MODELING THE EFFECTS OF REMOVING MOTORIZED VEHICLE LANES TO CREATE SPACE FOR BICYCLE FACILITIES: A CASE STUDY OF MLK DRIVE PHILADELPHIA, PA

by

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ABSTRACT

Nationally, the last decade has seen sharp increases in bicycle ridership. Streets in our cities are trying to provide safe paths for cyclists, while continuing to accommodate motor vehicles. Bicycle networks are being expanded to roadways that currently do not have facilities with a goal of connecting areas that experience high levels of ridership. Transportation agencies constantly face the challenges of accommodating all system users, bicyclists, pedestrians, transit, freight, personal vehicles, etc, with limited and sometimes, shrinking financial resources. So often the question of "what is the safest facility that could be provided to cyclists, which minimizes the impact to private autos at the lowest cost" arises.

The research presented in this thesis provides a methodology that can be used by transportation agencies when considering the feasibility of placing bicycle facilities on high volume arterial roadways. A case study based on Martin Luther King Drive in Philadelphia, PA is presented which includes a comparison of several alternative scenarios based upon the results of a microscopic traffic simulation. The challenge was to provide the safest and cheapest option to accommodate all system users. The methodology utilized could be applied to any urban center facing the challenges of accommodating ever increasing numbers of cyclists.

Chapter 1

INTRODUCTION

Throughout the latter half of the past decade, the City of Philadelphia has seen large increases in the number of people bicycling. The number of people bicycling in Philadelphia has doubled (Bicycle Coalition of Greater Philadelphia 2008a) in spite of no additional major bicycle facilities being built. In the late 1990's, Philadelphia had only installed bike lanes on streets with enough space to accommodate the lanes, not considering how the bike lanes could function together as an entire network. The disconnected network that was created did not prompt a large increase in the number of people bicycling. Recent events such as mass transit strikes, increased fuel prices, and increased popularity in urban bicycle culture have generated a sudden increase in ridership (Bicycle Coalition of Greater Philadelphia 2008a).

Recently the city has taken steps to accommodate this increase in bicycle traffic by installing bike lanes along popular cycling routes, at times removing motor vehicle travel lanes or narrowing these vehicle lanes. Along Pine and Spruce Streets, the city was willing to attempt an experimental pilot project and replace an entire traffic lane with a bike lane to create east and west bicycle connections across Center City. The City of Philadelphia has begun to realize that bicycle facilities should not just be added as an afterthought, but should be used to help promote cycling and add safe routes throughout the city. One location that experiences large levels of bicycling and has not seen many recent major improvements is Fairmount Park.

Philadelphia's Fairmount Park is a popular recreational destination for many bicyclists, joggers, and walkers in the City of Philadelphia and the surrounding areas. Many visitors enter the park from Center City near the Philadelphia Museum of Art and travel along the Schuylkill River, following one of the roads or multi-use trails that parallel the river's east and west sides into the heart of Fairmount Park. Kelly Drive parallels the Schuylkill River on its east side while Martin Luther King Jr. (MLK) Drive parallels the river on its west side. While each of these roadways serves as a direct connection to bring recreational users into the park, the roadways also provide a direct connection for motorists to travel to Center City, bypassing the often gridlocked Schuylkill Expressway (I-76).

As a result, motorists treat Kelly Drive and MLK Drive more like expressways rather than the 35mph park roads they are intended to be. MLK Drive, in particular, has received major attention within the past year by the bicycle advocacy group, the Bicycle Coalition of Greater Philadelphia, as unsafe conditions along the roadway led to a major crash involving an automobile and a bicycle, seriously injuring the father and son cyclists. In May 2009, the Bicycle Coalition of Greater Philadelphia started a campaign to "Take Back the Drives" to encourage the City of Philadelphia to create a safer bicycling and pedestrian environment on MLK Drive. In June 2009, the City of Philadelphia Mayor's Office took further action by requesting that the Delaware Valley Regional Planning Commission study the conditions on MLK Drive and evaluate options to improve safety for all users. My thesis will study MLK Drive and evaluate the feasibility of reorganizing the space on the roadway to better accommodate bicyclists while also calming traffic to create a safer environment for bicyclists and pedestrians, helping to turn MLK Drive back into a park road again.

Chapter 2

LITERATURE REVIEW

Solving the problem of creating a safer bicycling environment and better bicycling facilities on MLK Drive in Philadelphia involves tying innovative bicycle facility design and traffic calming such as road diet techniques together, two subjects which have individually received a lot of attention but together have not received a lot of in depth research. When looking at how to address this problem, the literature review will first consider the current standards in bicycle facility design and the benefits and problems associated with the various designs. Bicycle facility design should account for the types of riders who will use these features, so it is important to also consider the various types of cyclists and the route preferences associated with each cyclist. Philadelphia and the rest of the US have experienced many changes in the number of people bicycling in recent years. A review of ridership patterns in Philadelphia and the rest of the United States will help to place the MLK Drive problem into a broader perspective. Philadelphia and New York City have both been experimenting with new and innovative bicycle facility designs. This review will consider many of these new ideas and how they have been applied in each city. Innovative bicycle facility designs can often face backlash from the general public, as they are seen as taking away roadway space from motorists. This literature review will look at studies that have demonstrated the benefits bicycle facilities can have on an area. Finally, the literature review will look at issues with the lack of traffic law enforcement in the US and how changing the roadway design and implementing traffic calming can help encourage drivers to adhere to traffic laws without a law enforcement presence. Particularly, traffic calming for arterial roads similar to MLK Drive will be considered to aid in creating a safer bicycling environment.

Types of Cyclists

When figuring out what type of bicycle facilities to use throughout a region, it is important to consider the skill levels of the different riders that will use the facilities. The American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities* defines three main types of cyclists (1999). Type A cyclists consist of advanced and experienced cyclists who will use their bicycle as if it were a motor vehicle and choose routes based on convenience and speed. Type B cyclists include basic and less confident adult riders who choose to avoid busier roads and prefer cycling facilities. Type C cyclists are children who ride alone or with parents and prefer calm residential streets or bike paths. Commonly, type B and C cyclists are considered together. The Federal Highway Administration (FHWA) report *Selecting Roadway Design Treatments to Accommodate Bicycles* emphasizes the fact that bicycle routes must be carefully selected and designed to accommodate B/C cyclists since they will not be as comfortable in traffic and will only have limited skills (1992). The FHWA recommends designing roadways for B/C cyclists when high levels of these riders are expected and at a minimum all highways and streets should be designed to accommodate type A cyclists because type A riders will accept a much wider range of operating conditions than B/C riders (FHWA 1992; FHWA 1994). Research has shown that cyclists prefer to bicycle on routes that have a designated bicycle facility, with bike lanes preferred over bike paths, and cyclists prefer roadways with smaller volumes of traffic (Stinson and Bhat 2004). The same research has found that experienced individuals place more priority on routes that have smooth pavement, minimize travel time and delay, and have minimal numbers of traffic signals and stop signs, while inexperienced individuals place more priority on having marked facilities present due to their lack of comfort, skill, or experience riding in traffic (Stinson and Bhat 2004). Infrequent cyclists may prefer bike paths more than experienced cyclists due to their perceived safety concerns (U.S. Department of Transportation Bureau of Transportation Statistics 2004). Since a cyclist's level of experience will affect their comfort on different bicycle facilities, it is important to consider the different types of bicycle facilities and their respective advantages and disadvantages.

Bicycle Facilities

The main types of bicycle facilities in the United States can usually be arranged into one of the following categories; shared use roadways (including shared lanes, wide curb lanes, and shoulders), bike lanes (adjacent to travel lanes and protected lanes), and shared multi-use paths (FHWA 1992; AASHTO 1999; Toole and Zimny 1999; Pucher and Buehler 2009).

Shared Use Roadways

Shared travel lanes can be good for cyclists when traffic speeds are lower than 30 mph (in areas like residential neighborhoods) but become less suitable as speeds increase (FHWA 1992). Shared use roadways may have been designed without cyclists in mind but well designed shoulders and outside curb lanes can help make these roadways more accommodating to cyclists (AASHTO 1999). Outside curb lanes wider than twelve feet with no striping can accommodate cyclists and require minimal maintenance because automobiles "sweep" the lanes clear of debris. Sharing these wide curb lanes with cars can discourage type B/C riders (FHWA 1992; FHWA 1994; AASHTO 1999). Research has also shown that when there is on street parking present along a wide curb lane, cyclists may ride too close to parked cars placing them in the path of the vehicle's door opening zone (Duthie, Brady et al. 2009). Improved roadway shoulders can also help to accommodate cyclists, particularly in rural areas, but design consideration must be given with regards to rumble strips, narrow right of ways, and intersections (FHWA 1992). AASHTO recommends at least a four to five foot shoulder, but any improved shoulder can help cyclists as well as extend roadway life (1999). Some local authorities may choose to stripe wide curb lanes to convert them to shoulders even if there is inadequate room for a bike lane, using the marking to control traffic and provide a traffic calming measure to help cyclists (Dennison 2008).

Bike Lanes

Bike lanes help encourage use by type B/C riders more than shared roadways because they channelize traffic flow and create more predictable behavior between automobiles and cyclists (FHWA 1992; Dennison 2008). AASHTO defines bicycle lanes as being a minimum of four feet in width on roadways without curbs and at least five feet in width if the roadway has parked cars, with a six inch white line used to delineate the bike lane from the travel lane (1999). Bicycle lane striping provides cyclists with additional comfort that is not found on shared use roadways by making it easier for motorists and cyclists to predict each other's movement (Dennison 2008). There are several factors that must be carefully considered when designing bike lanes. A bike lane full of broken glass and rocks is useless to a cyclists, bike lanes may require more maintenance to keep the lanes clear of debris than shared use roadways since motor vehicles will not be traveling in the lane and "sweeping" the bicycle lane clear (FHWA 1992; FHWA 1994; Toole and Zimny 1999). If designing a protected bike lane (with a buffer between the bike lane and motorized vehicle lane such as parked cars or concrete median), local municipalities must consider if their current equipment will be able to handle removal of accumulated debris or even snow. Special attention must also be given to types of drainage grates in bike lanes. The grates must be designed so that bicycle wheels will not slip through and that the grates are flush with pavement levels (AASHTO 1999; Toole and Zimny 1999).

When installing bike lanes in urban environments, careful attention must be given to their placement so that the lanes do not encourage cyclists to ride in the "door zone" of parked automobiles (FHWA 1992; Toole and Zimny 1999; Dennison 2008; Duthie, Brady et al. 2009). "Dooring" occurs when a cyclist is traveling next to parallel parked cars and a person exiting from their car open theirs door into the path of the cyclist, causing a collision. In some urban environments a street may not have enough width to accommodate standard size bike lanes and automobile travel lanes. Even though there may not be adequate width, some cities have attempted to install bike lanes on these narrow streets, creating bike lanes that channelize cyclists into the "door zone" of parked automobiles (Dennison 2008). Although the "dooring" risk can still be high in some bike lanes, research has shown that bike lanes are safer at keeping cyclists out of the "door zone" rather than not having any designated bicycle facility present by allowing cyclists to more comfortably ride further away from parked cars (Duthie, Brady et al. 2009). This risk can be reduced by placing a buffer between a bicycle lane and a parking lane (Duthie, Brady et al. 2009). In cases where there is inadequate space for a bike and motor vehicle to travel side by side, the problem of creating safe bicycle facilities is being solved through the use of shared lane markings (FHWA 2009). The shared lane markings are painted on the roadway vehicle travel lane and show cyclists where they are expected to ride while informing motorists of a cyclist's presence (FHWA 2009). Figure 1 shows how shared lane markings can be applied on roadways without enough room for bike lanes.

Figure 1: Shared Lane Markings (Seattle Department of Transportation 2009)

One of the final major considerations that must be given to on road bicycle facility design is how to reduce conflicts with turning vehicles at intersections.

Problems at intersections can arise when cyclists are encouraged to stay to the right and motorists are encouraged to stay to the left but the motorist may want to make a right hand turn (FHWA 1992). Over the past decade, design guidelines have placed emphasis on how to incorporate bike lanes along roadways with less research being done on intersection treatments, and most intersection research that has been done has focused on conflicts between right turning motorists and straight traveling cyclists (Weigand 2008). Currently the AASHTO guide states that at major intersections bike lane markings should go from a solid to a dashed line with additional markings that encourage right turning motorists and bicyclists traveling straight to merge before the intersection to reduce conflicts (1999). The guide also states that if there is not enough room for a bike lane to continue appropriate signage and warning should be given to cyclists and motorists (AASHTO 1999). Current research in improving intersections for cyclists is drawing many innovative ideas from Europe. This research has focused on using new pavement marking techniques and changes in traffic signals. Colored bike lanes through an intersection can be used to provide a route for cyclists and to warn drivers of a cyclist's presence and can also be used to help reduce conflicts at merge points before the intersection between right turning motorists and cyclists (Weigand 2008). An example of a colored bike lane through an intersection can be found in Figure 2.

Figure 2: Colored bike lane in Philadelphia, PA

In some areas colored bike boxes have been placed in front of the vehicle stop bar to allow cyclists to move in front of vehicles at a signalized intersection, reducing conflicts between right hand turning motorists and cyclists as well as giving cyclists a better opportunity to turn left across the motorist lanes (Weigand 2008). An example of a bike box can be found in Figure 3.

Figure 3: Bike box in Portland, OR (Raisman 2010)

Some cities are also beginning to employ traffic signal changes to help cyclists. The two main changes have been bicycle scramble phases (where bicycles can proceed freely from all directions while motor vehicles must stop and wait in all directions) and bicycle only signal phases that help reduce conflicts with turning motorists (Weigand 2008).

<u>Off Road Multi-Use Paths</u>

Off road shared multi-use paths can be a very important bicycling facility to help attract new B/C type riders (FHWA 1994) and may be necessary for those B/C riders who do not wish to face the perceived dangers of riding alongside automobiles (Pucher and Buehler 2009). Off road paths are typically shared with other users including pedestrians, joggers, and skaters. These paths usually parallel a roadway or river or exist independently in their own right of way. Safety of off road paths when compared to parallel on road routes has been researched with parallel on road routes found to be safer due to decreased conflicts with turning vehicles and vehicles approaching on side streets (AASHTO 1999; Pucher, Komanoff et al. 1999; FHWA 2006; Haake 2009; Reynolds, Harris et al. 2009). Although shared use off road paths parallel to roadways are not as safe as on road routes, they continue to be built due to perceived safety from type B/C cyclists (FHWA 1992; Stinson and Bhat 2004; U.S. Department of Transportation Bureau of Transportation Statistics 2004; Pucher and Buehler 2009). The AASHTO *Guide for the Development of Bicycle Facilities* recommends that a two-way shared use path be ten feet in width, and in some areas with high expected volumes of joggers, cyclists, and pedestrians that the path be twelve to fourteen feet wide.

One of the major issues with shared use paths is conflicts between different user groups. The popularity of these trails creates congestion and confusion during peak use periods which lead to increased conflicts and risk of injuries (FHWA 2006). Congested bike paths will cause users to pass others in an unsafe manner (Haake 2009). These crowded conditions can make bike paths slow and cumbersome to faster riders and encourage these cyclists to ride on neighboring streets (FHWA 1994; Pucher, Komanoff et al. 1999). The faster cyclists may want on road facilities but the presence of off road facilities reduces the political impetus to better accommodate cyclists on roadways (Pucher, Komanoff et al. 1999). In some cases, motorists may harass cyclists because they feel they should be using the neighboring path even if the path is less convenient, unsafe, and not well maintained (AASHTO 1999). Lack of maintenance and poor surface conditions are further issues that plague shared use paths across the country. When these paths are built they are nice and new, but it is difficult to convince municipalities to perform regular maintenance. Over time these paths can become neglected and fall into disrepair (Haake 2009). During the winter months, shared use paths will tend to become unreliable bicycle routes. Rarely are they cleared of snow and ice in a timely fashion if they are even cleared at all (Haake 2009). Many times shared use paths exist in parks that close after dark or do not contain adequate lighting, forcing commuters that may rely on these paths to find an alternative way home from work.

Shared use paths paralleling roadways present another danger to cyclists, motorists turning into the path of a cyclist. Motorists entering and exiting a parallel roadway may not be aware of a cyclist's presence on the path or expect cyclists to yield at intersections, creating conflict points (AASHTO 1999; Haake 2009). Multi-use paths need to be designed to minimize intersections with roadways in order to minimize conflicts with motorists (FHWA 1992).

Poorly designed paths can be more dangerous than neighboring roadways (FHWA 1994) and rates of bicycle crashes on shared use paths tend to be higher on average compared to on road facilities due to poor surface conditions, narrow widths, intersection conflicts, and conflicts with other users (Pucher, Komanoff et al. 1999). A literature review by Reynolds and Harris (2009) has found that bicycle infrastructure including sidewalks and multi-use trails pose the highest risk to a cyclist's safety.

The level of service, or the measure of the quality of service a cyclist experiences, on multi-use paths is another factor which may influence a cyclist's choice to use the path. Width is one of the key factors in determining multi-use path's level of service; every additional foot of trail width has a positive impact on overall level of service (FHWA 2006). A cyclist's level of service on pathways is especially sensitive to user mix. When the amount of foot traffic exceeds fifteen percent, the level of service can become significantly impacted (FHWA 2006). Level of service is also greatly affected when cyclists encounter a large number of delayed passing situations, or when they arrive behind a slower path user and must wait to pass due to the lack of an acceptable gap. User stress levels on multi-use paths tend to increase when the paths are directly adjacent to high speed traffic lanes with no protection barrier or buffer. A study by the FHWA of on road bicycle facilities found that stress levels of cyclists were at their highest level when motor vehicle volumes of 450 vehicles per hour traveling at speeds of 45 mph or higher were reached in eleven foot curb lanes adjacent to the bicycle facility (2006).

Ridership Patterns

Cycling facilities need to cater to all types of riders so that more people, besides only the fit and in shape riders, can enjoy bicycling (Pucher and Buehler 2009). There is a lack of adequate bicycle facilities in the US that causes people to perceive that riding a bicycle is an extremely dangerous activity (Pucher and Dijkstra 2000). The lack of adequate facilities in many parts of the country has created conditions in which walking and cycling are almost three times more dangerous than riding in a car (Pucher and Dijkstra 2000). The media reinforces the idea of bicycling as a dangerous activity through cultural attitudes that portray bicycle accidents being associated with "the supposedly intrinsic perils of bicycles" (Pucher, Komanoff et al. 1999). The perceived and real dangers of bicycling have contributed to low ridership levels throughout the US. Increasing the quality and number of bicycle facilities in an area can help to increase overall ridership and as ridership increases the "safety in numbers" effect can be seen with lower accident rates (Pucher and Buehler 2008; Pucher and Buehler 2009).

Cyclists desire to use quality bicycle facilities. Research has shown that cyclists will travel an average of 67% longer to reach a high quality bicycle facility that will help take them to their destination (Krizek, El-Geneidy et al. 2007). Cyclists who make longer trips and those traveling on the weekend were more inclined to travel out of their way to use a highly attractive facility (Krizek, El-Geneidy et al. 2007). One example of increased ridership as a result of increased bicycle facilities occurred in Portland, OR. From 1992 to 2005, Portland has expanded its bicycle network from 83 miles to 260 miles, creating a complete bicycle network of high quality well designed facilities (Burk and Geller 2005). As a result of this, the city has seen a 210% increase in bicycle trips (Burk and Geller 2005). Research has also shown that cities with higher levels of bicycle infrastructure tend to see high levels of bicycle commuters. But bike lanes and paths alone are not enough to increase commuting. Additional education and places to store bikes at destinations are key components as well (Dill and Carr 2003). In Portland, it was found that only areas that were well connected to the bicycle network and had quality bicycle facilities saw increased ridership while those areas that were not as well connected to the bike network saw ridership remain flat (Burk and Geller 2005). A study performed in St. Petersburg, FL has shown that adding bike lanes on streets that were not part of a well connected network without any consideration of adjacent land use and convenient origin and destinations along the roadways did not significantly increase bicycle traffic (Hunter, Srinivasan et al. 2009). In order to have a successful bike network, connections must be provided everywhere and provide people with route options to most destinations (Pucher and Buehler 2008).

Bicycling in Philadelphia

In the Philadelphia area, bicycling ridership has seen dramatic increases over the past several years due to the city expanding its bicycle network and improving its connectivity. Between 2005 and 2008, bicycling doubled at all Bicycle Coalition of Greater Philadelphia (BCGP) counting locations (BCGP 2008a). For the entire city of Philadelphia, 2% of all trips are made by bicycle, which are approximately 75,000 trips per day (BCGP 2008a). Cycling has the potential to be a very viable transportation option within the city. As of 2006, 35% of the occupied housing units and 51% of the occupied rental housing units did not have a motor vehicle (BCGP 2008b). Within the Delaware Valley region surrounding Philadelphia, nearly two thirds of all bicycle trips are being made for utilitarian transportation purposes as opposed to recreation (Delaware Valley Regional Planning Commission 2007). The Delaware Valley Regional Planning Commission (DVRPC) estimates that the average utilitarian trips in the region range between 2.4 and 5.7 miles while the average recreational trip is about 12.6 miles and the average work commute trip is 5.5 miles (DVRPC 2007). Even the Pennsylvania Department of Transportation (PennDOT) has revised their bicycle and pedestrian plan to more fully integrate bicycle and pedestrian transportation improvements into the standard project development process (PennDOT2007). As bicycling becomes incorporated into roadway design and ridership levels in the greater Philadelphia region continue to grow, Philadelphia continues to add new bike lanes and experiment with new infrastructure, such as the Spruce and Pine bike lanes.

Philadelphia has over 200 miles of on road bike lanes and over 30 miles of off road bicycle trails (BCGP 2008a). A majority of these bike lanes were installed in the late 1990's on streets that already had more than enough width to accommodate the installation of a five foot wide bike lane, such as those found along current West Philadelphia trolley routes. Other bike lanes were made by converting four lane roads into three lane roads with a two-way center turning lane plus two bike lanes (BCGP 2008a). Many of these bike lanes were installed in areas outside of Center City due to the fact that Center City roadways are very narrow with little to no room to accommodate bike lanes (BCGP 2008a). In 2005, approximately six percent of all trips in Center City were made by bicycle, while only two percent of the city's total bike lanes are in Center City (BCGP 2008a; BCGP 2008b). The city had installed bike lanes in places that were had extra width and were easy to install, but were not necessarily where most cycling trips were being made.

Although many of the city's bike lanes were installed in the late 90's, during the fifteen year period from 1990 to 2005 bicycling trips increased by 98% while during the three year period from 2005 to 2008 bicycling trips increased by 104% (BCGP 2008a). The installation of bike lanes did not immediately lead to increases in ridership since they were installed only in areas that had space and not strategically placed to provide continuous connected routes throughout the city. The increased ridership in the late 2000's may have been the result of other factors including the 2005 SEPTA strike, increasing gas prices, the completion of the

Schuylkill River Trail south of the Art Museum, and an overall increase in popularity of urban bicycle culture (BCGP 2008a).

The Philadelphia Streets Department has responded to the recent increase in cycling by installing many miles of new bike lanes throughout the city along popular routes as well as improving the safety and connectivity on existing routes. The entire area around the Art Museum has been reconfigured in 2009 to improve bicycle and pedestrian safety, West Philadelphia has seen new bicycle facilities installed along popular routes through Drexel University and the University of Pennsylvania after roadways are repaved, and the city has installed the first continuous east-west bike lanes in Center City south of Spring Garden Street.

The first dedicated east-west bike lanes in Center City were installed in September 2009. The City of Philadelphia removed a traffic lane on Pine and Spruce Streets between the Schuylkill River and the Delaware River to allow the creation of a seven foot bike lane with two foot buffer in its place (Carmalt 2009). The installation of bicycle lanes on Pine and Spruce Streets from the Schuylkill River to the Delaware River in September 2009 provided a continuous east-west connection for bicyclists wishing to travel through the heart of Center City. The new bike lanes immediately attracted cyclists with an overall increase of 95% of cyclists using Spruce and Pine Streets (BCGP 2009a).

Innovation in New York City

Many other large cities in the US have begun to incorporate various other innovative bicycle facility designs into their bicycle network, drawing many creative ideas from European countries. Over the past few years, the New York City

Department of Transportation (NYCDOT) has been implementing several new and innovative bicycle facility designs in addition to its more than 200 mile network of bicycle paths and lanes (NYCDOT 2009). These new and innovative ideas are beginning to be constructed around different areas of the city where roadway conditions have created serious safety hazards to cyclists.

Two examples of recent innovations in NYC are the Grand Street bike lanes and the 8th and 9th Avenue bike lanes. NYCDOT has created a protected on street bicycle lane on Grand Street in lower Manhattan by moving the parking lane away from the curb and placing a five foot bike lane with a three foot buffer between the parked cars and the curb (NYCDOT 2009). Eighth and Ninth Avenues on the lower west side of Manhattan have been given another form of physically protected bike lanes. These large avenues use to have four travel lanes and two parking lanes on either side, creating automobile dominated corridors that had excess capacity and provided unsafe conditions for bicyclists and pedestrians. NYCDOT has eliminated a travel lane on each avenue and created a one way ten foot wide bike lane with an eight foot wide buffer zone consisting of concrete medians and parked cars. These protected bike lanes have been given their own signal timings to further reduce conflicts between turning motorists at intersections (NYCDOT 2009). As innovative bicycle facility ideas continue to emerge in cities throughout the US, it is important to understand the benefits these facilities can have on the surrounding communities.

Benefits of Bicycle Facilities

In many areas, new bike lane construction along commercial corridors is often opposed by local businesses due to concerns of eliminating parking spaces or inconveniencing motorists. A study along the Bloor Street corridor in Toronto has found that a majority of businesses, residents, and visitors would prefer to see a parking lane removed and bike lanes placed on the roadway. A majority of merchants believed that the bike lane would not impact or instead help their business (Clean Air Partnership 2009). It was found that most of the mode share for economic activity along Bloor Street came from bicyclists and pedestrians. Any lost motorized vehicle parking along the corridor could be easily offset by increased bicycle traffic along the corridor. Similar results were found when merchants were surveyed four years after Valencia Street in San Francisco, CA was taken on a four lane to three lane road diet with bike lanes added after the fourth lane was removed. Merchants reported that the bike lanes increased the attractiveness of the street, increased pedestrian safety, increased the numbers of customers who bike, increased the amount of residents who shop locally, and increased employee convenience (Drennen 2003). Two thirds of Valencia Street merchants surveyed felt that the added bike lanes had a positive impact on their sales. Gaining the support of local businesses along a commercial corridor is one of the main keys in helping to establish new bike lanes or other types of traffic calming measures (Drennen 2003). These studies have shown that adding bike lanes and implementing traffic calming can be beneficial to both the users of the bike lane and the merchants.

Taking space from the automobile to promote more cyclist and pedestrian activity can also be important in parks throughout the country. Transportation Alternatives performed a study of pedestrian use patterns in Prospect Park in New York City. The park is used by millions of people each year and experiences large amounts of recreational activity. Automobile traffic is allowed to travel through the park's roadway loop each weekday during the peak rush hours, 7-9am in the morning and 5-7pm in the evening with the loop remaining car free all other hours. The study found that people leave the park at a higher rate when cars enter the park as opposed to when the park is car free (Transportation Alternatives 2006). The automobile has taken over many areas that have the potential to be used and enjoyed by cyclists and pedestrians. Unsafe driving and speeding of motorists can create a large safety hazard for non-motorized roadway users, in many situations physical measures such as the addition of bike lanes or the process of a road diet are needed because other traffic enforcement methods are ineffective.

Traffic Law Enforcement Issues

In their article "Making Walking and Cycling Safer," Pucher and Dijkstra (2000) state that the lack of enforcement in the US is one reason people continue to break laws such as speeding and running red lights while driving. Often, motorists are treated with extreme leniency when they are involved in a bicycle or pedestrian collision (Pucher and Dijkstra 2000). Increased vehicle speeds by motorists often increase the likelihood of a motor vehicle collision with a pedestrian or other vulnerable roadway user (LaPlante 2007). The number of fatal collisions between motor vehicles and pedestrians or bicyclists increases with increasing motor vehicle speed. A pedestrian hit by a vehicle traveling at 20 mph has an 85% survival rate, but when this speed is double a pedestrian hit by a vehicle traveling at 40 mph has a 15% chance of survival (LaPlante 2007).

Speeding is a major issue in large cities throughout the US, with motorists routinely disregarding posted speed limits. In New York, speeding is the primary factor in more than 2,300 motor vehicle crashes in the city each year, triple the number of alcohol related collisions (Transportation Alternatives 2009). In a study performed by Transportation Alternatives, field data collected at various points throughout New York City showed that 39% of all motorists recorded were exceeding the 30mph speed limit (Transportation Alternatives 2009). Changing speed limits will not help to curb speeding either, research by the FHWA has shown that raising and lowering speed limits on urban and rural non-limited access highways did not significantly change the mean or 85th percentile of motorist's speeds (FHWA 1997). Raising and lowering speed limits did not result in a change in motorist behavior (FHWA 1997) and enforcement can be too lenient in many parts of the US. The biggest way to help alter driver behavior is through changes in physical roadway design. Traffic calming engineering measures can be used to help reduce motor vehicle speeds.

Traffic Calming

MLK Drive in Philadelphia is a unique park road with low amounts of intersections and no development along its entire route, but this road carries about 25,000 vehicles per day and functions like an arterial roadway. Most instances of traffic calming in the US are found on local or collector streets. Arterial streets are not frequently considered for traffic calming. Some cities in North America have been able to demonstrate successful traffic calming measures on these high volume roadways (Macbeth 1998). In many situations, urban arterial streets have been designed to maximize mobility without considering the context of the urban roadway and how it fits in with the surrounding community (LaPlante 2007). Traffic calming along arterials can be used to provide better bicycle and pedestrian accessibility in retail areas, reduce traffic speeds in residential areas, and improve safety for bicycle and pedestrians (Macbeth 1998). The difficulty in implementing traffic calming techniques on arterial roadways is how to handle larger vehicle volumes that calming measures used for local and collector traffic would not be suitable for (LaPlante 2007).

Most arterial traffic calming research has looked at narrowing travel lanes or reducing the number of travel lanes. Other techniques such as tightening corner radii, the elimination of freeway ramps, adding medians, and creating curbside parking can also be used (LaPlante 2007). Narrowing lane widths is an inexpensive measure which can be completed as a roadway is re-striped after resurfacing. Reducing lane width from twelve feet to ten feet on many arterial roadways can be implemented with little to no effect on increasing accident frequency and with no measurable decrease in saturated flow rates on urban streets (Petritsch 2007). The narrower lane widths can help reduce vehicle speeds and provide more room within the roadway right of way to create space for bicycles or pedestrians. Many cities have also begun to remove travel lanes and implement “road diets” as a roadway is repaved and re-striped in order to calm traffic and create additional room for bicycle facilities.

Road Diets

A “road diet” is typically defined as the conversion of a four lane undivided roadway into a three lane roadway with two travel lanes and a center lane reserved for two-way left turning traffic. In cases where there are minimal turning movements, four lane to two lane conversions are possible as long as storage lanes for turning are kept at intersections (Burden and Lagerwey 1999). The additional space created by removing a lane of traffic can be converted into bike lanes, parking lanes, or sidewalk space. There are many benefits associated with the "road diet" technique, including reducing crash rates along roadways where they are implemented. On some four lane undivided roadways, large amounts of left hand turn conflicts caused by drivers in the center lanes reached the point where center lane became a de facto left turn lane during certain hours of the day (Gates, Noyce et al. 2006). Motorists using the center lanes to turn left on a four lane roadway were at risk of being rear ended by drivers erratically changing lanes or aggressively speeding (Burden and Lagerwey 1999). A study by the Federal Highway Administration (FHWA) of arterial roadways in Iowa, Washington, and California found that road diets typically resulted in a reduction of crashes by 29% (FHWA 2010).

Prevailing speeds on roadways are typically set by impatient drivers, and generally the rest of the roadway users tend to match these speeds (Burden and Lagerwey 1999). By taking away a travel lane in each direction, road diets eliminate passing maneuvers and prevailing speeds are set by the leading vehicle of a platoon (Macbeth 1998; Burden and Lagerwey 1999). Road diets do not significantly lower roadway speeds, but they do help calm traffic due to fewer opportunities to pass, change lanes, and weave through traffic (Knapp 2001). Several studies of US roadways that have been transformed with a road diet show only minor reductions in 85th percentile speeds, ranging from decreases of two to five mph (Gates, Noyce et al. 2006). Road diets additionally help improve pedestrian and cyclist safety by creating a roadway cross section that requires a shorter distance to cross motor vehicle lanes and by adding bicycle facilities. Although road diets increase the safety of motorists, cyclists, and pedestrians, they are a controversial process and will only have the potential to be successful if the reduction or change in arterial level of service, or measure of the roadway's performance at effectively moving traffic, is locally acceptable (Burden and Lagerwey 1999; Knapp 2001).

Typically the ideal candidate that local authorities are comfortable with for a four lane to three lane road diet carries a vehicle volume of 15,000 to 18,000 ADT or less, any more daily traffic and the roadway has the potential to become congested with a decrease in the level of service (LOS) (Burden and Lagerwey 1999; Knapp 2001; FHWA 2010). Although 15,000 to 18,000 ADT is the maximum comfortable limit, in different road conditions road diets have been successful up to around 25,000 ADT with this appearing to be the upper limit before the roads are unable to accommodate vehicle volumes (Burden and Lagerwey 1999; Knapp 2001).

Research by different organizations have found a few notable examples where roadways with ADT greater than 20,000 have been successfully converted with little impact on roadway LOS and improved roadway safety (Knapp 2001, Burden and Lagerwey 1999, Skene 1999). Table 1 summarizes these studies and the results of several four lane to three lane road diets in several states in the US and Canada. The table lists the location of the road diet, the ADT along the roadway, and any major changes noted in the study.

Table 1: Road Diet Examples with High ADT

Location	ADT	Remarks
High Street, Oakland, CA	22,000-24,000	Crashes decreased, officials and residents notice traffic is calmed
Grand River Blvd, East Lansing, MI	23,000	Low amounts of commercial properties, minimal turning maneuvers
Lake Washington Blvd, Kirkland, WA	20,000	ADT increased to 30,000 after closing parallel roadway route, LOS still was not severely impacted
Cook Street, Victoria, BC	24,000	Initially traffic sought alternate routes, over time people began to accept increase in travel time

The feasibility of a road diet should be questioned when bi-directional peak hourly volumes begin to approach or exceed 1,750 vehicles per hour (Knapp 2001). On roadways with high amounts of intersections and more than 20,000 vehicles per day ADT, consideration should be given to keeping two through lanes in each direction at intersections to maintain an appropriate LOS (Knapp 2001). Before a roadway is taken on a road diet, consideration must be given to the neighboring land use and adjacent communities. Public approval is a large part of a successful road diet and the public must be educated and included in this controversial planning process (Burden and Lagerwey 1999).

Chapter 3

BACKGROUND

MLK Drive is a four mile long road that runs along the west side of the Schuylkill River in the heart of Fairmount Park, connecting Eakins Oval, near the Philadelphia Museum of Art, to Falls Bridge, near the East Falls section of Philadelphia. The roadway generally follows a north-south direction and its location within the city can be seen in Figure 4.

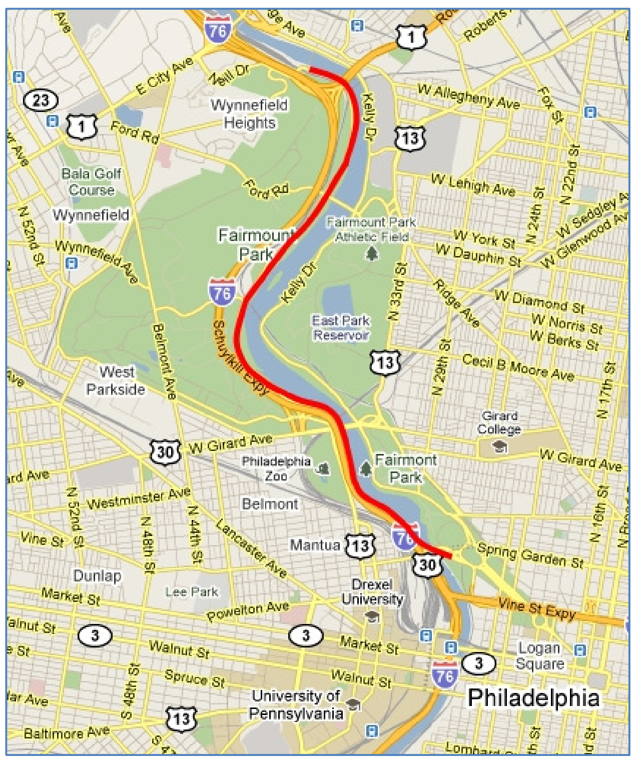

Figure 4: MLK Drive (shown in red)

Roadway Description

Along MLK Drive, there are two signalized intersections and three un-signalized intersections. The intersections with Sweet Briar Drive and Montgomery Drive are signalized, while the intersections with Black Road and the two Strawberry Mansion Bridge on ramps are un-signalized. For aerial images and intersection layouts see, Appendix A.

The roadway cross section varies throughout its length, ranging from two to four lanes at different points. The southern end of MLK Drive begins as a three lane bridge heading northwest from the Art Museum, with the three lane cross section lasting for one mile until reaching the first signalized intersection with Sweet Briar Drive. The three lane cross section has two ten foot southbound traffic lanes and one ten foot traffic lane going north from Center City. Upon reaching the Sweet Briar Drive intersection, MLK Drive turns into a four lane cross section with two ten foot northbound traffic lanes and two ten foot southbound traffic lanes. This cross section change can be seen in Figure 5. The four lane cross section lasts for two and a half miles, passing by the other signalized and three un-signalized intersections before reaching the US Route 1 overpass and two railroad bridges. The four lane cross section can be seen in Figure 6. At this point, MLK Drive becomes a two lane road with one ten foot lane in each direction and a five foot shoulder. After traveling under the railroad bridges, MLK Drive divides into one southbound lane and two northbound lanes for the last two tenths of a mile as it intersects with Falls Bridge.

Figure 5: Three Lane to Four Lane Cross Section

Figure 6: Four Lane Cross Section

MLK Drive Multi-Use Trail

A multi-use paved trail runs adjacent to MLK Drive between the roadway and the Schuylkill River along its entire length. For park visitors starting at the Art Museum, the MLK Drive paved trail is not very appealing with the alternate Kelly Drive path more attractive and more easily accessible. Leaving from the Art Museum, trail users must first cross a high speed vehicle exit lane, Eakins Oval exiting onto Spring Garden Street. After crossing Spring Garden Street, the MLK trail passes under an overpass, and then crosses a bridge over the Schuylkill River. Once on the bridge, the trail narrows to a five foot wide sidewalk that is expected to accommodate two-way bicycle and pedestrian traffic. The narrow sidewalk conditions can be seen in Figure 7. To help prevent conflicts, local cyclists regularly traveling out of the city typically ride in the two foot shoulder of the roadway over the bridge while those that are heading into the city ride on the sidewalk trail. This is only an informal understanding, so unfamiliar trail users or those uncomfortable riding on the shoulder will use the trail in both directions.

In addition to the narrow trail width, the bridge trail section also has many other problems. Concrete on the sidewalk is deteriorating and large chunks are chipping and falling out, creating potholes and jagged edges. The shoulder contains drainage grates that are over half the width of the shoulder and have narrow openings that run parallel with the roadway. The grate openings are large enough that bicycle wheels may become stuck causing riders to crash. Finally, a sharp curve on the western end of the bridge creates conditions where motorists routinely enter the shoulder to avoid slowing down, encroaching on any cyclists who may be riding in the shoulder. Additionally a bridge expansion joint located at this sharp curve creates another hazard to cyclists traveling on the edge of the roadway. This sharp turn also reduces visibility for users who are traveling on the trail in either direction, creating a blind curve leading to unsafe conditions that could cause a collision. The sharp curve and expansion joint conditions can be seen in Figure 8.

Figure 7: MLK Bridge Sidewalk Conditions

Figure 8: MLK Bridge Sharp Curve Conditions

Continuing on the multi-use trail beyond the bridge, the trail returns to a ten foot width throughout the rest of its length but poses other hazards. After the bridge, the trail is sandwiched between a metal fence and motorized traffic for four tenths of a mile, with no buffer beyond a three foot shoulder and curbs separating the users from traffic. Figure 9 shows the trail adjacent to the roadway. The trail has a blind sharp turn for its users in both directions under the Girard Avenue overpass. Painted centerline markings have been added here to aide cyclists. The risk of a head on collision still remains if a person moves out of their designated lane through the turn. Beyond the Sweet Briar Drive intersection, the trail moves into a more open green space with greater separation from the motorized vehicular traffic. Large bumps and cracks have started to form in many areas due to tree roots and frost heaves. An example of the frost heaves can be found in Figure 10. The City of Philadelphia has applied some spot treatments for the more serious bumps, but the quality of the MLK trail surface is nowhere near that of the adjacent roadway. The poor conditions of the multi-use trail cause many cyclists to ride on the adjacent roadway for greater comfort and speed, regardless of the safety of the road. Although many cyclists prefer to ride on the adjacent roadway, the City of Philadelphia has banned bicycle traffic on MLK Drive into the city during the morning rush hour from 7-10am and out of the city on MLK Drive during the evening rush hour from 4-6:30pm.

Figure 9: MLK Trail adjacent to roadway

Figure 10: Cracks forming in MLK Trail

Although the roadway does not permit cyclists during rush hour, the City has taken steps to allow bicyclists and pedestrians to access the roadway by closing it to motorized traffic on weekends during the summer. Every weekend from April to October, MLK Drive is closed to automobile traffic from 7am to 5pm, with the lower mile from the Art Museum to Sweet Briar Drive re-opening at 12pm. The closed roadway allows all types of walkers, joggers, and bikers to escape the confines of the side path and enjoy MLK Drive as a park road.

Connections to Fairmount Park Attractions

MLK Drive provides a link for bicyclists to travel from Center City to many of West Fairmount Park's destinations. Beginning at the Art Museum, cyclists can use the side trail to get from Center City to one of the many attractions found in West Fairmount Park. Using connecting routes at Sweet Briar Drive, Black Road, Montgomery Drive, and the Strawberry Mansion Bridge, cyclists can access the Philadelphia Zoo, Please Touch Museum, Mann Music Center, Horticultural Garden, Japanese Tea House, Belmont Plateau, and any of the wooded trails of West Fairmount Park. The alternative routes to any of these destinations would be longer and take cyclists through neighborhoods unfamiliar to them in the city. Improvements to the safety of MLK Drive could help encourage more people to bike to these destinations instead of driving.

Expressway Conditions on MLK Drive

One of the biggest issues to bicyclist and pedestrian safety on MLK Drive is the roadways location in relation to Interstate 76, otherwise known at the Schuylkill Expressway. The Schuylkill Expressway is the only highway into Philadelphia from the northwest, and this roadway is characterized by its heavy traffic and large delays. MLK Drive parallels the expressway from its intersection with US Route 1 to the Art Museum near Center City. As a result of its parallel location, many commuters into and out of Center City opt to use MLK Drive instead of getting stuck in traffic on I-76.

Additionally, MLK Drive will lead motorists directly to the Ben Franklin Parkway, a direct connection with Center City Philadelphia. Motorists using the Schuylkill Expressway have to use the often congested cross town Vine Street Expressway and a congested exit ramp to access Center City, making this less convenient than using MLK Drive to get directly to Center City. Figure 11 shows a comparison of the MLK Drive to Ben Franklin Parkway route versus the Schuylkill Expressway to Vine Street Expressway Route.

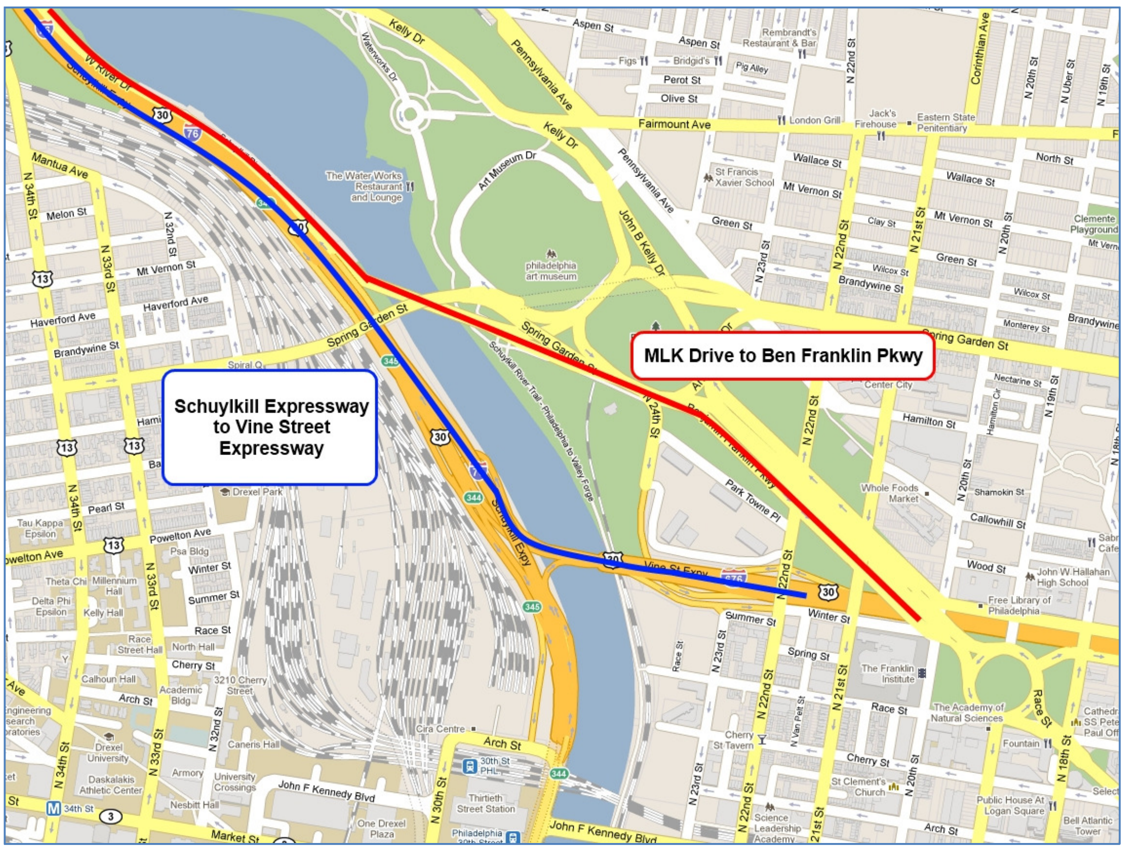

Figure 11: Ben Franklin Parkway vs. Vine Street Expressway

The entire length of MLK Drive has very limited access points, in turn leading to very few disruptions or delays to motorists who wish to use this as a bypass to the interstate. A majority of MLK Drive is four lanes wide with ten foot lanes and no median or shoulder. During field visits to the site, I have personally witnessed many drivers crossing the center yellow dividing line while overtaking another vehicle creating unsafe conditions along the roadway. Limited access points combined with many opportunities for vehicles to pass one another have allowed unsafe expressway like conditions to form on this park roadway.

Chapter 4

DATA COLLECTION

Having attended Drexel University and lived and biked in Philadelphia for five years, I saw firsthand what the conditions were like for bicyclists throughout the city. This experience is what led me to choose a roadway in Philadelphia to evaluate and determine ways to improve cyclist safety. MLK Drive in Fairmount Park was selected after talking to the bicycle advocacy director of the Bicycle Coalition of Greater Philadelphia, John Boyle, and the City of Philadelphia's bicycle and pedestrian coordinator, Charles Carmalt. Both John Boyle and Charles Carmalt had ideas for potential locations to perform a traffic study that would increase roadway space for bicyclists. Several potential locations were brought up – MLK Drive, JFK Boulevard in Center City, the roadways around Franklin Square, and a connection from Center City to Temple University in North Philadelphia.

Further research found that each of these potential locations already had projects underway or were too unfamiliar to me to serve as a good thesis topic. The Center City District Corporation was currently leading a study to investigate alternatives to reconfigure Market and JFK between 15th Street and the Schuylkill River, the area around Franklin Square and the Ben Franklin Bridge will be reconfigured in the next couple years as the Ben Franklin Bridge on ramp is rebuilt, and personally I have no familiarity with North Philadelphia or the Temple University area. After reviewing all the suggestions, MLK Drive appeared to be the best option to produce results that could be potentially useful to aide bicycle advocacy in the City of Philadelphia.

After determining a location to perform the study, the assistant chief traffic engineer for the City of Philadelphia Streets Department, Charles Denny, was contacted. Through him and the Streets Department, preliminary data was obtained for MLK Drive. The Philadelphia Streets Department provided the fixed traffic signal timings for the Sweet Briar Drive and Montgomery Drive intersections, radar speed data collected over a weeklong period from July 27 to August 3, 2009, a pedestrian and bike crash summary from 1999 to 2008, and vehicle volume counts from June and November, 2002.

Traffic Speeds on MLK Drive

The speed limit on MLK Drive is 35 mph, yet rarely do any vehicles travel below this speed. Using an automated radar detector, the Philadelphia Streets Department collected vehicle speed data for a weeklong period from July 27 to August 3, 2009 between Black Road and Sweet Briar Drive. A summary of these results is shown in Table 2.

Table 2: MLK Drive Speed Data – Sweet Briar Drive to Black Road

	Percentile	Speed (mph)
Northbound MLK Drive	15	38
	50	45
	85	**51**
	95	55
Southbound MLK Drive	15	12
	50	45
	85	**53**
	95	58

Over the week long period of time, 85th percentile speeds were found to be 51mph for drivers traveling northbound and 53mph for drivers traveling southbound. The disparity in 15th percentile speeds is due to the presence of the Sweet Briar Drive traffic signal south of the data collection point. The Institute of Transportation Engineers (ITE) states that speed limits are typically set at or below the speed which 85 percent of vehicles are traveling (2004). For the case of MLK Drive, 85 percent of vehicles are traveling around 50mph on a park road with a speed limit of 35mph. Roadway conditions are allowing vehicles to travel at these high speeds. These speeds combined with aggressive passing maneuvers and the presence of bicyclists and pedestrians are creating unsafe conditions for non-motorized users of the trail and roadway.

Accidents on MLK Drive

In the past decade MLK Drive has been the scene of several automobile and bicycle/pedestrian collisions. Data collected by the Philadelphia Streets Department has recorded six collisions between automobiles and bicycles/pedestrians between 2002 and 2008. Of those six collisions, three resulted in injuries to pedestrians, two resulted in injuries to cyclists, and one resulted in a cyclist fatality. The cyclist fatality occurred in May 2004 on a Saturday afternoon, after the portion of MLK Drive south of Sweet Briar Drive had been reopened to traffic and the northern portion remained closed. An automobile traveling north on MLK Drive had slammed into one of the large metal gates that close the northern portion of the roadway, causing the gate to slam open and strike and kill a six year old boy (Bicycle Coalition of Greater Philadelphia 2006). A member of the Bicycle Coalition of Greater Philadelphia was visiting the site only two hours after the boy's death paying his respects to the boy's family and he observed an almost identical collision of a van speeding and colliding into the gate at what appeared to be close to 50 mph (Bicycle Coalition of Greater Philadelphia 2006). This same type of accident had occurred previously and was not recorded in the Streets Department data. In April 2004, a northbound car struck the metal gate and it swung open into six cyclists, injuring three (Bicycle Coalition of Greater Philadelphia 2004).

Most recently, in May 2009, a 29 year old father was cycling with his four year old son on a tandem bicycle while attempting to cross MLK Drive at its southern end near the Art Museum. The father and son were using a marked crosswalk to cross the two southbound traffic lanes heading into center city. As they began to cross, one vehicle stopped and yielded to them, but an impatient driver proceeded to speed around the stopped vehicle and struck the father and son, fracturing the young boy's skull and breaking his pelvis and fracturing the father's arm (Bicycle Coalition of Greater Philadelphia 2009b). Through the persistence of the Bicycle Coalition of Greater Philadelphia, improvements have been made to this intersection, including a recently installed pedestrian activated traffic signal. Although the City has made efforts to improve this intersection, the rest of MLK Drive has not been evaluated to see what improvements can be made to improve the safety of all the roadway users.

Vehicle Counts on MLK Drive

To create a computer micro simulation model of MLK Drive, vehicle volumes and turning movements were collected. Information on trucks and buses was not needed. These vehicles are prohibited from using the roadway because MLK Drive is a winding park road with narrow ten foot lanes and large amounts of bicyclist and pedestrian activity.

Philadelphia Streets Department Data

The Philadelphia Streets Department collected vehicle volumes along the roadway in 2002 and obtained the following data. On Wednesday June 19, 2002, 21,178 vehicles traveled on MLK Drive in both directions from Montgomery Drive to Sweet Briar Drive and on Wednesday November 13, 2002, 26,765 vehicles traveled on MLK Drive in both directions from Black Road to Sweet Briar Drive. The Streets Department traffic counts were divided into one hour intervals and it was found that peak daily volumes occurred during the morning rush hours from 7 to 10am. Although research has shown that the maximum comfortable limit for a road diet is around 15,000 to 18,000 ADT, road diets have been successful up to around 25,000 ADT with this appearing to be the upper limit before LOS becomes seriously affected and unable to accommodate vehicle volumes (Burden and Lagerwey 1999; Knapp

2001). MLK Drive daily traffic volumes are very close to what would be considered the upper most limit of a 4-lane to 3-lane road diet.

For this thesis, AM peak hour data was collected for each of the five intersections along MLK Drive between 7:30am and 9:30am. These included the two signalized intersections at Sweet Briar Drive and Montgomery Drive, the un-signalized intersection at Black Road, and the two un-signalized Strawberry Mansion Bridge on ramps. Montgomery Drive is the only intersection with a dedicated left turn lane from MLK Drive northbound; the others have no dedicated turning lanes. The phasing of the signals at Sweet Briar Drive is shown in Figure 12 and the phasing of Montgomery Drive is shown in Figure 13.

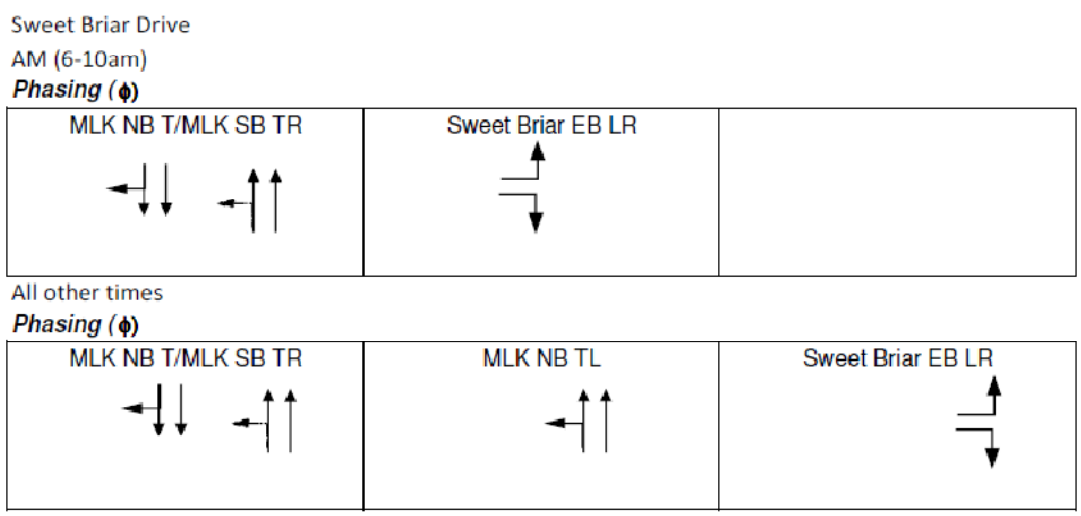

Figure 12: Sweet Briar Drive Phasing

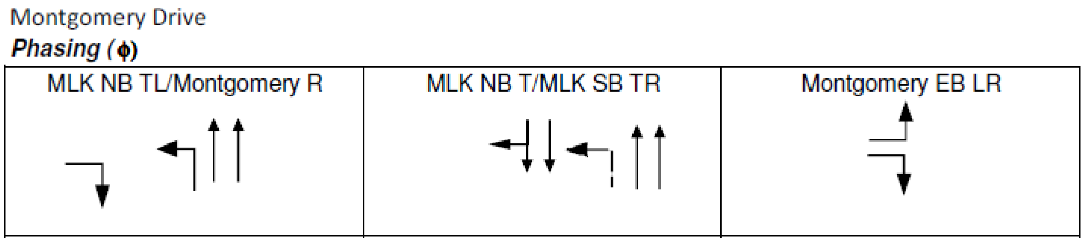

Figure 13: Montgomery Drive Phasing

The Philadelphia Streets Department provided the fixed signal timings for Sweet Briar Drive and Montgomery Drive. Each intersection has a 60 second cycle and the phase timings are listed in Table 3.

Table 3: MLK Drive Signal Timings

MLK Drive Signal Timings (seconds)

Sweet Briar Drive	Green	Yellow	Red
AM Peak (6-10am)			
MLK Drive	33	3.6	2.4
Sweet Briar Drive	14	3.2	2.8
All Other Times			
MLK Drive	20	3.6	2.4
MLK Drive Northbound Lag Left	7	3.6	2.4
Sweet Briar Drive Left/Right Turns	14	3.2	2.8

Montgomery Drive	Green	Yellow	Red
MLK Drive Northbound Protected Left	7	3	2
MLK Drive	22	3	2
Montgomery Drive	16	3	2

Turning Movement Counts

Turning movements and intersection traffic count data were collected during the morning peak hours from 7:30am to 9:30am. Traffic counts were performed manually using counting boxes on a Tuesday, Wednesday, or Thursday to avoid any changes in traffic patterns caused by the weekend. The first series of counts was performed on Tuesday, May 25^{th}, 2010 from 7:30 to 9:15 am under normal conditions and no traffic incidents on the nearby Schuylkill Expressway or Kelly Drive. Three locations were chosen for the first series of counts, the Sweet Briar Drive intersection, Montgomery Drive intersection, and a location on MLK Drive north of the Strawberry Mansion Bridge on-ramps. These locations were chosen so that through movement data could be used to aide in determining turning movements at the lower volume un-signalized intersections. Data counting sheets that show each location and were distributed to the counters can be found in Appendix B.

A second series of counts was performed on Tuesday June 15^{th}, 2010 under normal conditions and no traffic incidents on nearby roads. The first location for the second count was at Black Road. Counts were performed here and only turning movements to and from Black Road were recorded. The second location for the second count was on the Strawberry Mansion Bridge at the intersection where the two on-ramps meet. Counts were performed here to record vehicles entering and exiting the Strawberry Mansion on-ramps. Because turns are restricted to and from the Strawberry Mansion Bridge on-ramps on MLK Drive, the location where the two ramps meet was chosen for the counts. Diagrams of each intersection and the turning movements at each can be found in Appendix A.

Based off of the counts at Sweet Briar Drive, Montgomery Drive, and north of the Strawberry Mansion Bridge, it was found that the peak hour occurred from 7:30am to 8:30am. Traffic count data can be found in Appendix B. The traffic volumes recorded turning to and from Black Road and the Strawberry Mansion on-ramps were observed to be very low while the largest turning movements occurred at Montgomery and Sweet Briar Drives. Although the volumes recorded on Black Road and the Strawberry Mansion on-ramps were not recorded through the entire peak time period, they were representative of the amount of turning movements off of MLK Drive in relation to the amount of through movements during the peak hour. The collected Black Road data was used for the 7:30am to 8:30am peak hour. The collected Strawberry Mansion on-ramp data was only recorded for three 15 minute periods, so the peak hour volumes were determined by approximating the 4th 15 minute period based off of the trend shown in the three collected periods. The resulting traffic volumes at each intersection for the peak hour periods can be found in Appendix B.

Chapter 5

METHODOLOGY

In order to determine the feasibility of implementing a road diet on MLK Drive, a micro simulation model was developed to test alternate roadway configurations. Roadway configurations were limited to only those that could be achieved through changing the pavement markings on the road or minimally modifying the existing bike path at certain locations. The project needed to remain economically feasible and realistic for the City of Philadelphia to implement, so no alternatives were chosen that involved making the roadway wider or required any major construction. All alternatives chosen could be implemented as a pilot project and easily removed in the future if they did not prove to be successful.

The model needed to be able to accurately show various lane width configurations that stayed within the current roadway boundaries as well as incorporate bicycles and their interactions with motorized vehicles. The software used accomplish these goals was VISSIM, developed by PTV America. The VISSIM software can model any roadway vehicle including bicycles. VISSIM can model any roadway layout to match even the most complex geometric design. What really helps make a VISSIM model accurately represent real world conditions is the ability to set up base data distributions for aspects such as vehicle speed and acceleration and control driver behavior parameters such as car following behaviors, lane change movements, lateral, and how drivers respond to signal changes at yellow. These controls help to create a roadway network that has unique vehicles behaving differently from one another, similar to what a person would encounter in real life.

VISSIM also has the ability to create 3D outputs of its simulation models. The 3D mode can be used to create videos from any desired perspective. Aerial views can be recorded to provide an overview of the roadway or videos can be created from the perspective of a bicyclist or automobile driver. These videos enable VISSIM to be a very useful presentation tool for a wide range of audiences who may not be familiar with traffic modeling software.

Base Model

Before modeling any alternative roadway configurations, MLK Drive's current conditions were modeled to create a base scenario that served as a check that the model was working properly. The model was created by first importing an orthographic image of MLK Drive into VISSIM and scaling the image to the model. Next, the base conditions of the model were defined, which included items such as vehicle compositions and speed profiles. Network links and connectors representing the roadway geometry were drawn along the roadway using its existing lane widths and current lane configurations. Vehicle speed decision points and reduced speed areas along MLK drive and the connecting roadways were then defined based off of data provided by the Philadelphia Streets Department. Traffic volumes were input at the edges of the roadway network using the volumes collected in the field. Static routing decisions combined with the turning movement counts were then used to create routes through each intersection. Conflict areas were determined at each intersection to define which traffic flow would yield in situations where two traffic routes conflicted. Finally, signal programs were created based off of the Streets Department data and stop signs were placed at the appropriate intersections. No time offsets were provided by the Streets Department so both traffic signals were set at zero offset. The signal programs used in the base model are shown in Figures 14 and 15.

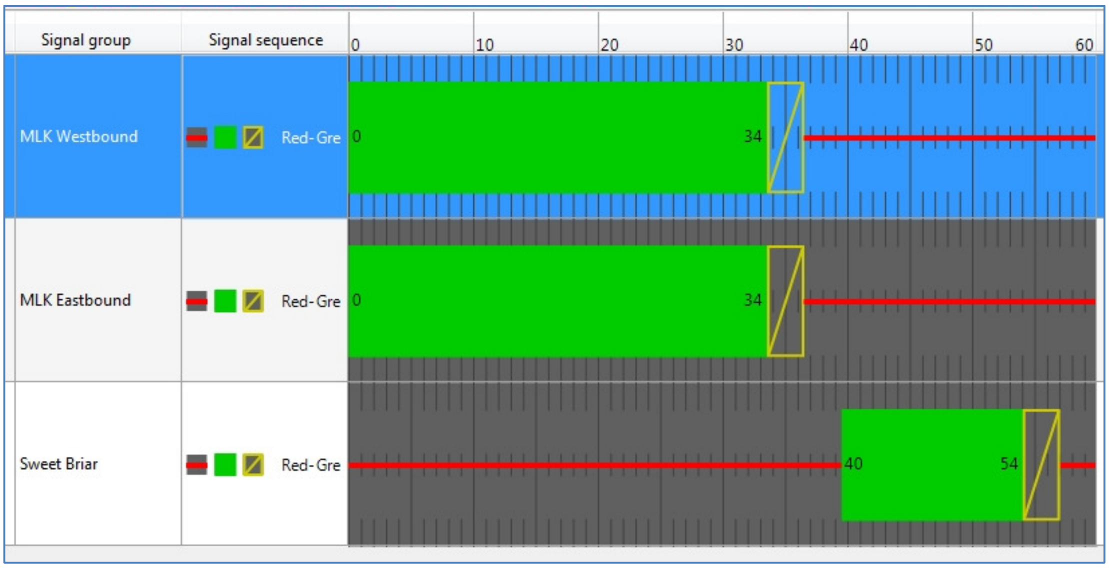

Figure 14: Sweet Briar Drive Signal Program

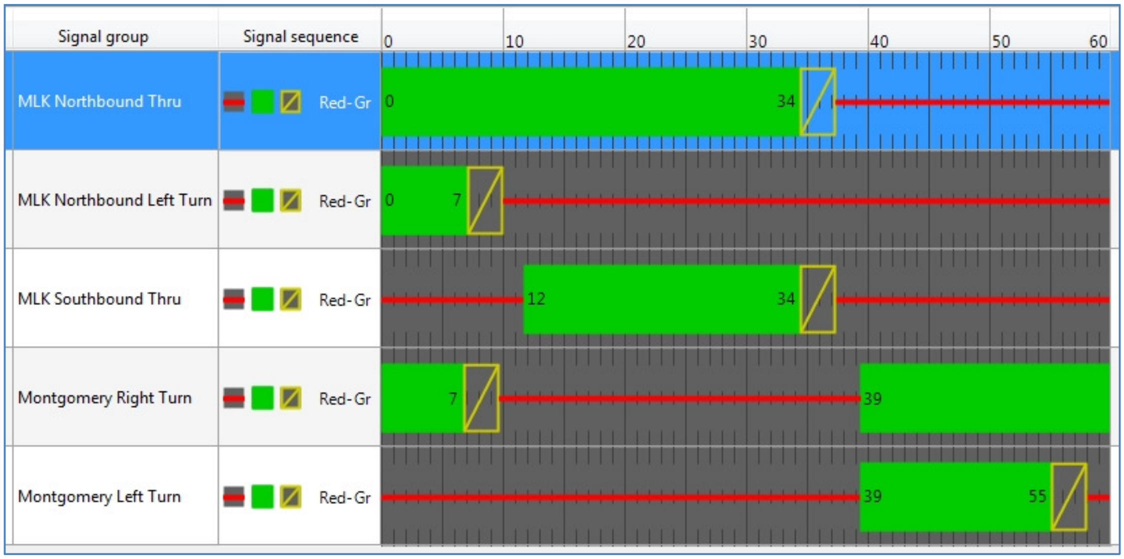

Figure 15: Montgomery Drive Signal Program

After building the base model, the simulation was run and observed for errors in traffic flows that were different from current conditions. Upon observing an error, the base model was edited to correct the error. This process was repeated until the base model functioned the same way MLK currently does in real life. The completed base model would serve as a framework for each alternative scenario so that the network and driver parameters would remain consistent. The parameters need to remain consistent so outputs from each alternative scenario could be compared against the base model. Travel times, delay, and queue lengths at the signalized intersections were the outputs chosen to compare each scenario.

Alternative 1

The first alternative chosen to model involved a road diet implemented along the entire length of MLK Drive. To install this, only the pavement markings would change and the design would remain within the existing curb to curb roadway space. The roadway would be reduced to one motorized vehicle lane in each direction for its entire length. Additionally, a bike lane would be added in each direction along the road. Due to varying roadway widths along its length, motor vehicle travel lanes and the bike lanes would vary in their width as well. Motor vehicle lanes would never become narrower than their current ten foot width and bike lanes would not be narrower than the five foot minimum recommended by AASHTO on roadways with curbs as stated in the Guide for the Development of Bicycle Facilities (1999). The following summarizes the geometry used for alternative 1.

- Art Museum to Sweet Briar Drive – 35ft wide
    - Two 11ft travel lanes with two 6ft bike lanes
- Sweet Briar Drive intersection – 40ft wide
    - Add 10ft left turn lane on MLK Drive northbound
    - Through lanes reduced to 10ft wide
    - 5 ft wide bike lanes through intersection
    - MLK Drive southbound bike lane merges with 8ft southbound right turn lane
- Sweet Briar Drive to Montgomery Drive – 40ft wide
    - Two 12ft travel lanes with two 8ft bike lanes
- Montgomery Drive intersection – increases from 40ft to 50ft wide
    - Two 12ft through travel lanes, 10ft northbound left turn lane, two 8 ft bike lanes
    - MLK Drive southbound bike lane merges with 8ft southbound right turn lane

- Montgomery Drive to train bridge north of Strawberry Mansion – 40ft wide
    - Two 12ft travel lanes with two 8ft bike lanes
- Train bridge narrows road to 30ft width
    - Two 10 ft travel lanes with two 5ft bike lanes
- Train bridge to Falls Road – 35 ft width
    - Two 11ft travel lanes with two 6.5ft bike lanes

A diagram of alternative 1 through Sweet Briar Drive is shown in Figure 16. Bike lanes are drawn in green. More diagrams can be found in Appendix D.

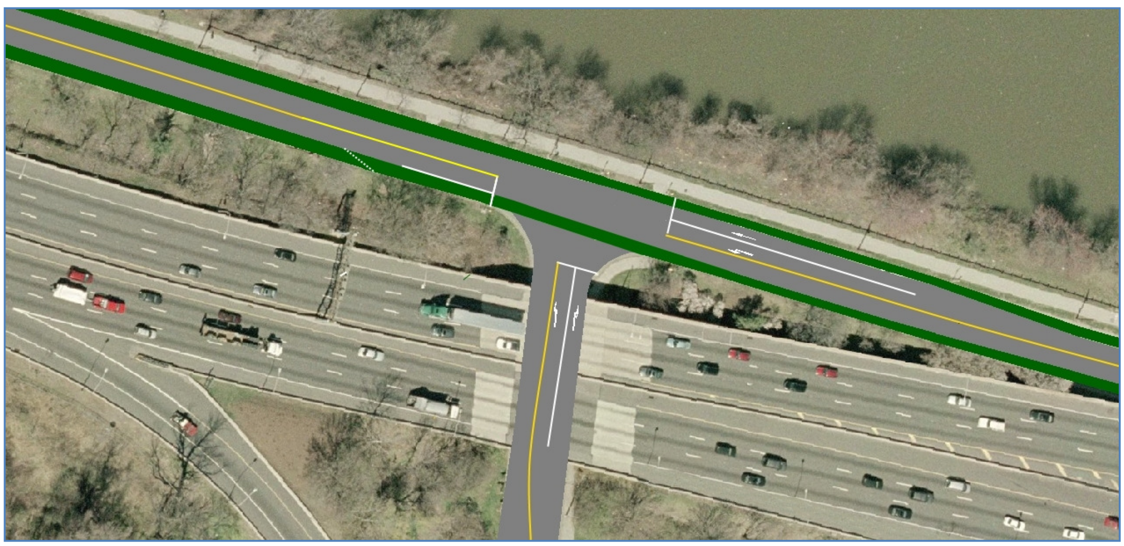

Figure 16: Alternative 1 at Sweet Briar Drive

After modifying the roadway geometry, two scenarios using different traffic signal timings were tested. The first, alternative 1a, looked at what would happen along the road if a road diet was implemented and the traffic signal timings were not changed from their current state. After observing the model it was found that the current signal timings would not work to accommodate the current traffic volumes on a one lane MLK Drive. Because a majority of the traffic is heading into center city in the AM peak, congestion occurred at the Montgomery Drive intersection, creating very long queues north and west of the intersection. A second alternative needed to be considered.

The second scenario, alternative 1b, modified the signal timings at Montgomery Drive and Sweet Briar Drive using a combination of critical movement summary calculations, a Synchro model, and observations in the VISSIM model in an attempt to accommodate the traffic volumes on less roadway space. Alternative 1b also had a protected left turn phase added at the Sweet Briar Drive intersection. Observations of alternative 1a found that the Montgomery Drive intersection was causing large queues to occur for traffic traveling southbound into the city. In the morning peak hour, this is the first signalized intersection vehicles will encounter along MLK Drive as they travel south into the city. Due to these factors, Montgomery Drive was chosen as the critical intersection to analyze and calculate new signal timings for.

The critical movement analysis presented in the Delaware Department of Transportation manual *Standards and Regulations for Subdivision Streets and State Highway Access* (2010) was the first step used in the new signal timing calculations. The full analysis can be found in Appendix C. This analysis determined the critical lane vehicular volumes that would need to move through the intersection during each of its three phases. The critical lane volumes at Montgomery Drive are shown in Table 4.

Table 4: Alternative 1b Critical Movement Analysis

Road	Critical Movement	Critical Lane Volume
MLK	NB Left Turns	216
MLK	SB Through/Right	1586
Montgomery	EB Left Turns	249

After determining the lane volumes that would need to be handled during each of the three groups of phases of the signal, the amount of green time required was calculated using the Greenshield's Model. The full analysis can be found in Appendix C. It was found that even as the cycle length was increased for the intersection, the amount of green time and clearance time (yellow and red time, 3 seconds yellow and 2 seconds red) required continued exceeding the cycle length. There was no cycle length that could accommodate all of the green and clearance time needed for each critical lane volume.

A Synchro model was then built to use to attempt to optimize the signal splits. A 120 second cycle length was chosen based on the green time calculations. Increasing the cycle length above 120 seconds began to significantly increase the difference between the amount of green and clearance time needed versus the desired length of the cycle. Synchro was then used to find the optimal signal timings based on vehicle volumes. The Synchro model produced errors for all directions except the northbound through movements that stated that the volume of traffic exceeded the capacity of the signal after the splits were optimized. This was confirmed by running the Synchro model with a 120 second cycle and the splits optimized. Traffic continued to create very large queues on MLK Drive southbound and on Montgomery Drive.

The results of the critical movement analysis and Synchro model were used to input some initial estimates into the VISSIM model. The initial estimates were based on the assumption that the model would use green times for Montgomery Drive and MLK Drive northbound that were calculated using the 120 second cycle length in the CMS analysis. After observing two of the legs of the intersection flowing properly, the signal controller was adjusted to provide more time for MLK southbound through movements while still allowing the queues to clear out for MLK northbound lefts and both of the turning movements on Montgomery Drive. After many iterations of adjusting the model, the results of the Synchro model were confirmed. There was no signal timing that would work without creating significant queues at the intersection. For the purposes of scenario comparison, the signal timings that allowed Montgomery Drive and MLK Drive northbound left turns to clear without queuing were used. The actual signal timing used in the model compared to the green time calculations and the Synchro model is shown in Table 5.

Table 5: Alternative 1b Green Time Comparison

Alternative 1b
MLK Drive Green Times (seconds)
120 second Cycle, Yellow = 3 sec, Red = 2 sec

Montgomery Drive	**Synchro Optimized Splits**	**Greenshields based on CMS**	**Times Used in Model**
MLK Drive Northbound Protected Left	8	18.4	12
MLK Drive Northbound Through	97	-	90
MLK Drive Southbound Through/Right	84	115	73
Montgomery Drive Right Turns	26	-	37
Montgomery Drive Left Turns	13	20.5	20

The timing for the Sweet Briar Drive intersection was initially started using the same timing as Montgomery Drive and was adjusted with several iterations of observing the VISSIM model run and then changing the amount of time given to each phase. The full timings for each intersection used in alternative 1b can be found in Appendix C.

Alternative 2

After modeling alternative 1 it became clear that very large queues were forming at the signalized intersections. Alternative 2 uses the same roadway configuration as alternative 1 except for at the Sweet Briar and Montgomery Drive intersections. Again in this scenario the only modifications to the roadway are changing the pavement markings, the entire design will fit in the existing curb to curb roadway space. The current design of two through lanes at each of the two signalized intersections is maintained in alternative 2 to allow more capacity through the traffic signals. At all other locations before and after the intersections, MLK Drive returns to the configuration described in alternative 1 with one motorized vehicle travel lane and one bike lane in each direction. In the areas at the two signalized intersections where the bike lane disappears and is replaced with another motorized vehicle travel lane, bicyclists will be forced to share the right most travel lane with automobiles. The VISSIM model was able to show the interaction between bicycles and automobiles sharing these lanes.

While collecting data for the roadway, bicycle counts were not included. MLK Drive is primarily used for recreation outside of the peak rush hour periods with very few origins or destinations found along its length. An approximation of 50 bicycles per hour in the VISSIM model or about 2% of the total number of vehicles on the road was used, consistent with the finding by the Bicycle Coalition that approximately 2% of all trips in the city are made by bicycle (BCGP 2008a).

At Montgomery Drive, the current configuration of two ten foot lanes in each direction is maintained for approximately one eighth of a mile before and after the intersection. At Sweet Briar Drive, the current configuration is maintained one eighth of a mile on the northern side of the intersection but is limited on the southern end by the current three to four lane cross section location which is about one tenth of a mile south of the intersection. At all other locations MLK Drive has one travel lane and one bike lane in each direction that uses the same cross section widths as defined in alternative 1. A diagram of alternative 2 at Sweet Briar Drive is shown in Figure 17, bike lanes shown in green. More diagrams can be found in Appendix D.

Figure 17: Alternative 2 at Sweet Briar Drive

Traffic signal timings for alternative 2 will not change from those in the base model. The intersection design has maintained the same amount of travel lanes so the capacity has not been changed.

Alternative 3

The third alternative differs from alternatives 1 and 2 in the fact that instead of incorporating a bike lane on the roadway, existing roadway space is used to improve the multi-use path that runs along the side of the road. As discussed previously, the multi-use path along MLK Drive is in bad condition at certain locations, the most notable being where it is only five feet wide as it goes over the bridge near the art museum. After the bridge, the path continues to run directly adjacent to the roadway with no buffer other than a three foot shoulder and curb for the next four tenths of a mile. Just south of the Sweet Briar Drive intersection, the path has a very sharp blind curve under the Girard Avenue overpass. As described in further detail in the background section, this first mile of the trail can be unsafe and difficult to use.

Alternative 3 studies the feasibility of making MLK Drive one lane in each direction south of Sweet Briar Drive and keeping the rest of the roadway in its current configuration. This southern section of MLK Drive will have two twelve foot lanes shifted west so that they are adjacent to the Schuylkill Expressway retaining wall. The newly opened space on the right hand side of the roadway can be used to expand the multi-use path or provide a separate two way on road path for cyclists to use through this narrow portion of the trail, connecting back up to the trail after the Girard Avenue overpass. This option may require more work than simply remarking the pavement. Ramps to the trail may need to be built, the trail may need to be expanded, or some type of buffer may need to be constructed to separate vehicular traffic from trail users. No modifications will need to be made to MLK Drive north of and including the Sweet Briar Drive intersection.

Figure 18 shows a diagram of alternative 3 at the bridge over the Schuylkill River. The multi-use path is shown in bright green while a buffer area is represented in brown.

Figure 18: Alternative 3 at the MLK Bridge over the Schuylkill River

<u>Alternative 4</u>

The problem with alternative 2 was the fact that the bike lanes suddenly ended at each of the two signalized intersections. Alternative 4 provides a solution to maintaining two through lanes in the peak traffic direction at each signalized intersection while also creating an unbroken bike lane the entire length of MLK Drive. This scenario will use the same roadway cross sections as alternative 2 for most of its length, except five foot wide bike lanes will be maintained through each signalized intersection and reversible lanes will be used through the intersection depending on the direction of peak traffic flow along the roadway. MLK Drive is mostly used as a commuter arterial bringing people into Center City Philadelphia to work in the morning and taking people out of Center City in the evening. The traffic flows along the road are much higher towards Center City during the AM peak hours and are much higher away from Center City during the PM peak hours. This alternative will use reversible lanes at Montgomery Drive and Sweet Briar Drive to allow two through lanes into the city in the morning and two through lanes out of the city in the evening.

Aside from teaching the public how to use the reversible lanes, the biggest obstacle will be designing them so that a center lane can easily be reversed while also ensuring that left turns can be made and there is room for at least a five foot bike lane. A preliminary layout of both the Sweet Briar Drive intersection and the Montgomery Drive intersection has been designed to accomplish these goals.

Sweet Briar Drive Intersection

The Sweet Briar Drive intersection has a forty foot wide curb to curb width. Currently, there are four ten foot wide lanes squeezed in this area. To accommodate a five foot bike lane in each direction with reversible lanes, alternative 4 will have a cross section at this intersection with two five foot bike lanes and three ten foot motor vehicle lanes. During the morning peak (6-10am at the same time the traffic signal is currently set to function on), two of the motor vehicle lanes will be reserved for traveling into the city and one will be reserved for leaving the city. Only 121 left turns from MLK northbound on to Sweet Briar were counted in the morning. This number is low compared to 419 through movements in the MLK northbound lanes, 1279 through movements in the MLK southbound lanes, and 411 right turns from Sweet Briar to MLK. To make the reversible lanes work, left turns will be prohibited during the morning peak (6-10am). During the evening peak (3-7pm), two lanes will be reserved for motorists traveling out of the city while one lane will remain for those traveling into Center City Philadelphia. At all other times of day, the center lane will become a left turn only lane for motorists traveling northbound on MLK

Drive. Left turns will also be permitted during the evening rush hour as the reversible lane condition will create a similar scenario to what currently exists in the evening, two outbound lanes with a lag protected left turn phase onto Sweet Briar Drive. Figure 19 shows a schematic of how MLK drive could be striped to accomplish these goals.

Figure 19: Alternative 4 with reversible lanes at Sweet Briar Drive

<u>Montgomery Drive Intersection</u>

Montgomery Drive was a bit more challenging to design reversible lanes through due to the higher amount of left hand turns. The width of this intersection has been increased as compared to the roadway before and after it to accommodate a dedicated left hand turn lane from MLK Drive northbound. The approaches to and from this intersection are forty foot wide, with the intersection enlarging to fifty foot wide at the signal. The fifty foot wide cross section only lasts for about 300ft south of the intersection and 100ft north of the intersection. A similar strategy will be used for

Montgomery Drive that was used at Sweet Briar Drive. Two through lanes will be reserved for motorists entering the city during the morning peak hours (6-10am) and two through lanes will be reserved for motorists leaving the city during the evening (3-7pm) peak hours. At all other times the center lane will be reserved for left turns from MLK Drive northbound. The amount of left turns from MLK Drive northbound during the AM peak hour is very close to the number of through movements (216 left turns, 285 through movements). Additionally, motorists who are now unable to turn left at Sweet Briar Drive may choose to turn left at Montgomery Drive in the alternative 4 scenario.

Because of these reasons it was important to ensure that left turns could be made while still allowing through movements to pass during the AM peak. If left turns were allowed and through movements did not have a dedicated space to pass, motorists may end up using the bike lane instead and endanger cyclists. Using a dedicated left hand turn lane would make reversing the lanes even more confusing to drivers by additional pavement markings. Instead, a slip lane was placed to the right of the rightmost northbound through lane. The slip lane would only need to be used in the morning peak to allow motorists to bypass automobiles that are waiting to turn left from MLK Drive to Montgomery Drive. At the other times of the day there will either be two through lanes or a dedicated center turning lane. More detail on how to mark the pavement to prevent motorists from using this slip lane feature at other times of the day would need to be designed at a later point if this alternative was chosen to be used. A diagram of the pavement markings at this intersection are shown in Figures 20 and 21. Bike lanes are shown in green and the reversible lane boundaries are a dashed yellow line.

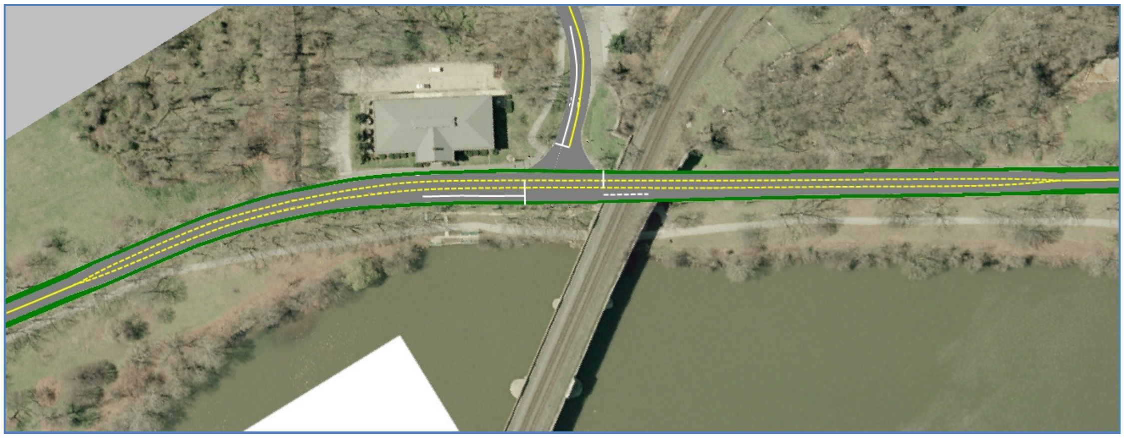

Figure 20: Alternative 4 at Montgomery Drive with reversible lanes

Figure 21: Alternative 4 slip lane at Montgomery Drive

There is only one aspect of this design that will not be able to be modeled. The PM peak configuration at Montgomery Drive will have two through lanes with the left most lane being a shared left turn/through lane. Because there is currently a dedicated left turn lane and in this alternative the PM peak will not have one, further data collection and modeling of the PM peak would need to be done to see if this scenario could work.

Comparison Measures of Performance

Three main measures of performance were used to compare the four alternative roadway configurations to the current conditions. VISSIM is able to record travel times, delays, and queue lengths for different sections of the roadway as determined by the user. To determine the feasibility of each alternative roadway configuration, travel times along various points of the roadway, delays in each direction of MLK Drive, and queue lengths at each signalized intersection were compared to the conditions present in the base model. The VISSIM model was configured to run for one hour of simulation time. When the simulation is initially run, vehicles are only entering the network at the endpoints of the links, each end of MLK Drive and the five intersecting roads. In order to ensure that the network had been seeded and all of the entering vehicles were dispersed throughout, data was collected from fifteen minutes to one hour of simulation time.

As previously indicated, the largest traffic volumes during the morning rush hour occur on the southbound lanes of MLK Drive that take traffic into Center City Philadelphia. Changes in the roadway configuration will have the biggest impact on the southbound MLK Drive traffic flow during the AM peak hour. Four locations along MLK Drive southbound were chosen to record travel times in order to see where the trouble locations occurred and one travel time location was used to compare travel times on MLK Drive northbound. Travel times were recorded for the entire length of

MLK Drive in each direction and three smaller segments were additionally recorded for portions of MLK Drive southbound. The following summarizes where the travel times were recorded.

- 1 - MLK Southbound – Railroad bridge under Route 1 to western side of Schuylkill River bridge near Art Museum
    - Distance – 19420 ft (3.68 mi)
- 2 - MLK Northbound – Western side of Schuylkill River bridge near Art Museum to Railroad bridge under Route 1
    - Distance – 19400 ft (3.67 mi)
- 3 - MLK Southbound – Strawberry Mansion Southern On-Ramp to western side of Schuylkill River bridge near Art Museum
    - Distance – 14400 ft (2.73 mi)
- 4 - MLK Southbound – Montgomery Drive to western side of Schuylkill River bridge near Art Museum
    - Distance – 10920 ft (2.07 mi)
- 5 - MLK Southbound – Sweet Briar Drive to western side of Schuylkill River bridge near Art Museum
    - Distance – 6370 ft (1.21 mi)

Delay times were recorded for the entire length of MLK Drive in both directions. In VISSIM the delay is measured by comparing the ideal travel time with no signals or no other vehicles to the actual travel time. Speed decision points and reduced speed areas are considered in the ideal travel time. Delay times were only measured using the locations of travel time 1 (MLK Southbound entire length) and travel time 2 (MLK Northbound entire length).

Finally queue lengths were used to determine if any areas were becoming more congested than the base model conditions. Queue counters were placed at the signalized intersections at Montgomery Drive and Sweet Briar Drive to record average queue lengths and maximum queue lengths in each direction.

Chapter 6

RESULTS

The large amount of traffic using MLK Drive to enter Center City Philadelphia during the AM peak hour had the biggest impact on changes to travel times, delays, and queue lengths of alternative scenarios in comparison to the current conditions. In alternative 1, it was observed that large queues formed at the Montgomery Drive intersection. The traffic volumes at this intersection were exceeding the capacity on Montgomery Drive and MLK Drive southbound, creating queues on these approaches that only kept increasing with time. Alternatives 2, 3, and 4 each looked at maintaining capacity through the two signalized intersections while also creating space for bicycles on the roadway. Although these three alternatives maintained capacity through each intersection, they took away travel lanes elsewhere. The analyses will quantify the effects of each alternative roadway configuration as compared to the base model.

Travel Times

The first performance measure looked at was the travel times along MLK Drive. Table 6 summarizes the results generated after running each scenario. A more detailed breakdown of travel time results can be found in Appendix E.

Table 6: Travel Times Summary

Travel Time Section 1 - MLK Southbound – Entire length						
3.68 miles	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
Time (minutes)	5.89	17.19	11.67	7.18	6.40	6.79
Ave Speed (mph)	37.5	12.8	18.9	30.7	34.5	32.5

Travel Time Section 2 - MLK Northbound – Entire length						
3.67 miles	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
Time (minutes)	5.24	5.59	5.54	5.60	5.24	6.47
Ave Speed (mph)	42.1	39.5	39.8	39.3	42.1	34.1

Travel Time Section 3 - MLK Southbound – Straw. Mansion South Ramp to bridge near Art Museum						
2.73 miles	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
Time (minutes)	4.56	9.08	7.65	5.72	5.08	5.32
Ave Speed (mph)	35.9	18.0	21.4	28.6	32.2	30.8

Travel Time Section 4 - MLK Southbound – Montgomery Drive to bridge near Art Museum						
2.07 miles	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
Time (minutes)	3.25	3.55	4.50	3.83	3.75	3.76
Ave Speed (mph)	38.1	34.9	27.6	32.4	33.1	33.0

Travel Time Section 5 - MLK Southbound – Sweet Briar Drive to bridge near Art Museum						
1.21 miles	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
Time (minutes)	1.75	1.91	1.95	2.06	2.23	2.01
Ave Speed (mph)	41.4	37.9	37.2	35.2	32.4	36.1

As observed when running the model, the largest area of concern was traffic traveling on MLK southbound at the Montgomery Drive intersection. Travel time section 1 was first looked at to see the effects each configuration had along the entire length of MLK Drive southbound. The first major discrepancy to notice is that the travel times for alternative 1a went up by a factor of 3 and alternative 1b went up by a factor of 2 as compared to the base model. The base model travel time for the entire length of MLK Drive heading southbound was 5.89 minutes. Alternative 1a increased this travel time to a total of 17.19 minutes while alternative 1b increased it slightly less to 11.67 minutes. Modifying the signal timings for alternative 1b helped to improve travel times from alternative 1a, yet these increases are still too high for either alternative to be considered acceptable to motorists. Alternatives 2, 3, and 4 each showed only a slight increase in travel times from the base model's time of 5.88 minutes (5 min 53 sec). Along the entire length of MLK Drive southbound the travel times for alternative 2 increased by 1.29 minutes (1 minute 17 seconds), alternative 3 by 0.51 minutes (30 seconds), and alternative 4 by 0.9 minutes (54 seconds). Although alternative 2 and alternative 4 had very similar lane configurations, alternative 2 demonstrated a larger increase in travel times due to the fact that bicyclists were forced to share the lane with motorists. Alternatives 2, 3, and 4 did not increase travel times along MLK Drive southbound by more than one and a half minutes from the base model's time. The low increase in travel times indicates that these alternatives could be feasibly implemented with only minor impacts to the motorists who travel along this road.

Travel times in section 2 along MLK Drive northbound did not change very much from the base model. As discussed previously, a majority of traffic is heading into the city during the AM peak hour so volumes out of the city were low. The largest increase in travel times northbound occurred in alternative 4 with an increase of 1.23 minutes (1 minute 14 seconds). This increase was due to the additional volume of vehicles that were forced to go straight through the Sweet Briar intersection and either continue straight or turn left at Montgomery Drive. There were times during the alternative 4 model run when vehicles waiting to turn left onto Montgomery queued up to a point where they blocked the through traffic from progressing through. Alternative 3 did not change the configuration of MLK Drive northbound from its current condition and northbound travel times did not change. Alternatives 1 and 2 northbound travel time increased by 20 seconds due to the loss of lanes and additional merge points created.

Travel time sections 3, 4, and 5 were used to look for locations along MLK Drive southbound where travel times changed significantly after going through a congested area. As expected, travel times for alternative 1 increased greatly when measured starting north of Montgomery Drive, but fell to a similar range of all the other alternatives when measured starting south of Montgomery Drive. The other alternatives did not exhibit any large changes caused by bottlenecks as seen with alternative 1.

After reviewing the travel times it was found that alternative 1 would not be a feasible configuration to implement along MLK Drive when considering current traffic volumes. Alternatives 2, 3, and 4 would not impose a significant increase in travel times to motorists traveling into the city and would be considered feasible designs. Although these alternatives have a slight increase in travel times, travel times still remained within one and a half minutes of the base model and the average speed along the road decreased, helping to calm traffic.

Delay

After looking at travel times I then wanted to compare the average delay of the base model to each alternative. VISSIM defines delay as the increase in travel times as compared to an ideal road with no traffic signals or other traffic present (speed decisions and reduced speed areas are still in place). Table 7 summarizes the overall delay along the entire length of MLK Drive southbound and northbound. A detailed breakdown of delay times can be found in Appendix E.

Table 7: Delay Times Summary

Delay Section 1 - MLK Southbound – Entire length						
	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
Average Delay (sec)	60.4	740.9	406.7	135.1	93.6	102.9
Average Delay (min)	1.01	12.35	6.78	2.25	1.56	1.72

Delay Section 2 - MLK Northbound – Entire length						
	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
Average Delay (sec)	20.6	41.7	39.5	38.3	22.4	94.0
Average Delay (min)	0.34	0.69	0.66	0.64	0.37	1.57

The delay time results are consistent with the observed travel times. Along MLK Drive southbound, alternative 1a and 1b show a significant increase in delay as compared to the base model. The delay for alternative 1a increased by 11.34 minutes while the delay for alternative 1b increased by 5.77 minutes. These increases in delay are almost identical to the increases in travel time for alternative 1 as compared to the base model. Compared to the base model the remaining delays increased by 75 seconds for alternative 2, 33 seconds for alternative 3, and 43 seconds for alternative 4. The increases in delay for alternatives 2, 3, and 4 remained low and would still be acceptable along the roadway. The northbound increase in delays as compared to the base model continued to remain very low and was consistent with the results observed in the travel time section.

Queue Length

Finally, queue lengths at each signalized intersection were compared to see if traffic was backing up or reaching lengths similar to the base model. Looking at the queue lengths helped to determine if the queue was able to clear out after every cycle or if they gradually built up over time. Queue lengths gradually building up over time would exhibit average lengths significantly higher than the base model and would noticeably increase over the 15 minute observation periods. Table 8 shows a summary of average queue lengths and maximum queue lengths measured in feet at each signalized intersection along MLK Drive. Queues forming on Montgomery Drive and Sweet Briar Drive were not considered because the lights were timed to allow these roads to clear. If bottlenecks were forming along these side roads, MLK Drive would also be bottlenecking to due to a problem downstream of the intersection. A detailed breakdown of queue lengths by the time interval they were measured in can be found in Appendix E.

Table 8: Queue Length Summary

Queue 1 - MLK Southbound at Montgomery Drive												
	Base Model		Alt 1a		Alt 1b		Alt 2		Alt 3		Alt 4	
	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length
Length (ft)	96	420	3864	4018	3715	4018	225	581	107	484	122	416

Queue 2 - MLK Northbound at Montgomery Drive												
	Base Model		Alt 1a		Alt 1b		Alt 2		Alt 3		Alt 4	
	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length
Length (ft)	2.333	52	6	102	4	77	3	55	3	46	130	691

Queue 3 - MLK Southbound at Sweet Briar Drive												
	Base Model		Alt 1a		Alt 1b		Alt 2		Alt 3		Alt 4	
	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length
Length (ft)	82	348	111	568	2111	3503	39	241	81	369	39	239

Queue 4 - MLK Northbound at Sweet Briar Drive												
	Base Model		Alt 1a		Alt 1b		Alt 2		Alt 3		Alt 4	
	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length
Length (ft)	19	99	11	142	4	100	20	61	12	110	14	169

The biggest concerns for queuing were along MLK Drive southbound. While running the model for alternative 1, it was observed that large volumes of traffic queued up north of Montgomery Drive. The analysis results confirm this with the average queue length reaching close to 0.75 miles long in alternative 1, near the maximum queue length measurement of 4000ft that had been defined in VISSIM. The average queue length of 0.75 miles further shows that alternative 1 would not be feasible to implement. When looking at the next intersection south of Montgomery, Sweet Briar Drive, alternative 1a begins to function without significant queuing while alternative 1b has a queue that slowly increases throughout the hour. The detailed data by 15 minute interval in appendix E shows the queue starting at 945 ft and increasing to 2700 ft by the end of the hour. This indicates that even after changing the signal timing at Montgomery and Sweet Briar Drives, alternative 1 will continue to not have enough capacity to move the current vehicle volumes.

Along MLK Drive southbound, alternatives 3 and 4 exhibit levels of queuing that are similar to the base model. Each of these alternatives' southbound queues cleared out after every light cycle and did not create any backup. Alternative 2 has an average queue length of 225 feet along MLK Drive southbound at Montgomery Drive, 129 feet longer than the base models average queue of 96 feet. Although the queue length is about 6 car lengths longer than the base model, MLK Drive southbound at Montgomery Drive in alternative 2 still cleared out after every cycle and did not create a constantly growing queue. At Sweet Briar Drive the queue lengths for alternative 2 returned to levels similar to the base model that also continued to clear after each cycle.

The queue lengths for each alternative along MLK Drive northbound remained very short and able to clear out after every light cycle. The only place the average queue lengths increased was in alternative 4 at Montgomery Drive. This is due to the presence of the slip lane and left turning vehicles remaining in the main through lane. Occasionally the vehicles waiting to turn left onto Montgomery would block through movements. In a real situation, motorists would probably use the bike lane to go around this. This design issue would need to be dealt with in more detail at a later point. Although this configuration showed slightly longer queuing than the base model, it still cleared out after each light cycle.

Chapter 7

CONCLUSIONS AND FUTURE WORK

After reviewing the results of each alternative model configuration, it has become clear that some of the alternatives proposed would be feasible with current traffic volumes while others would not work. In addition to feasibility as determined through travel times, delays, and queues in the VISSIM model, each alternative design also presents unique challenges to the City of Philadelphia in getting drivers to comply with the new potential roadway configuration. Future work will need to be done to better understand the effects each alternative design could have on driver behavior and how the design could be modified to account for those behaviors.

A common solution proposed to improve cycling conditions along MLK Drive has been to implement a road diet along its entire length, reducing the roadway to one through lane in each direction. The model results for alternative 1 showed that this configuration will not be able to handle current AM peak hour traffic volumes along MLK Drive. Even after attempting to optimize the signal timings at Montgomery and Sweet Briar Drives, unacceptable queues still occurred at each intersection. Assuming traffic levels would remain similar to their current conditions; this alternative would not be feasible.

The study of alternative 1 did not account for the effect that implementing a road diet would have on changing overall traffic volumes and patterns. Motorists may realize that MLK Drive has become congested and choose one of many alternate routes in the area. If this design were implemented, motorists may adjust their traffic patterns to take alternate routes and traffic volumes could balance out to a point where a road diet along the entire length would be feasible. Further research is needed to look at current conditions on the surrounding roadway network and routes into Center City in the area to determine if some of the traffic from MLK Drive would be shifted elsewhere. By increasing the study area and looking at commuting patterns along the Schuylkill River corridor, the potential shift in traffic volumes from MLK Drive could be considered. It is important to note that this effect can already be observed with weekend traffic patterns during the spring and summer when MLK Drive is completely closed to automobile traffic.

After realizing a road diet would not work along the entire length with current volumes, alternatives 2 and 4 each looked at ways to maintain current capacity through the signalized intersections while implementing a road diet on MLK Drive in between. The changes in travel times, delay, and queue lengths from the base model were much lower than the road diet along the entire length option and showed that either of these designs could be feasible with current vehicle volumes. Alternative 2 poses a safety hazard to cyclists at each signalized intersection by requiring the cyclist to share the right most travel lane with automobile traffic. Sharing the lane for a quarter mile at each intersection may intimidate inexperienced cyclists and discourage them from using the bike lane. Conflicts could emerge with automobiles overtaking cyclists too closely or exhibiting road rage because a cyclist was in the motorist’s way. Because MLK Drive is primarily a recreational cycling route and is widely used throughout the day, a partial solution to this problem would be to only allow the right most travel lane through each intersection to be used during the weekday peak rush hour. Future research could be done to determine whether appropriate signage or pavements markings could be used to inform motorists of the available use of the right hand lane during rush hour. This research would also need to consider issues such as motorists disregarding the signage and using the right most lanes to aggressively pass slower drivers throughout other times of the day.

The reversible lanes found in alternative 4 offers a solution to the shared lane problem found in alternative 2. This configuration allows enough space to run a bike lane through each intersection while also maintaining two lanes of through capacity in the peak travel direction based on the time of day. The biggest obstacle this alternative would face is teaching motorists how to properly use the reversible lanes. This type of configuration is not present anywhere else within the city of Philadelphia and would require a publicity campaign and lots of signage to inform motorists of the proper use. Even if motorists were aware of the proper use, a disproportionate amount may choose to remain in the outermost lane for fear of getting confused about time of day rules in the center lane. The VISSIM model did not account for motorists using each lane at an un-proportional rate; this could affect proper functioning of the roadway. Further research could look at cities that have implemented reversible lanes and what the initial public reaction was to these designs. Additionally, a study would need to be performed to analyze the effects of the reversible lane configuration on the PM peak rush hour. The left hand turn lane at Montgomery Drive would be removed during the PM rush hour; it is unclear how this would affect traffic flows.

In alternatives 1, 2, and 4 another issue will need to be solved, the problem of impatient motorists attempting to use the bike lane as a travel lane. On several occasions I have witnessed Philadelphia motorists blatantly disregarding traffic laws to get ahead of a traffic queue at a signal or to pass slower moving motorists. I have heard stories from friends who still encounter motorists still attempting to use the new bike lanes on Spruce and Pine Streets as a travel lane. Future work may need to be done to determine the best way to design the bike lane so that bicyclists are safe and motorists do not attempt to use the lane to travel in. Buffer areas should be considered with some sort of physical markers, such as evenly spaced flexible plastic vertical posts. Creating a small median buffer space with paint between travel lanes and reducing the bike lane width could also discourage motorists from using the bike lane. For modeling purposes an eight foot bike lane was used, but future work should refine this design to help keep motorists out of the bike lane while also allowing regular maintenance such as street sweeping and snow removal.

Expanding the bike path in alternative 3 is the only configuration that focuses on using roadway space to improve the existing path. This alternative has the smallest impact on the current roadway configuration and after running the model it was found that this would be a very feasible design alternative. The biggest issue with expanding the bike path is the construction costs. All of the other alternatives relied on restriping the roadway and creating additional signage, alternative 3 may require new path construction or at a minimum the addition of curb cuts to and from the current path. If the path is expanded, large amounts of construction will be needed to relocate curbs and create a new level space next to the existing path. Expanding the path will not be easily reversible and may be a permanent commitment by the city. This alternative allowed flexibility to also use the right most travel lane as a two way bike path to help avoid the narrow conditions of the existing path. Designing the alternative in this way will require less construction but still may need to create buffer zones, add curb cuts to transition from the existing path, and potentially cut through the existing guide rail near Sweet Briar Drive. Future work could involve developing a cost effective design for improving the bike path along the southernmost mile of MLK Drive.

The VISSIM software was able to demonstrate that there is potential to create a more bicycle friendly MLK Drive without significantly effecting current motor vehicle traffic flow. While a simple road diet may need to be studied in more detail to determine its effects on the surrounding roadway network, designs that maintain capacity through the signalized intersections have been shown to have a minimal effect on roadway performance. Alternatives 2, 3, and 4 are all very feasible configurations to implement on MLK Drive. Any or a combination of these layouts could be studied further to create a design to use as a pilot project for the City of Philadelphia.

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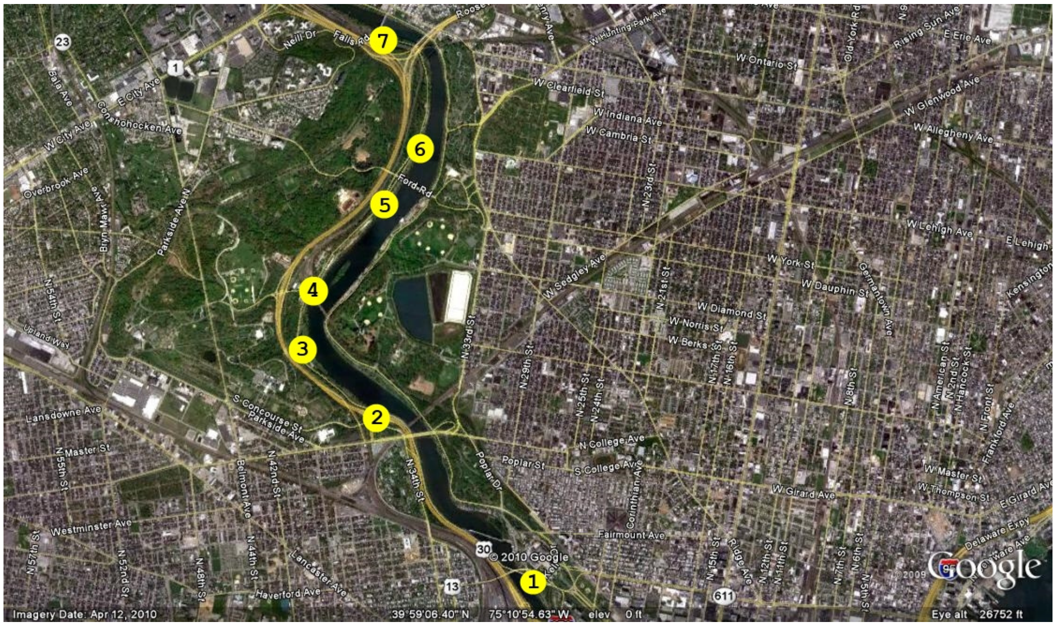
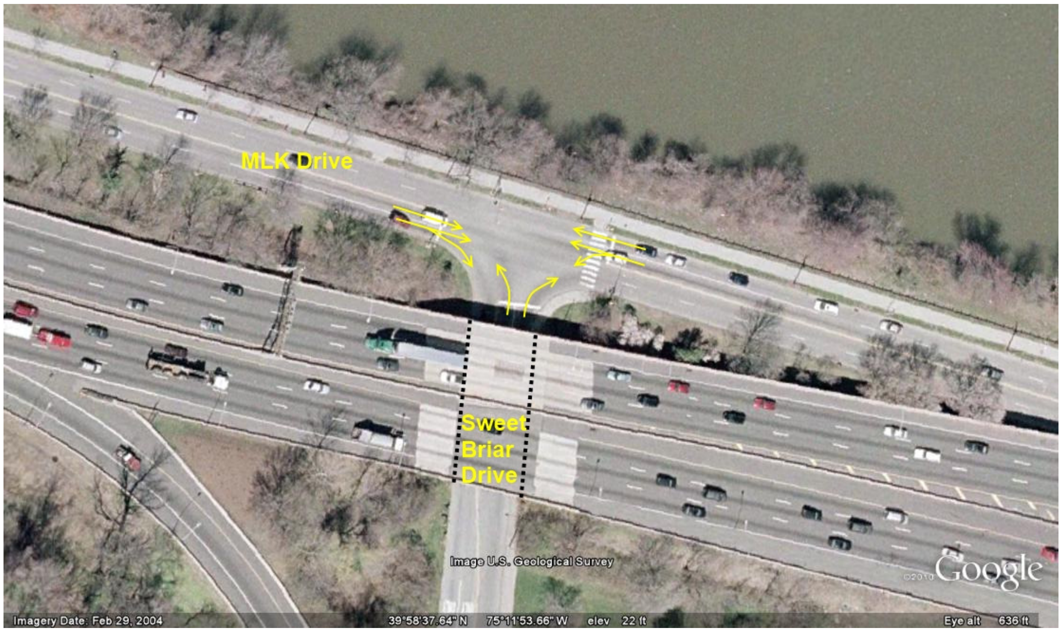
APPENDIX A – INTERSECTION DIAGRAMS

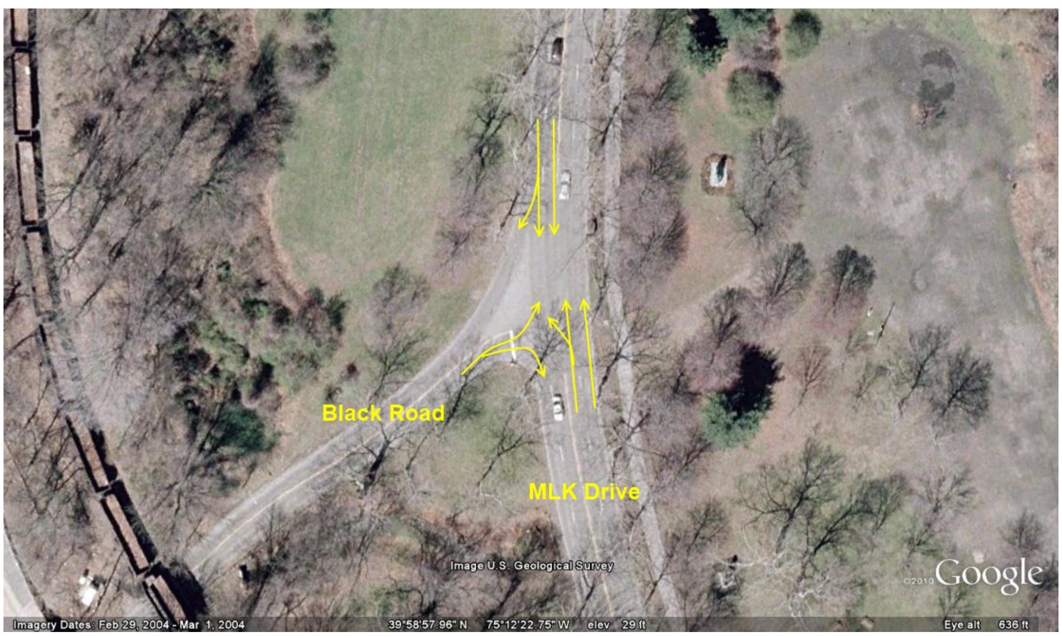


MLK Drive Overview

1 - MLK Drive Southern Terminus near Art Museum



2 – Sweet Briar Drive

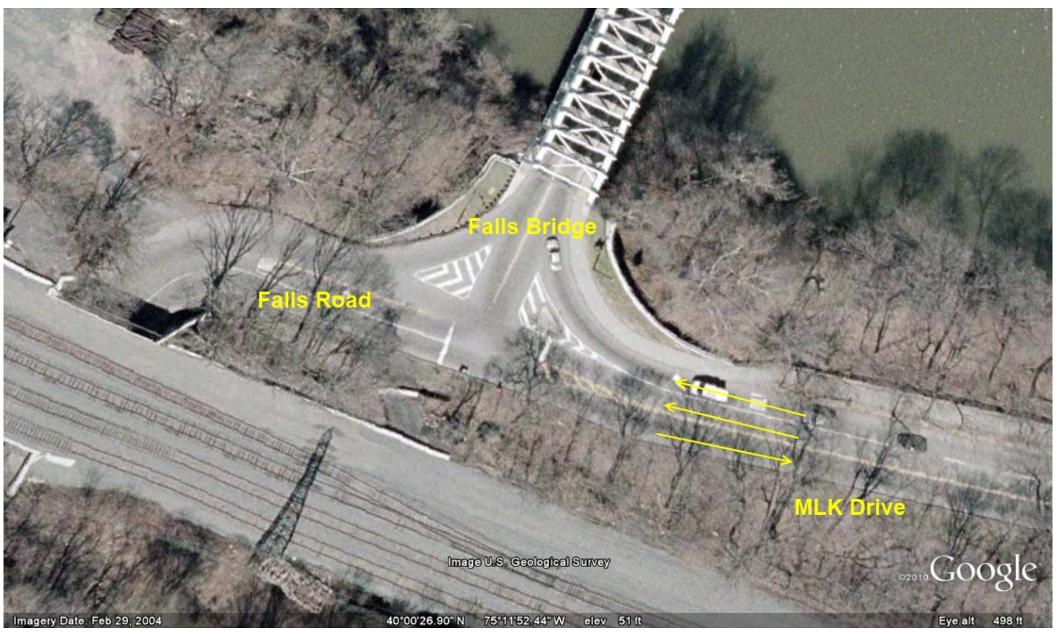


3 – Black Road

4 – Montgomery Drive

5 – Strawberry Mansion Bridge Southern Ramp

6 – Strawberry Mansion Bridge Northern Ramp



7 – MLK Drive Northern Terminus at Falls Bridge

APPENDIX B – TRAFFIC COUNT DATA

Counting Sheets

Intersection: West River Drive North of Strawberry Mansion

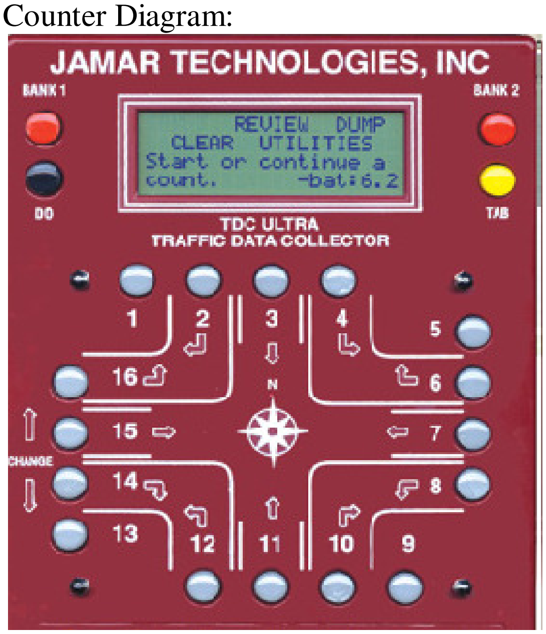
Intersection Code 1

Counter ID Number: ______________________

Machine Count Number: __________________________

Location Diagram:

Counter Diagram:



Intersection: West River Drive and Montgomery Drive

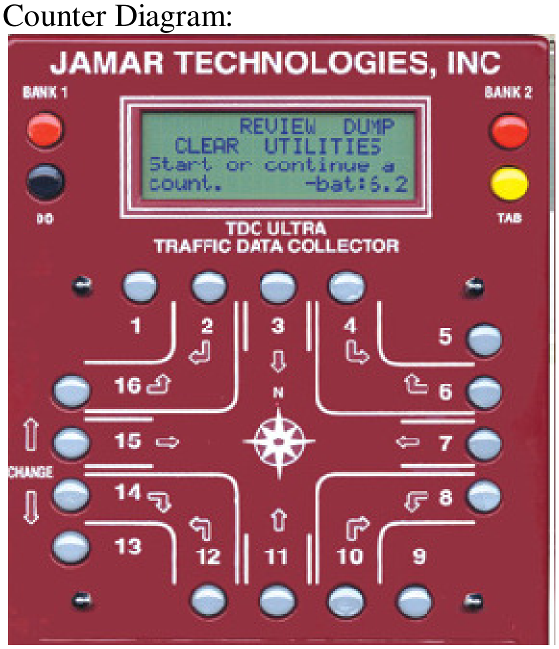
Intersection Code 2

Counter ID Number: ______________________

Machine Count Number: __________________________

Location Diagram:

Counter Diagram:



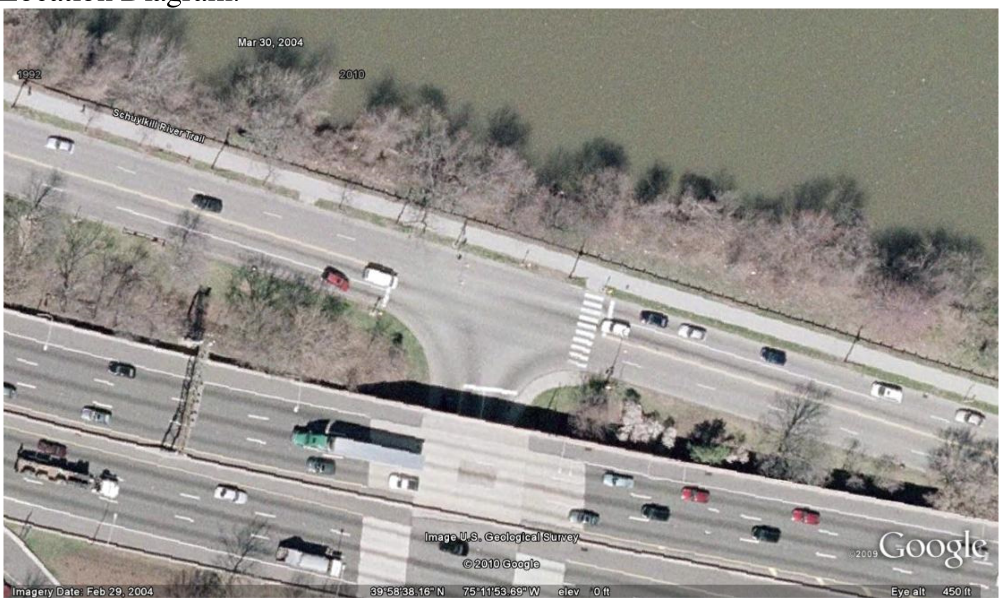
Intersection: West River Drive and Sweet Briar Drive

Intersection Code 3

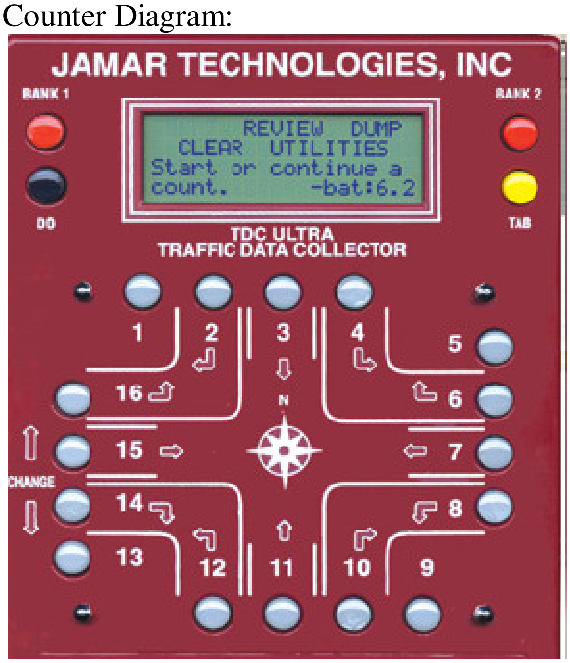
Counter ID Number: ______________________

Machine Count Number: __________________________

Location Diagram:



Counter Diagram:



Raw Data

Location: MLK Drive North of Strawberry Mansion Bridge
Start Date: 5/25/2010
Start Time: 7:30:00 AM

	MLK Drive From North	MLK Drive From South
Start Time	Thru	Thru
07:30 AM	336	130
07:45 AM	369	123
08:00 AM	336	144
08:15 AM	357	130
08:30 AM	321	128
08:45 AM	353	95
09:00 AM	239	73

Location: MLK Drive and Montgomery Drive
Start Date: 5/25/2010
Start Time: 7:30:00 AM

	Montgomery Drive From West		MLK Drive From North		MLK Drive From South	
Start Time	Right	Left	Right	Thru	Thru	Left
7:30 AM	87	50	32	335	86	41
7:45 AM	120	57	55	386	67	61
8:00 AM	84	76	42	338	65	54
8:15 AM	121	66	37	361	67	60
8:30 AM	100	54	43	322	66	48
8:45 AM	119	43	35	360	54	52
9:00 AM	91	34	38	260	43	44

Location:	MLK Drive and Sweet Briar Drive					
Start Date:	5/25/2010					
Start Time:	7:30:00 AM					
	Sweet Briar Drive From South From North		MLK Drive From West From East		MLK Drive From East From West	
Start Time	Right	Left	Right	Thru	Thru	Left
7:30 AM	119	19	97	296	111	27
7:45 AM	112	20	102	364	99	32
8:00 AM	107	28	109	302	96	37
8:15 AM	103	18	103	317	113	25
8:30 AM	96	21	98	313	92	25
8:45 AM	86	5	115	341	88	35
9:00 AM	83	11	95	262	61	23

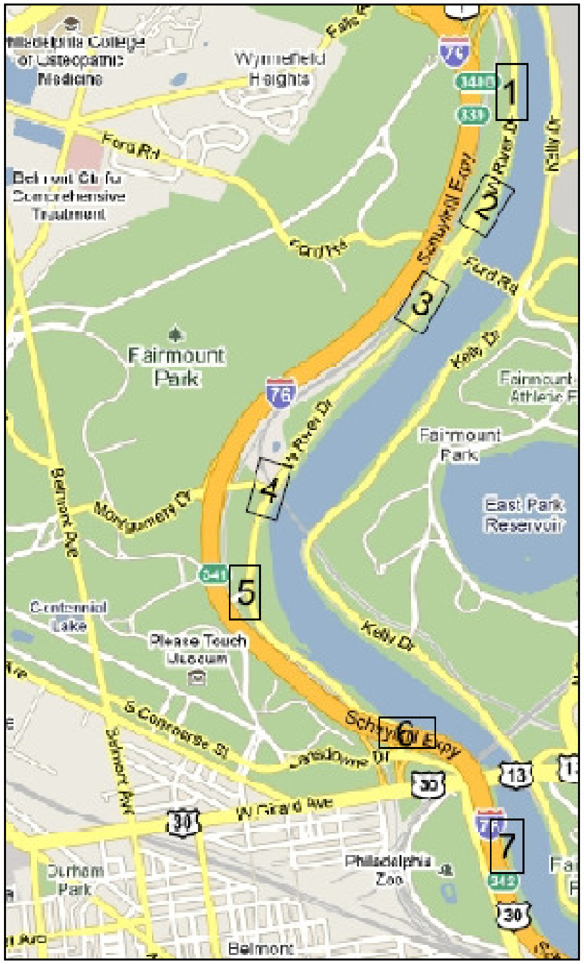
Location:	MLK Drive and Black Road					
Start Date:	6/15/2010					
Start Time:	7:00:00 AM					
	Black Road From West From North		MLK Drive From North		MLK Drive From South From West	
Start Time	Right	Left	Right	Thru	Thru	Left
7:00 AM	1	3	20	-	-	0
7:15 AM	2	4	26	-	-	1
7:30 AM	3	1	31	-	-	0
7:45 AM	4	7	35	-	-	3

Location:	MLK Drive and Strawberry Mansion South On Ramp					
Start Date:	6/15/2010					
Start Time:	8:15:00 AM					
	South On Ramp From West From North		MLK Drive From North		MLK Drive From South From West	
Start Time	Right	Left	Right	Thru	Thru	Left
8:15 AM	43	0	-	-	-	-
8:30 AM	65	0	-	-	-	-
8:45 AM	45	0	-	-	-	-

Location:	MLK Drive and Strawberry Mansion North On Ramp					
Start Date:	6/15/2010					
Start Time:	8:15:00 AM					
	North On Ramp From West From North		MLK Drive From North		MLK Drive From South From West	
Start Time	Right	Left	Right	Thru	Thru	Left
8:15 AM	0	2	15	-	-	-
8:30 AM	0	2	16	-	-	-
8:45 AM	0	2	10	-	-	-

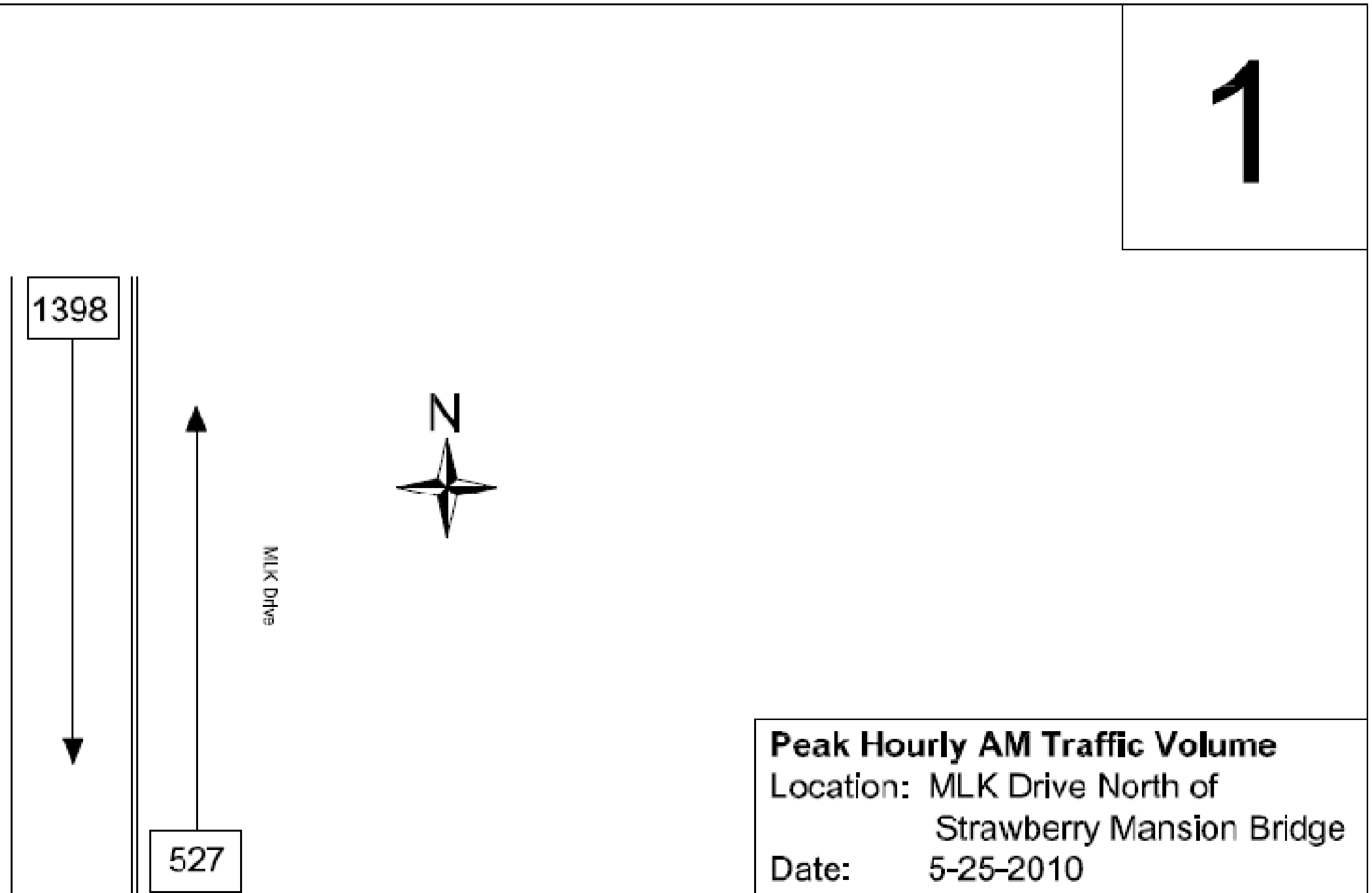
Peak Hour Diagrams

0



Peak Hourly AM Traffic Volume
Location: Index
Date: 5-25-2010
Time: 7:30 - 8:30 AM

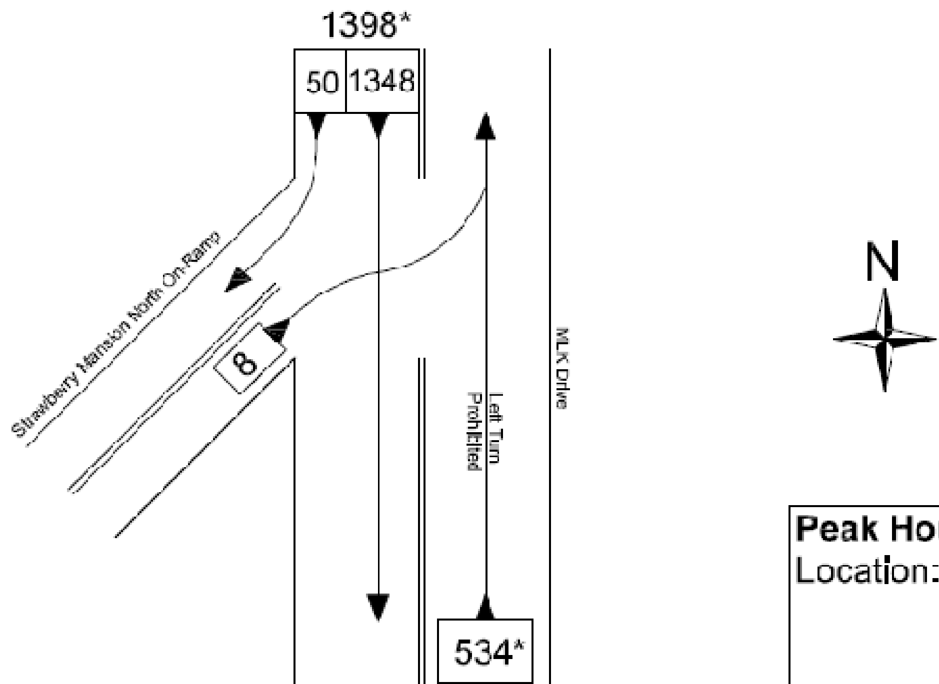
Data Collection Performed by:
University of Delaware
Booz, Lee, Bedeley



Peak Hourly AM Traffic Volume
Location: MLK Drive North of Strawberry Mansion Bridge
Date: 5-25-2010
Time: 7:30 - 8:30 AM

Data Collection Performed by:
University of Delaware
Booz, Lee, Bedeley

2

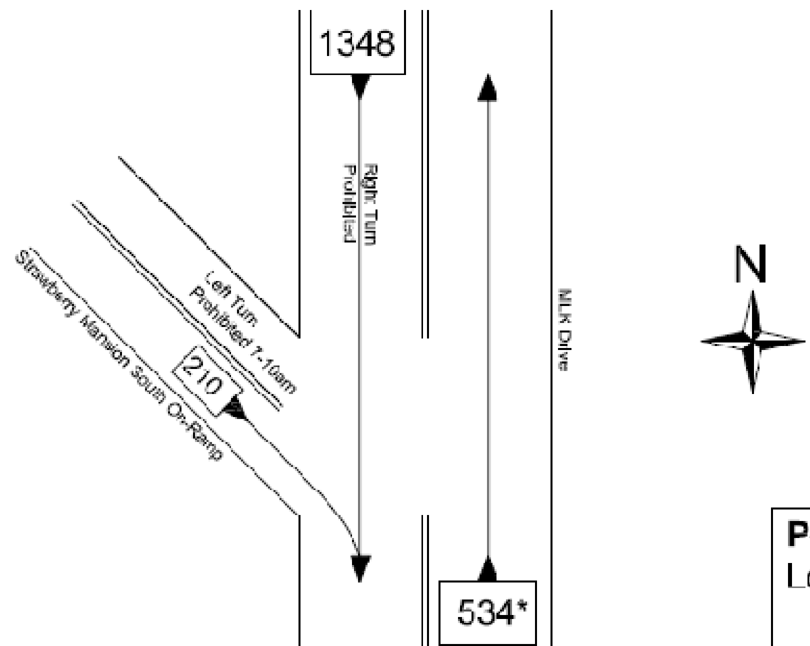


*MLK Volume from 5-25-2010 Count Used

Peak Hourly AM Traffic Volume
Location: MLK Drive and Strawberry Mansion Bridge North On-Ramp
Date: 6-15-2010
Time: 7:30 - 8:30 AM

Data Collection Performed by:
University of Delaware
Booz, Lee, Bedeley

3

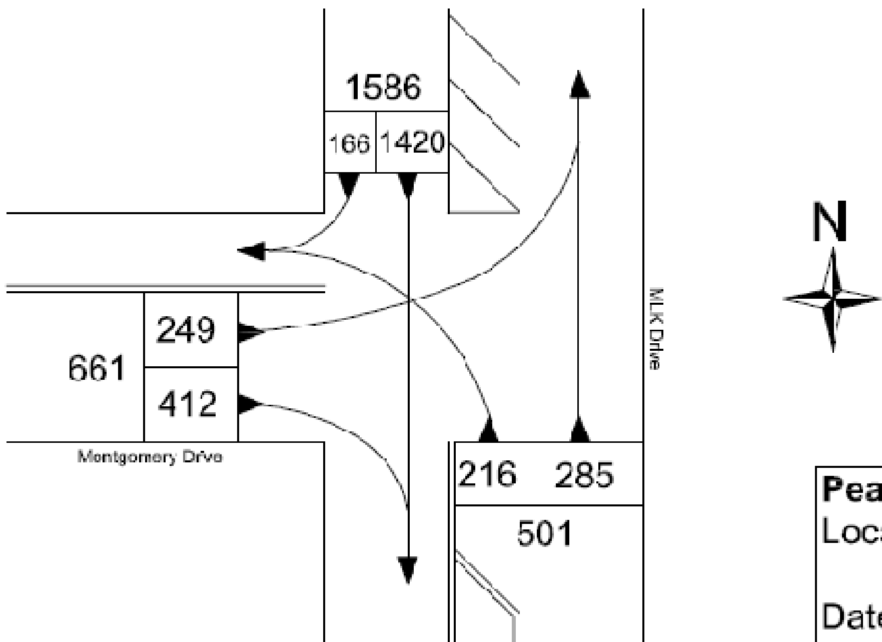


Peak Hourly AM Traffic Volume
Location: MLK Drive and Strawberry Mansion Bridge South On-Ramp
Date: 5-25-2010
Time: 7:30 - 8:30 AM

Data Collection Performed by:
University of Delaware
Booz, Lee, Bedeley

*MLK Volume from 5-25-2010 Count Used

4



Peak Hourly AM Traffic Volume

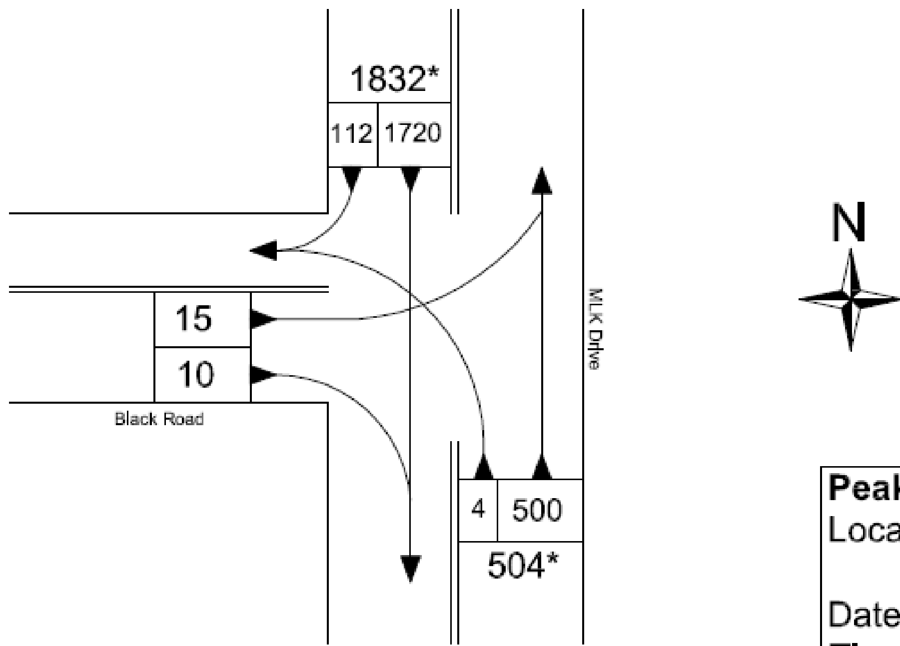
Location: MLK Drive and Montgomery Drive

Date: 5-25-2010

Time: 7:30 - 8:30 AM

Data Collection Performed by:
University of Delaware
Booz, Lee, Bedeley

5

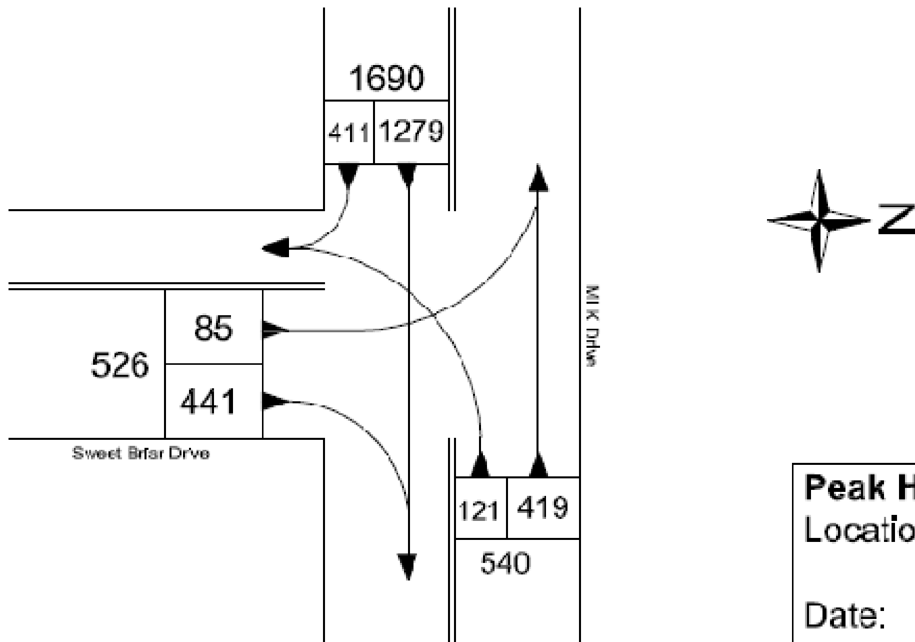


Peak Hourly AM Traffic Volume
Location: MLK Drive and Black Road
Date: 5-25-2010
Time: 7:30 - 8:30 AM

Data Collection Performed by:
University of Delaware
Booz, Lee, Bedeley

*MLK Volume from 5-25-2010 Count Used

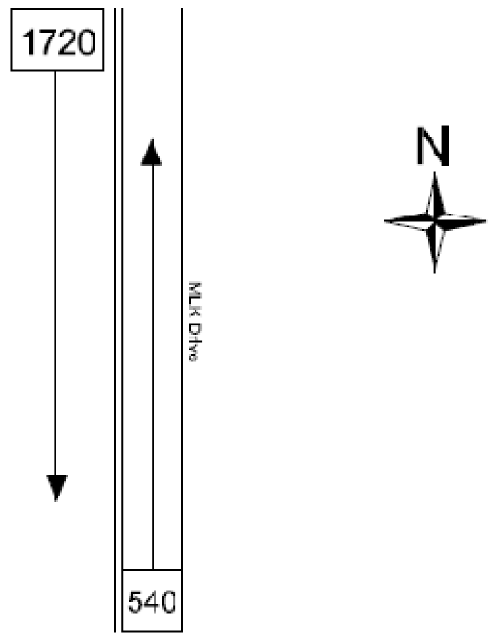
6



Peak Hourly AM Traffic Volume
Location: MLK Drive and
Sweet Briar Drive
Date: 5-25-2010
Time: 7:30 - 8:30 AM

Data Collection Performed by:
University of Delaware
Booz, Lee, Bedeley

7



Peak Hourly AM Traffic Volume
Location: MLK Drive South of Sweet Briar Drive
Date: 5-25-2010
Time: 7:30 - 8:30 AM

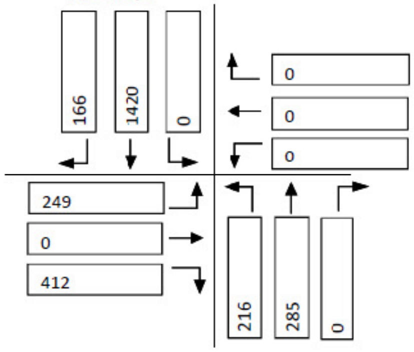
Data Collection Performed by:
University of Delaware
Booz, Lee, Bedeley

APPENDIX C – ALTERNATIVE 1B SIGNAL TIMING CALCULATIONS

Critical Movement Analysis

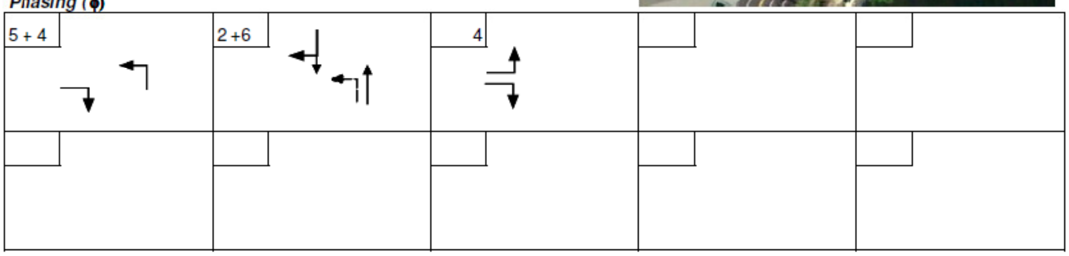
DelDOT **CRITICAL LANE MOVEMENT SUMMATION AND LEVEL OF SERVICE**	Location: MLK Drive and Mongtomery Drive Count Date: 5/25/2010 Scenario: Alternative 1b - 1 through lane in each direction on MLK Drive Computed By: TLB Checked By: Date: 12/14/2010 Date:

Peak Hour:



Lane Configuration:

Phasing (ϕ)



ϕ	Movement	Volume	LU	Lane Volume	OL	LTC	Critical Lane Volume	CM (*)
5	NB L	216	1.00	216			216	*
6	SB TR	1586	1.00	1586			1586	*
2	NB T	285	1.00	285		216	69	
4	EB L	249	1.00	249			249	*
4	EB R	412	1.00	412		216	196	
Remarks:	EB R and NB L are conncurrent, credit given to EB R for NB L turns					TOTAL	1998	
						LEVEL OF SERVICE	F	

Level of Service

Level	Critical Movement Volume
A	Less than 1,000 veh/hr
B	1,000 to 1,150 veh/hr
C	1,151 to 1,300 veh/hr
D	1,301 to 1,450 veh/hr
E	1,451 to 1,600 veh/hr
F	More than 1,600 veh/hr

Lane Use Factors

No. of Lanes	Lane Use Factor (LU)
1	1.00
2	0.55
3	0.40
4	0.30

OL = Opposing Lefts
LTC = Left Turn Credit

Green Time Calculations

Alternative 1b
Signal Timing Calculations
MLK and Montgomery Drive
AM Peak: 7:30 - 8:30 AM

Cycle Length (seconds) 60		Cycles Per Hour 60				
Road	Critical Movement	Critical Lane Volume	Vehicles per Cycle	Green Time Required	Clearance	
MLK	NB Left Turns	216	3.6	12	5	
MLK	SB Through/Right	1586	26.4	60.4	5	
Montgomery	EB Left Turns	249	4.2	12	5	
			Total	84.4	15	99.4

Cycle Length (seconds) 75		Cycles Per Hour 48				
Road	Critical Movement	Critical Lane Volume	Vehicles per Cycle	Green Time Required	Clearance	
MLK	NB Left Turns	216	4.5	14.2	5	
MLK	SB Through/Right	1586	33.0	73	5	
Montgomery	EB Left Turns	249	5.2	14.2	5	
			Total	101.4	15	116.4

Cycle Length (seconds) 90		Cycles Per Hour 40				
Road	Critical Movement	Critical Lane Volume	Vehicles per Cycle	Green Time Required	Clearance	
MLK	NB Left Turns	216	5.4	14.2	5	
MLK	SB Through/Right	1586	39.7	87.7	5	
Montgomery	EB Left Turns	249	6.2	14.2	5	
			Total	116.1	15	131.1

Cycle Length (seconds) 100		Cycles Per Hour 36			
Road	Critical Movement	Critical Lane	Vehicles per Cycle	Green Time Required	Clearance

		Volume				
MLK	NB Left Turns	216	6.0	16.3	5	
MLK	SB Through/Right	1586	44.1	96.1	5	
Montgomery	EB Left Turns	249	6.9	18.4	5	
			Total	130.8	15	145.8

Cycle Length (seconds) 120		Cycles Per Hour 30				
Road	Critical Movement	Critical Lane Volume	Vehicles per Cycle	Green Time Required	Clearance	
MLK	NB Left Turns	216	7.2	18.4	5	
MLK	SB Through/Right	1586	52.9	115	5	
Montgomery	EB Left Turns	249	8.3	20.5	5	
			Total	153.9	15	168.9

Cycle Length (seconds) 150		Cycles Per Hour 24				
Road	Critical Movement	Critical Lane Volume	Vehicles per Cycle	Green Time Required	Clearance	
MLK	NB Left Turns	216	9.0	22.6	5	
MLK	SB Through/Right	1586	66.1	142.3	5	
Montgomery	EB Left Turns	249	10.4	24.7	5	
			Total	189.6	15	204.6

Signal Timings used in VISSIM Model

Alternative 1b

MLK Drive Signal Timings (seconds)

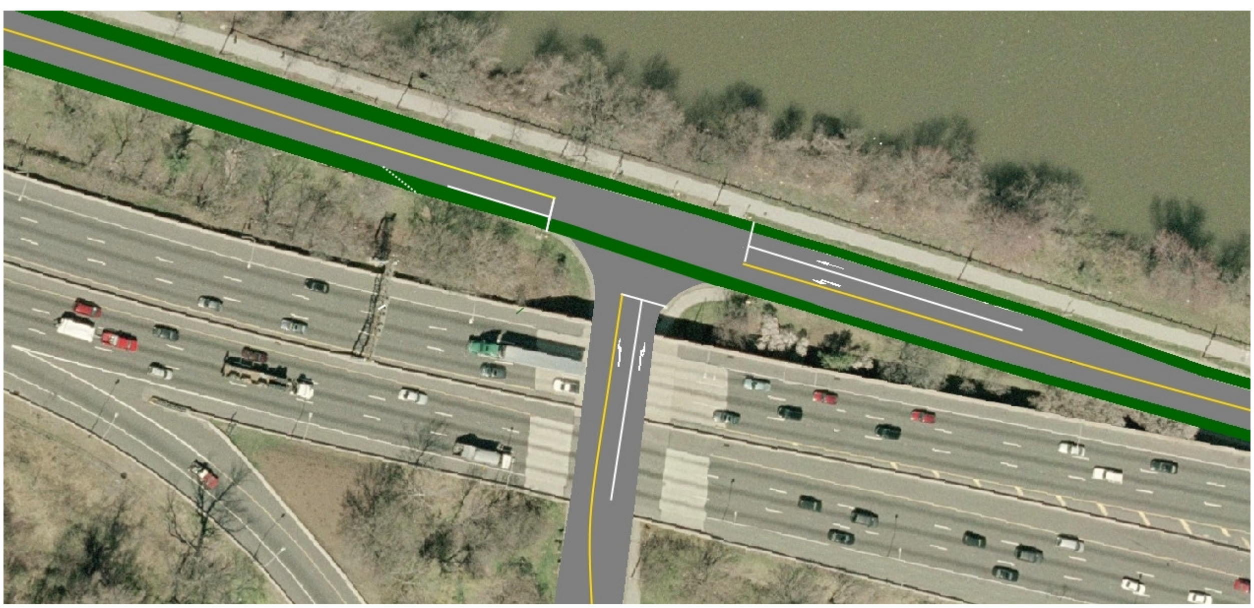
Sweet Briar Drive	Green	Yellow	Red
MLK Drive Westbound Protected Left	15	3	2
MLK Drive Westbound Through	98	3	2
MLK Drive Eastbound Through	78	3	2
Sweet Briar Drive Right Turns	32	3	2
Sweet Briar Drive Left Turns	12	3	2

Montgomery Drive	Green	Yellow	Red
MLK Drive Northbound Protected Left	12	3	2
MLK Drive Northbound Through	90	3	2
MLK Drive Southbound Through/Right	73	3	2
Montgomery Drive Right Turns	37	3	2
Montgomery Drive Left Turns	20	3	2

APPENDIX D – ALTERNATIVE CONFIGURATION DIAGRAMS

<u>Alternative 1</u>

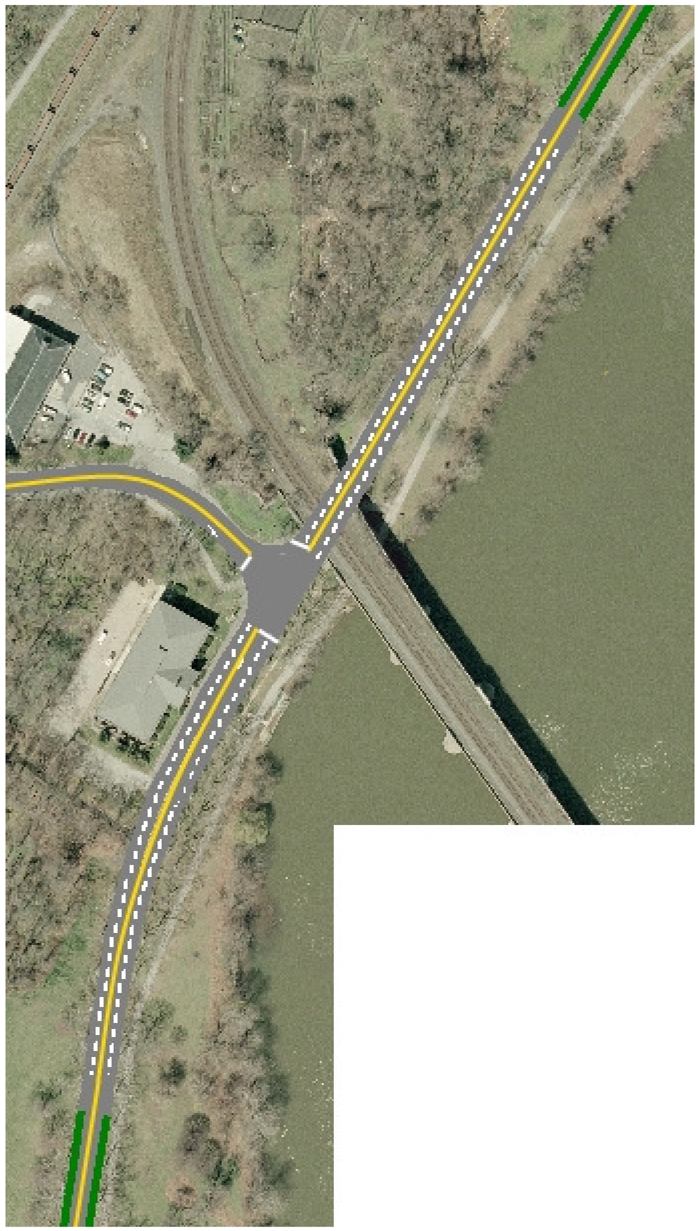
Alternative 1 at Montgomery Drive Intersection



Alternative 1 at Sweet Briar Drive Intersection

Alternative 1 Typical Section

Alternative 2



Alternative 2 at Montgomery Drive Intersection


Alternative 2 at Sweet Briar Drive Intersection

Alternative 3


Alternative 3 at MLK Drive bridge over Schuylkill River

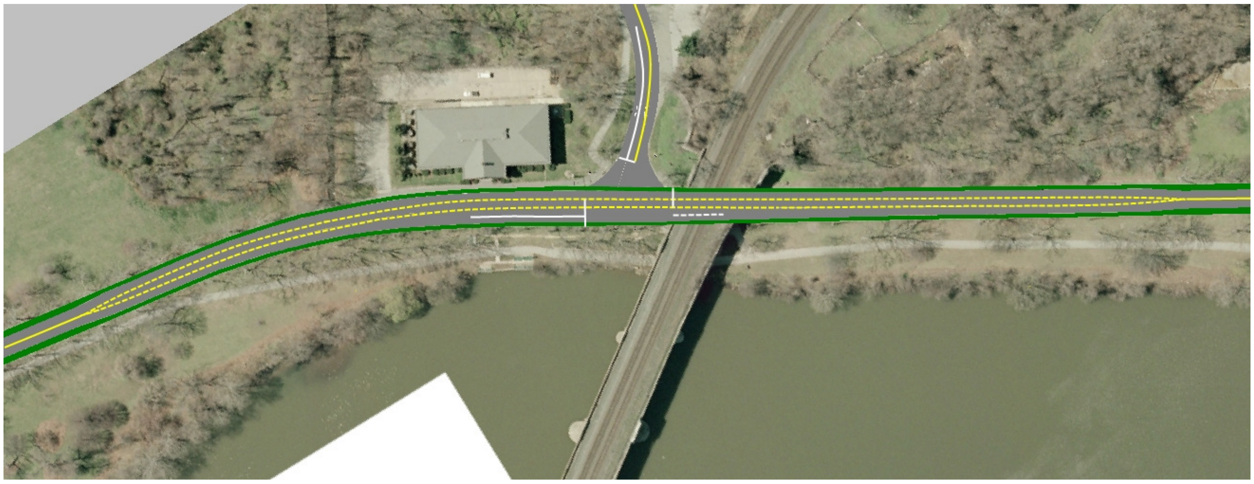
Alternative 3 path with increased buffer between itself and MLK Drive

Alternative 3 split at Girard Avenue underpass

Alternative 3 at Sweet Briar Drive intersection

Alternative 4

Alternative 4 at Sweet Briar Drive



Alternative 4 at Montgomery Drive intersection

Alternative 4 slip lane at Montgomery Drive

APPENDIX E – ANALYSIS RESULTS

<u>Travel Times</u>

Travel Time Section 1 - MLK Southbound – Railroad bridge under Route 1 to start of Schuylkill River bridge near Art Museum						
Distance	19420 ft					
Time Interval	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
1800	356.9	718.5	534.7	407.7	391.8	400.2
2700	350.3	1125.4	722.9	448.0	387.3	412.9
3600	352.7	1250.9	842.9	436.8	373.6	408.4
Average Time (sec)	**353.3**	**1031.6**	**700.2**	**430.8**	**384.2**	**407.2**
Average Time (min)	5.89	17.19	11.67	7.18	6.40	6.79
Ave Speed (mph)	37.5	12.8	18.9	30.7	34.5	32.5

Travel Time Section 2 - MLK Northbound – Start of Schuylkill River bridge near Art Museum to Railroad bridge under Route 1						
Distance	19400 ft					
Time Interval	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
1800	317.8	339.2	331.4	337.4	309.8	360.7
2700	314.8	331.7	335.7	331.4	313.4	437.1
3600	311.0	334.7	330.2	340.0	319.2	366.5
Average Time (sec)	**314.5**	**335.2**	**332.4**	**336.3**	**314.1**	**388.1**
Average Time (min)	5.24	5.59	5.54	5.60	5.24	6.47
Ave Speed (mph)	42.1	39.5	39.8	39.3	42.1	34.1

Travel Time Section 3 - MLK Southbound – Strawberry Mansion Southern On-Ramp to bridge near Art Museum						
Distance	14400 ft					
Time Interval	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
1800	276.7	530.2	417.8	319.8	312.5	313.3
2700	270.4	551.6	464.9	360.5	306.8	324.8
3600	273.7	552.8	493.8	349.4	294.8	319.3
Average Time (sec)	**273.6**	**544.9**	**458.8**	**343.2**	**304.7**	**319.1**
Average Time (min)	4.56	9.08	7.65	5.72	5.08	5.32
Ave Speed (mph)	35.9	18.0	21.4	28.6	32.2	30.8

Travel Time Section 4 - MLK Southbound – Montgomery Drive to bridge near Art Museum						
Distance	10920 ft					
Time Interval	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
1800	196.9	214.2	241.9	221.6	234.4	222.9
2700	194.6	212.6	274.6	234.7	225.5	231.6
3600	194.3	212.5	293.9	232.5	214.7	223.1
Average Time (sec)	**195.3**	**213.1**	**270.1**	**229.6**	**224.9**	**225.9**
Average Time (min)	3.25	3.55	4.50	3.83	3.75	3.76
Ave Speed (mph)	38.1	34.9	27.6	32.4	33.1	33.0

Travel Time Section 5 - MLK Southbound – Sweet Briar Drive to bridge near Art Museum						
Distance	6370 ft					
Time Interval	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
1800	105.4	115.9	116.7	121.1	144.2	120
2700	105.1	114.3	117.2	124.6	132.9	120.8
3600	104.5	113.9	116.3	124.8	124.8	120.3
Average Time (sec)	**105.0**	**114.7**	**116.7**	**123.5**	**134.0**	**120.4**
Average Time (min)	1.75	1.91	1.95	2.06	2.23	2.01
Ave Speed (mph)	41.4	37.9	37.2	35.2	32.4	36.1

Delay Times

Delay Section 1 - MLK Southbound – Railroad bridge under Route 1 to start of Schuylkill River bridge near Art Museum						
Distance	19420 ft					
Time Interval	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
1800	62.0	428.5	239.4	111.5	99.1	95.9
2700	57.3	831.1	430.4	152.3	96.3	108.4
3600	61.9	963	550.3	141.4	85.3	104.4
Average Delay (sec)	**60.4**	**740.9**	**406.7**	**135.1**	**93.6**	**102.9**

Delay Section 2 - MLK Northbound – Start of Schuylkill River bridge near Art Museum to Railroad bridge under Route 1						
Distance	19400 ft					
Time Interval	Base Model	Alt 1a	Alt 1b	Alt 2	Alt 3	Alt 4
1800	18.1	45.1	37.2	42.7	21.8	66.1
2700	23.2	40.3	45.1	33.3	21.7	141.7
3600	20.4	39.6	36.3	39	23.8	74.1
Average Delay (sec)	**20.6**	**41.7**	**39.5**	**38.3**	**22.4**	**94.0**

Queue Lengths

Queue 1 - MLK Southbound at Montgomery Drive												
Time Interval	Base Model		Alt 1a		Alt 1b		Alt 2		Alt 3		Alt 4	
	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length
1800	105	380	3855	4018	3587	4018	197	576	131	585	121	442
2700	78	343	3873	4018	3751	4018	280	603	85	363	132	451
3600	105	536	3865	4018	3806	4018	199	564	106	504	113	355
Average (ft)	**96**	**420**	**3864**	**4018**	**3715**	**4018**	**225**	**581**	**107**	**484**	**122**	**416**

Queue 2 - MLK Northbound at Montgomery Drive												
Time Interval	Base Model		Alt 1a		Alt 1b		Alt 2		Alt 3		Alt 4	
	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length
1800	3	67	6	120	3	69	3	69	3	46	49	271
2700	2	44	5	94	4	52	3	49	3	44	298	1525
3600	2	46	6	92	5	111	4	47	4	49	43	278
Average (ft)	**2.333**	**52**	**6**	**102**	**4**	**77.3**	**3**	**55.0**	**3**	**46**	**130**	**691**

Queue 3 - MLK Southbound at Sweet Briar Drive												
Time Interval	Base Model		Alt 1a		Alt 1b		Alt 2		Alt 3		Alt 4	
	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length
1800	95	392	129	622	795	2474	35	230	92	398	37	199
2700	75	345	130	706	2231	4017	40	210	79	385	39	279
3600	75	308	75	377	3307	4018	43	284	73	325	41	238
Average (ft)	**82**	**348**	**111**	**568**	**2111**	**3503**	**39**	**241**	**81**	**369**	**39**	**239**

Queue 4 - MLK Northbound at Sweet Briar Drive												
Time Interval	Base Model		Alt 1a		Alt 1b		Alt 2		Alt 3		Alt 4	
	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length	Ave Length	Max Length

1800	9	69	11	188	3	96	16	55	11	116	12	185
2700	23	129	10	116	4	116	14	52	8	70	12	134
3600	24	100	13	122	5	89	29	75	16	145	17	189
Average (ft)	**19**	**99**	**11**	**142**	**4**	**100**	**20**	**61**	**12**	**110**	**14**	**169**