryland Avenue, Rockville, Maryland 20850
Phone: (240) 777-7900
www.montgomerycountymd.gov/council

MAXIMIZING THE EFFICIENCY AND SAFETY OF THE ROAD NETWORK

Montgomery County's traffic management system is one of the most advanced of its type in the nation. The Advanced Transportation Management System of interconnected and centrally controlled traffic signals and traffic cameras has allowed the County to carry more traffic efficiently than comparable road networks elsewhere. We have established roving incident response teams that respond to calls from the Transportation Management Center to tow stalled vehicles from the roadway. Furthermore, a program is underway to replace Walk/Don't Walk lights at intersections with "count-down" signals that alert pedestrians precisely as to how many seconds they will have to cross an intersection safely.

MASTER PLANS

The County Council has given its approval to a landuse approach put forward by the County Planning Board that incrementally will amend master plans over time to locate more jobs and less additional housing in the eastern portion of the County and place more housing and fewer additional jobs in the I-270 corridor. In this way, more persons will have greater opportunities to live closer to where they work.

Projections show that these master plan changes, together with expanding transit service and promoting transit-oriented design practices, would reduce cross-County afternoon work trips by 18 percent and increase transit use by as much as 45 percent. These changes would increase jobs within a half-mile of rail stations from 40 percent in 1998 to 60 percent in 2050 and would increase housing within a half-mile of transit from 12 percent in 1998 to 33 percent in 2050.

BENEFITS FROM THE NEW COUNTY TRANSPORTATION PLAN

By building the projects identified in the 10-Year Plan, traffic congestion should be reduced and mobility should be improved by Year 2015.

Travel speeds will be higher and travel time will be lower. Travel times for certain trips would be dramatically better. Here are forecasted evening rush hour travel times in Year 2015 for selected trips:

	WITHOUT THE PLAN	UNDER THE PLAN
Bethesda - Silver Spring (by transit)	*33 minutes*	*17 minutes*
Bethesda - Germantown (by transit)	*79 minutes*	*51 minutes*
Silver Spring - Burtonsville (by transit)	*76 minutes*	*60 minutes*
Silver Spring - Olney (by car)	*45 minutes*	*39 minutes*
Burtonsville - Shady Grove West (by car)	*40 minutes*	*29 minutes*
Gaithersburg - Norbeck (by car)	*29 minutes*	*22 minutes*
Rockville - Clarksburg (by car)	*43 minutes*	*35 minutes*

Congestion should be less prominent. Without the plan, 39.6 percent of all rush hour traffic is projected to be traveling in congested conditions. Upon completion of the plan, 32.6 percent would be traveling in congestion. It is projected that 23.5 percent of all traffic lanes would be congested in Year 2015, but under the plan, only 19.1 percent would be congested.

Transit ridership is appending to increase. Under the plan, transit ridership is forecasted to increase by more than 75 percent in the rush hour, from nearly 34,000 to nearly 60,000. The share of rush hour trips by transit would increase from 15.2 percent to 17.4 percent.

OTHER WAYS TO GET THE COUNTY MOVING

Montgomery County's traffic congestion and mobility problems will only partly be solved by building new roads, transit lines, bikeways and sidewalks. Other supportive programs and policies in the 10-Year Plan are just as important in addressing these problems.

EXPANDED BUS AND METRORAIL SERVICE

Bus Service

The plan calls for the expansion of Metrobus and Ride On bus service by 50 percent in the next decade. There are three ways the bus service will expand:

- *More routes.* The County will add bus routes connecting various points in the Upcounty to the Downcounty and to Virginia via the continuous I-270 HOV lanes and their extension to Tysons Corner and Dulles Airport. Traveling on these separate lanes, buses will travel at the posted speed limit and not be slowed by congestion. Already, new local routes have been added in the areas of Gaithersburg, Germantown, Clarksburg and the Eastern County.
- *More frequent service.* Many bus routes run only every 30 minutes in the rush hours, leaving little schedule flexibility for potential riders. Within the next decade, bus service will run as frequently as every 15 minutes on many routes, and even as often as every 10 minutes on the routes with the heaviest ridership.
- *Earlier and later service.* Most routes start after 6 a.m. and run only until 10 p.m. on weekdays. Hours are more limited on weekends and holidays. Since the initiation of the plan, more routes now start before 6 a.m. and extend until at least 12 midnight on Monday-through-Thursday nights, and until the early morning hours on Friday and Saturday nights. Weekend hours also will be extended.

The County will also improve the bus service in the following ways:

- The most heavily patronized bus stops are receiving shelters outfitted with benches, lighting and, eventually, real-time schedule information that will display when the next buses will arrive.
- Many bus stops are being connected by sidewalks. Some bus stops are being moved to maximize pedestrian access and safety.
- Several intersections on Randolph Road, University Boulevard, U.S. Route 29 and Veirs Mill Road will be re-designed. Traffic signals will be installed and synchronized to allow buses on these highways to bypass points of congestion and speed up service.
- A discounted rate for two-week and 20-ride Ride On passes will be continued, and the County will press for the same discount for Metrobus service in Montgomery County as well. Seniors and disabled individuals now ride free on Ride On and Metrobus at all times, and kids ride free on any Ride On and Metrobus between 2 p.m. and 7 p.m. The County will continue to experiment with providing free and reduced-fare service on selected routes where traffic congestion is particularly acute.

Metrorail Service

The 10-Year Plan calls for expanding the number of cars in the Metrorail fleet to provide eight-car trains on the Red Line. The plan also calls for running all trains between Shady Grove and Glenmont through downtown Washington. Currently, only half the trains during rush hours operate over the entire line.

During the next decade, access to Metrorail stations could be greatly eased. Montgomery County will add more frequent bus service to the stations. The proposed Purple Line (at Bethesda and Silver Spring) and the Corridor Cities Transitway (at Shady Grove) would enhance connections to Metrorail. During the past few years a second parking garage at Shady Grove was opened and a garage at Grosvenor was built. Soon, a second garage at Glenmont will be under construction.

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NEW ROADS

✓**RD-1** **Bordly Drive - extend to Georgia Avenue**
RD-2 Burtonsville Access Road
RD-3 Century Boulevard / Crystal Rock Drive Loop
RD-4 Chapman Ave / Citadel Ave - Nicholson La to Randolph Rd
RD-5 Dorsey Mill Road - Century Blvd to Observation Drive
RD-6 Father Hurley Boulevard Extended over CSX RR
RD-7 Georgia Avenue (MD 97) Bypass around Brookeville
✓**RD-8** **Germantown Road - Scenery Drive to Watkins Mill Road**
RD-9 Intercounty Connector - I-370 to I-95
RD-10 Snowden Farm Parkway - Clarksburg Road to MD 355
RD-11 Snowden Farm Parkway - Ridge Road to Clarksburg Road
RD-12 Midcounty Highway - Middlebook Road to Ridge Road
RD-13 Montrose Parkway - I-270 to Veirs Mill Road
RD-14 Nebel Street Extended - Randolph Road to Bou Avenue
RD-15 Observation Drive - extend north to Stringtown Road
RD-16 Rainbow Drive - extend to Thompson Road
RD-17 Silver Spring CBD Ripley District - local street network
✓**RD-18** **Stringtown Road - I-270 to MD 355**
✓**RD-19** **Valley Park Drive - extend to Ridge Road**
RD-20 Watkins Mill Road Ext. - MD 355 to Clopper Road
RD-21 Midcounty Highway - ICC to Shady Grove Road
RD-22 Woodfield Road Extended - MD 108 to MD 27

ROAD WIDENINGS

✓**WI-1** **Briggs Chaney Road - Castle Blvd to Dogwood Drive**
WI-2 Clopper Road (MD 117) - Little Seneca Park to MD 118
WI-3 Clopper Road (MD 117) - west of Quince Orchard Road
✓**WI-4** **Darnestown Road (MD 28) - Gt. Sen. Hwy to Riffle Ford Rd**
WI-5 Frederick Road (MD 355) - Ridge Road to near Comus Rd
WI-6 Goshen Road - Gaithersburg City Limits to Warfield Road
WI-7 Great Seneca Hwy (MD 119) - MD 28 to Middlebrook Road
WI-8 Greencastle Road - Robey Road to Prince George's County
WI-9 I-270 HOV Lanes - Gaithersburg to Frederick County
WI-10 I-495 HOV Lanes - I-270 West Spur to Virginia
WI-11 Layhill Road (MD 182) - Longmead to Norbeck Road
WI-12 Longdraft Road - Clopper Road to Quince Orchard Road
WI-13 Middlebrook Road - MD 355 to Midcounty Highway
WI-14 Norbeck & Spencerville Roads - Georgia Ave to Burtonsville
WI-15 Redland Road - Crabbs Branch Way to Needwood Road
✓**WI-16** **Shady Grove Road - Briardale Rd to Muncaster Mill Road**
WI-17 Snouffer School Road - Centerway Road to Woodfield Road
WI-18 Veirs Mill Road (MD 586) - Randolph Rd to Twinbrook Pkwy
WI-19 Woodfield Road (MD 124) - Midcounty Hwy to Warfield Rd

BRIDGE REPLACEMENTS

✓**BR-1** **Clarksburg Road**
BR-2 Deer Park Drive
✓**BR-3** **Goshen Road**
✓**BR-4** **Howard Chapel Road**
BR-5 Mouth Of Monocacy Road
✓**BR-6** **Rock Creek Trestle**
✓**BR-7** **Wayne Avenue**
✓**BR-8** **Brink Road**
✓**BR-9** **Inwood Avenue**
BR-10 Nicholson Lane
BR-11 White Ground Road

✓Note: Completed projects in bold

GRADE SEPARATED INTERCHANGE IMPROVEMENTS

✓**GS-1** **Columbia Pike (US 29) / Briggs Chaney Road**
GS-2 Columbia Pike (US 29) / Fairland Road
✓**GS-3** **Columbia Pike (US 29) / East Randolph Road**
✓**GS-4** **Columbia Pike (US 29) /Sandy Spring Road (MD 198)**
GS-5 Frederick Road (MD 355) / Gude Drive
GS-6 Georgia Avenue (MD 97) / Norbeck Road (MD 28)
GS-7 Georgia Avenue (MD 97) / Randolph Road
GS-8 Great Seneca Highway (MD 119) / Sam Eig Highway
GS-9 Hungerford Drive (MD 355) / Middle Lane
GS-10 Rockvillle Pike (MD 355) / Veirs Mill Road (MD 28)
✓**GS-11** **I-270 / Clopper Road (MD 117)**
✓**GS-12** **I-270 / Democracy Boulevard**
✓**GS-13** **I-270 / Fernwood Road**
✓**GS-14** **I-270 / Old Georgetown Road (MD 187) / Rockledge Drive**
GS-15 I-270 / Watkins Mill Road
GS-16 Norbeck Road (MD 28) / Veirs Mill Road (MD 586)
GS-17 Rockville Pike (MD 355) / Montrose Road / Montrose Pkwy
GS-18 Rockville Pike (MD 355) / Nicholson Lane

INTERSECTION IMPROVEMENTS

✓**IN-1** **Clopper Rd (MD 117) / Quince Orchard Road (MD 124)**
IN-2 Colesville Road (US 29) / Dale Drive
✓**IN-3** **Connecticut Ave (MD 185) / East / West Hwy (MD 410)**
✓**IN-4** **Connecticut Ave (MD 185) / Veirs Mill Road (MD 586)**
✓**IN-5** **Falls Road (MD 189) / River Road (MD 190)**
✓**IN-6** **East West Highway (MD 410) / 16th Street (MD 390)**
✓**IN-7** **Frederick Road (MD 355) / Shady Grove Road**
✓**IN-8** **Great Seneca Hwy (MD 119) / Muddy Branch Road**
✓**IN-9** **Montgomery Village Avenue (MD 124) / Lost Knife Road**
✓**IN-10** **Montgomery Village Avenue (MD 124) / Midcounty Hwy**
✓**IN-11** **Montrose Road / East Jefferson Street**
✓**IN-12** **New Hampshire Avenue (MD 650) / FDA**
✓**IN-13** **Old Georgetown Road (MD 187) / Democracy Blvd**
✓**IN-14** **Old Georgetown Road (MD 187) / Tuckerman Lane**
IN-15 Randolph Road / Parklawn Drive
✓**IN-16** **Rockville Pike (MD 355) / Jones Bridge Road**
✓**IN-17** **Shady Grove Road / Gaither Road**
✓**IN-18** **Veirs Mill Road (MD 586) / Aspen Hill Road**
✓**IN-19** **Veirs Mill Road (MD 586) / Randolph Road**
IN-20 Veirs Mill Road (MD 586) / Twinbrook Parkway

BIKE PATHS

BK-1 Capital Crescent Trail - Bethesda to Silver Spring
✓**BK-2** **Falls Road Bike Path - Potomac**
✓**BK-3** **Forest Glen Ped. Bridge - Forest Glen Road to Mont. Hills**
BK-4 Metropolitan Branch Trail - Silver Spring to D.C.
✓**BK-5** **North Bethesda Trail - Cedar Lane to Tuckerman Lane**
BK-6 Silver Spring Green Trail - Fenton St to Sligo Ck Parkway
BK-7 Woodglen Avenue Trail - Marinelli Road to Nicholson Lane
BK-8 Shady Grove Access Bike Path

COMMERCIAL REVITALIZATION PROJECTS

CR-1 Frederick Avenue (MD 355) in Gaithersburg
CR-2 Georgia Avenue (MD 97) in Montgomery Hills
CR-3 Spencerville Road (MD 198) in Burtonsville
CR-4 University Boulevard (MD 193) in Langley Park

LIGHT RAIL LINES, BUSWAYS, & BUS RAPID TRANSITWAYS (BRT)

TR-1   Clarksburg Transit Center
TR-2   Colesville Rd (US 29) BRT - Burtonsville to Silver Spring
TR-3   Corridor Cities Transitway - Shady Grove to Clarksburg
TR-4   Four Corners Transit Center
TR-5   Georgia Avenue (MD 97) Busway - Glenmont to Olney
TR-6   Inner Purple Line (light rail) - Bethesda to New Carrollton
TR-7   Inner Purple Line Spur - Langley Park to White Oak
TR-8   Olney Transit Center
TR-9   Randolph Road BRT - Columbia Pike to Rockville Pike
TR-10   Silver Spring Transit Center
TR-11   Takoma / Langley Transit Center
TR-12   University Blvd (MD 193) BRT - Langley Park to Wheaton
TR-13   Veirs Mill Road (MD 586) BRT - Wheaton to Rockville
TR-14   White Oak Transit Center

PARKING GARAGES AND LOTS

✓ PK-1   Bethesda / Cheltenham Parking Garage
✓ PK-2   Damascus Park And Ride Lot
  PK-3   Glenmont Metro Garage
✓ PK-4   Grosvenor Metro Garage
  PK-5   Norbeck Road Park & Ride Lot Enhancements
✓ PK-6   Shady Grove Metro Parking Garage
✓ PK-7   Silver Spring Silver Circle Parking Garage
✓ PK-8   Silver Spring Town Center Garage

SAFETY IMPROVEMENTS

  SA-1   Fairland Road - Columbia Pike to Prince George's Co.
  SA-2   Goshen Road - north of Warfield Road
  SA-3   Layhill / Norwood Roads (MD 182) - Ednor Road to MD 108
✓ SA-4   Muncaster Mill Road - Shady Grove Road to Norbeck Road
✓ SA-5   Muncaster Road - at Rock Creek
✓ SA-6   Old Columbia Pike - Nalls Lane to East Randolph Road
  SA-7   Quince Orchard Road - Darnestown Rd to Muddy Branch Rd
  SA-8   Travilah Road - Darnestown Road to Dufief Mill Road

LEGEND

RD- **1** NEW ROADS

WI- **1** ROAD WIDENINGS

BR- **1** BRIDGE REPLACEMENTS

GS- **1** GRADE SEPARATED INTERCHANGE IMPROVEMENTS
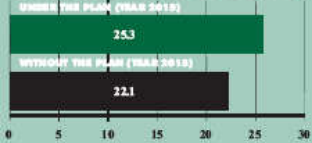
IN- **1** INTERSECTION IMPROVEMENTS

BK- **1** BIKE PATHS

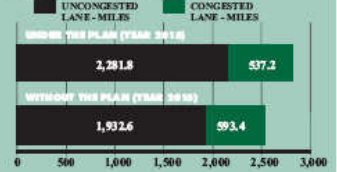CR- **1** COMMERCIAL REVITALIZATION PROJECTS

TR- **1** LIGHT RAIL LINES, BUSWAYS, & BUS RAPID TRANSITWAYS (BRT)

TRANSPORTATION PROJECTS TO BE COMPLETED IN MONTGOMERY COUNTY BY YEAR 2015

RUSH PERIOD AVERAGE SPEED (MPH)

UNDER THE PLAN (YEAR 2015)
25.3

WITHOUT THE PLAN (YEAR 2015)
22.1

0   5   10   15   20   25   30

RUSH HOUR CONGESTION

■ UNCONGESTED LANE - MILES   ■ CONGESTED LANE - MILES

UNDER THE PLAN (YEAR 2015)
2,281.8 | 537.2

WITHOUT THE PLAN (YEAR 2015)
1,932.6 | 593.4

0   500   1,000   1,500   2,000   2,500   3,000

PERCENT TRIPS TO WORK BY TRANSIT

UNDER THE PLAN (YEAR 2015)
17.38%

WITHOUT THE PLAN (YEAR 2015)
15.20%

0   5   10   15   20
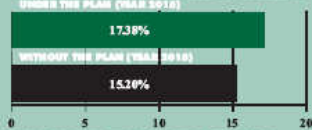
RUSH HOUR TRANSIT BOARDINGS

UNDER THE PLAN (2015)
59,146

WITHOUT THE PLAN (YEAR 2015)
34,049

0   10,000   20,000   30,000   40,000   50,000   60,000

BARNESVILLE
POOLESVILLE
LAYTONSVILLE
BROOKVILLE
GAITHERSBURG
ROCKVILLE
KENSINGTON
TAKOMA PARK
CHEVY CHASE
FRIENDSHIP HEIGHTS

WOODFIELD ROAD
DAMASCUS ROAD
GERMANTOWN ROAD
DARNESTOWN ROAD
RIVER ROAD
MUDDY BRANCH ROAD
ROCKVILLE PIKE
GEORGIA AVENUE
CONNECTICUT AVENUE
COLUMBIA PIKE
I-270
I-495

0'   5,000'   20,000'

Appendix C- Route Information

Route Number	Description
55	Highest Ridership in county, travels from Germantown to Rockville
46	High ridership, stops at 6 Metro Stations, all along Rockville Pike
16	Travels from Takoma to Silver Spring
20	Travels from silver spring to Hillandale

Appendix D- Focus Group questions for discussion

- As bus operators, what do you find most troublesome in navigating buses?
- Do you notice the same thing as personal drivers?
- What has changed in driving a bus in the past 5 years? 10 years?
- How efficient do you think the loading and unloading of buses is?
- What would you change about unloading/loading?
- What are your feelings about SmarTrip?
- Have you ever worked for a transit agency that uses rapid bus boarding techniques?

Appendix E- Focus Group w/operators 11-5-08

Time Issues

- Scheduling is too tight, there is not enough time in between runs
- Dead-end time is to short, may be given 10 minutes, but it may in actuality take 12-15 minutes to complete the turn-around
- Layover time is an issue, 4 minutes is not enough
- Running time is a big factor
  - Ex) Route 55, you need to turn around and go back to the beginning and run it again, instead of waiting 5 minutes and making a round trip

Bus Issues

- Sometimes the fare boxes won't take bills, sometimes rejects nickels
- Too difficult to get fare box to take cash
- Tandem busses would really help out on busy routes, such as Route 55
  - Trying to fit people into a full or semi-full bus can delay run time
  - Also, sometimes need to pass up riders because bus is full
- A lot of time is wasted waiting for the back door to close, it sometimes take a long time for it to fully close
- Maintenance is not very efficient

Route/Run Issues

- Some bus stops are too close to each other, sometimes they are only 25-50 feet apart, and if people are waiting at both stops, time is wasted
- At places like the Medical Center, there are many different busses and cars as well that are trying to make it thought the light
  - This is tough to do because there are so many vehicles and the light is short, so maybe only three busses and a handful of cars make it through the light each cycle.
- Some bus stops are in dark areas, maybe a light could be put in, or stop could be moved to a light so that the driver can know ahead of time if there is someone at the stop and doesn't have to slow down near the stop to find out
- Traffic lights are sometimes an issue
  - Busses sometimes sit a red arrows to turn left, but there is no oncoming traffic
  - Increasing number of straight runs could decrease number of red lights sat at, and decrease run time
- Nowhere to layover in Germantown
- Many stops have blind spots, so that even if driver checks both mirrors, people may come "out of nowhere" and cut off the bus.
  - Ex) Third stop on the 59
- Much time waiting to merge with traffic, sometimes due to position of stop

- Some green lights are very fast
  - Ex) Route 59 at Lost Knife Rd.
- Pedestrians walking in front of the bus when they don't have the right of way
- Stops too close to traffic lights
- Ex) Hurley Ave and 28th St, need to quickly cross 3 lanes of traffic immediately coming out of the stop in order to get into the left-turn lane
- Possible routes that should be considered for traffic signal prioritization: 46, 54, 55, 56 &59
- Bigger, more readable signs, so that people dot have to run around trying to read what stop they are at, because this holds up busses
- An express route from Rockville to Germantown would relieve much of the stress on Route 55

Communication Problems
- Central needs to listen to drivers more, need better people skills, they are very ill-mannered
- Better communication with central
- Time is wasted waiting for answers to questions, even for simple schedule problems
- Drivers should be able to easily and quickly tell a customer when the bus they request will be there next, either better communication or some sort of driver interface

Miscellaneous Issues
- Meal break is in an odd position
  - Break times are odd, an 8 hour shift will get 45 minutes to an hour, while a 10 hour shift only gets about a 30 minutes
  - A longer run is more likely to run late
- More cash payers during peak hours, because it is the beginning of the riders commute, so there is no chance for transfers
- When you have a set schedule, you know that schedule better, as opposed to when you are covering someone else's shift, you aren't as efficient
- 3 minute idle time rule
  - When the bus is off, you can't open the doors, you need to do it manually
  - Also, on cold days, obviously when the bus is off, the heat doesn't work, so passengers may be sitting in a cold bus
- Maintenance sometimes isn't very efficient
- Safety concern
  - When silent alarm is pressed, central calls back and asks if the alarm was accidently pressed, which seems kind of counter-intuitive
  - Central should be able to look at the video in real time, so that they can decide if there is a threat present on the bus and send help without having to ask the driver

Appendix F –Survey Questionnaire

We are trying to improve the Ride On bus system. The following is a survey on the usage of the SmarTrip system in Montgomery County.

Are you a regular user of Ride On busses?	YES
NO	
Are you aware of the SmarTrip card system?	YES
NO	
Do you currently have a SmarTrip card?	YES
NO	
Have you ever had a SmarTrip card?	YES
NO	
Would you consider the use of a SmarTrip card?	YES
NO	

SmarTrip users currently get a discount on bus service compared to Cash users. If the SmarTrip card offered more significant discounts, would you be more inclined to purchase/use one?   YES
        NO

If yes, at what difference would you switch to SmarTrip? Circle the amount.

$0.20 difference $0.30 difference $0.40 difference $0.50 difference   N/A

Do you think that everyone should have a SmarTrip card?   YES
        NO

If you have any additional comments write them on the back of the survey.

Appendix G- Unrelated Results from Focus Group

- Communication between central and bus drivers is poor
- Poorly lit bus stops
- Issues with security cameras
- Issue with turning bus off in winter time during layover time

Appendix H- Other Cities TSP Implementations

Brief Summary	Chicago	Los Angeles	Vancuver
# Corridors Involved	1	9	2
# Intersection Equipped	15	654	63
# Buses Equipped	125	283	28
Benefits	**19-25%** reduced travel times	Average **15%** reduced running time	**40-50%** reduction in travel time variability. Resulted in 23% shift from auto to transit in corridor.
Impact on SOV's	Studies show little Impact	Minimal	No noticeable impact

Appendix I – Additional Uses for a Bus Network

A bus network would be a powerful tool for Montgomery County. It would create an unprecedented level of communication facilities between busses. There are many potential uses for a bus network. However, in our report we only described one, Dynamic Scheduling, in detail. Below is a list of other uses.

Security

- In today's age security should not be overlooked. If busses were connected in a bus network to central dispatch, it would be possible to have a real-time feed of the video from the bus. This feed would be able to be gathered from anywhere that has access to the bus network. If a security situation occurred on a bus, the video feed could automatically appear at central, allowing dispatchers to assess the situation.

Customer Service

- Using the bus network, Ride On officials could follow busses as they travel their routes. While this would provide an unprecedented level of data gathering for the scheduling and planning departments, it could also impact customers. Ride On could publish the real-time performance data of busses, such that riders could track the current location or even just the estimated time of arrival of their busses.

- The bus network could be interfaced with the route database, such that it would provide easy access to the data for operators. This would be a good service, as bus operators are customer service agents for Ride On. Occasionally, riders ask operators when the next bus in a particular route is arriving. Currently operators have to call central to get this information. With a bus network, operators could quickly look it up themselves.

- If the bus network is interfaced with the fare payment system, it would be possible to recharge a SmarTrip card online with a credit card. The customer could supply their information online and get properly billed by a billing server. This server would queue the credit until the next time the customer used their SmarTrip card. In order for this to work, it would require regional changes in the SmarTrip system.