March 2014

Redesign of Newton Square

Margaret Anne Corrigan
Worcester Polytechnic Institute

Meghan D. Hennessey
Worcester Polytechnic Institute

Susan M. Stukas
Worcester Polytechnic Institute

Redesign of Newton Square

Major Qualifying Project Report:

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for a

Degree of Bachelor of Science

Civil, Environmental, & Architectural Engineering Department

By

Margaret Corrigan

Meghan Hennessey

Susan Stukas

March 7, 2014

Professor Suzanne LePage

Table of Contents

Table of Figures

Table of Tables

Table of Equations

Authorship Page

As a group, all three members participated in data collection activities. We also co-wrote the introduction, recommendations and conclusions. Additionally, editing of report was conducted by the group as a whole.

Margaret Corrigan

In the Worcester Bikeways section, Margaret wrote the description about the street profiles of Highland Street. Margaret's contributions to the Newton Square Design Alternatives report was the Massachusetts Department of Transportation section of the Background, Observations in the Analysis section and recommendations regarding Coolidge Road, and the Cost Considerations section in the Recommendation section.

Meghan Hennessey

Meghan completed the analysis of the data including presentation in excel, volume/capacity calculations and Highway Capacity software. In conjunction with this analysis, she contributed several sections to the written report including Capstone Design, Determining Capacity and Level of Service in Methodology, Results section as well as the Analysis sections Volume/Capacity Calculations, Capacity Analysis and Highway Capacity Software Models. She also attended all interviews with both Massachusetts Department of Transportation and Worcester Department of Public Works offices.

Susan Stukas

Susan Stukas authored the Introduction for Worcester Bikeways, as well as the Background for WalkBike Worcester, the Methodology introduction, and the Deliverables in its entirety. For Newton Square Design Alternatives, she wrote the unit's Introduction, Background introduction, and Background for the Federal Highway Administration. Within the Methodology section, Susan composed the introduction, the Methodology for Trial, Installing Automatic Traffic Counters, Turning Movement Count (for both the morning and afternoon sessions), and Design Components. She also wrote the introduction for the Analysis section; additionally, Susan authored the scope of the project as a whole.

Abstract

This project focused on improving the efficiency of Newton Square, a five street roundabout located in Worcester, Massachusetts; the team collaborated with the Massachusetts Department of Transportation and other public agencies and committees. A turning movement count was completed at this intersection to determine the level of service, and simulations of how design alternatives would alleviate congestion were conducted. After analyzing the data collected, the optimal design alternative was determined to enhance the accessibility for motorists, bicyclists and pedestrians.

Executive Summary

Our project's main objective was to increase bicyclist and pedestrian safety in the City of Worcester, located in Central Massachusetts. We first began our project scope with the goal of establishing bike routes in Worcester while working with WalkBike Worcester, a community outreach group.

The first few months of our project involved collaborating with the Worcester Bike Working Group, which was comprised of WalkBike Worcester, the Central Massachusetts Regional Planning Commission, Worcester Polytechnic Institute students and employees, as well as general community members. During this time we contributed to their existing plans to implement a bike route system that connects the major colleges in the Worcester Consortium (WPI, Becker College, Assumption College, College of the Holy Cross, and Worcester State University). The organization was also in the process of reviewing current repaving projects; the working group received a list of potential streets to be repaved for the next construction season.

We took the aforementioned list, identified the location of the street segments that would be ideal candidates for different styles of bike lanes, and created a map displaying the different types. On this map, we also acknowledged major arterial roads that would benefit from some type of shared bike access. The overarching mission of the Worcester Bike Working Group is to create safe access for bicycles throughout the City of Worcester. To help visualize their goals, our group also created a map that displayed their plans involving short-term, long-term, and potential future projects alongside already existing bike lanes. Along with these maps, we also designed a street profile of Highland Street segmenting from Park Avenue to Newton Square. We mapped the existing conditions, as well as offered recommendations to improve upon the use of the available space. Our recommendations included redefining the parking lane in order to eliminate the artificial wideness that is created due to the temporary parking and bus stops on the outside of the street.

As our project developed, we decided to focus our efforts more on a specific location rather than bicycle and pedestrian safety as a whole. We chose Newton Square in Worcester due to its proximity to campus, outdated design, and the resulting confusion and safety concerns that are present. We began by working with the Massachusetts Department of Transportation (MassDOT) to discover more background information about the intersection itself, as well as to receive more information about other roundabouts in the Worcester area. In 2007, MassDOT completed an evaluation of Newton Square, including a turning movement count, crash analysis, and preliminary redesign options for the intersection. After discovering the work that had been completed approximately five years ago, our group sought to update the existing data. We completed a turning movement count of the intersection and accommodated for morning and afternoon peak hours.

Based upon the data that we collected from both turning movement counts, we calculated the Level of Service of the intersection's current conditions. After completing the calculations, we determined that the Level of Service for the intersection was failing. Using this information we verified that alternative designs should be considered to improve the intersection's Level of Service. We created five different design alternatives:

- Double Lane Roundabout from Pleasant Street West to Highland Street
- Double Lane Roundabout from Highland Street to Pleasant Street West
- Full Double Lane Roundabout
- Two Phase Signalized Design
- Four Phase Signalized Design

Our group then used Highway Capacity Software to assess the six different design alternatives and their level of service. After completing this analysis we selected a design alternative based upon our observations of the intersection, constructability, costs, political implications, improved level of service, and safety. The design alternative that we selected was the double lane roundabout from Pleasant Street West to Highland Street. After meeting with the Worcester Department of Public Works & Parks, we found that they were currently drafting design alternatives for Newton Square. Their design was similar to ours in the sense that it addressed the same concerns, as well as incorporated a double lane roundabout from Pleasant West to Highland Street.

Our design will allow for improved traffic flow through Newton Square and alleviate confusion that commonly occurs with unfamiliar users of the roundabout. While our project increased the efficiency of Newton Square, it also included measures to improve bicycle and pedestrian safety. With these accomplishments we were able to connect both halves of our project together through an overarching goal of improved safety for all users of transportation in the City of Worcester.

Capstone Design Statement

This Major Qualifying Project presents design alternatives to Newton Square, located in Worcester, Massachusetts. The square is a five-road intersection that is organized through use of a rotary, not signalization and has been an area of previous study by the Massachusetts Department of Transportation (MassDOT). We sought to continue their efforts in creating a beneficial design alternative. The current intersection is very congested, and motorists are able travel at a higher than expected speed due to the width of the travel lane. In creating our design alternatives, we first conducted a traffic count of the intersection to determine its capacity and level-of-service. In combination with the previous data collected by MassDOT, we developed several conceptual design alternatives with consideration paid to the following eight constraints of Capstone Design.

Economics- This Major Qualifying Project considered the financial constraints facing the city of Worcester in our potential designs of Newton Square. We kept our expectations of our designs in a realistic scope knowing that the budget for such a project would be determined by federal, state and local agencies.

Environmental- In any form of construction, environmental concerns are taken into consideration during both the design and execution phases. The footprint of all designs considered is within the same area of the current intersection, so the difference in environmental impact between designs was negligible.

Sustainability- The recommended design alternative is also a roundabout, meaning the intersection's upkeep will not create additional environmental impacts than the current square. By accounting for all different modes of transportation, our design made accommodations for the future.

Constructability- In order to create an engineered redesign of Newton Square, naturally constructability has to be considered, such as the amount of effort and temporary rerouting that needs to occur in order for the new final design to be implemented. In the case of Newton Square, we also needed to consider the amount of physical space that was available for the improvement project. The ease of construction is just as important as the cost of a particular project and the impact it will have on the community, therefore constructability was highly considered in the redesign of Newton Square.

Ethical- We considered the ethical implications of our redesign of Newton Square using the ASCE Code of Ethics standard across all types of construction projects.

Health & Safety-Safety was very highly considered in creating a redesign. We considered the safety for all who utilize Newton Square for transportation including motorists, cyclists, and pedestrians. All of the design alternatives have the goal of improving safety for all users.

Social- It is one thing to change the design, but quite another to convince the public to make use of those changes. The social implications of any design alternative were considered with high importance; it is the people who will be using the intersection who will determine if the design is in fact more functional. The impact of the residents and local businesses in and around the area was also taken into consideration.

Political- Similar to economics, because this project is dealing with a city right-of-way, any changes need to be approved by the city offices. Politics may not be the biggest consideration for the functional design of the square. However, it was an important factor in whether or not this design will be implemented. Because of this, we consulted with several city wide transportation agencies including Massachusetts Department of Transportation, Worcester Department of Public Works & the Central Massachusetts Regional Planning Commission.

1 Introduction

Our MQP report is divided into two phases: the first is regarding our initial plans as presented in our MQP proposal, focusing more on the pedestrian and cyclist safety in the vicinity of the roundabout at Newton Square. The second covers material after our project became an effort more directed towards redesigning Newton Square to increase its proficiency, in addition to increasing its level-of-service (LOS). The project began working with WalkBike Worcester, a community outreach group, on pedestrian and bicycle safety; however, we realized that our efforts would be better suited for a more focused design of an individual intersection. We selected Newton Square because it was a familiar intersection and we were aware of its safety concerns for both cyclists and pedestrians. Our design alternative strived to incorporate bicycle and pedestrian safety while also improving the traffic flow for motorists.

1.1 Scope of Work

Figure 1: Aerial View of Newton Square

For this project, our team coordinated with a few different key players involved in the transportation field, including WalkBike Worcester, the Worcester Bike Working Group, the Central Massachusetts Planning Commission, Massachusetts Department of Transportation, the Worcester Department of Public Works and Parks, as well as various community members willing to share input. We evaluated the Newton Square neighborhood, specifically the configuration of

Newton Square itself. Through this evaluation, we determined the feasibility of several proposed changes to accommodate pedestrians, cyclists and motorists alike, while greatly improving the efficiency and level of service of the intersection.

The assessment consisted of traffic counting through Newton Square to see the common traffic flow patterns that are produced, as well as taking measurements of roadways surrounding the rotary. The analysis of the collected data helped our group determine the best course of action. A design alternative to Newton Square is provided for a more pedestrian and cyclist friendly path that will ultimately simplify travel for these groups.

2 Worcester Bikeways

In the United States, pedestrians and cyclists are vulnerable users of our transportation system due to the lack of abundant designated bike paths and safe sidewalks provided to them. Pedestrian and bicycle accidents in the United States are remarkably high; in 2011, 4,432 pedestrians were killed, and an estimated 69,000 were injured in traffic crashes across the country. On average, a pedestrian was killed every two hours and injured every eight minutes in traffic crashes within the United States (Traffic Safety Facts, 2010). Additionally, 677 pedal cyclists were killed and an additional 48,000 were injured (Traffic Safety Facts, 2010). With over 5,000 fatalities and more than 117,000 injuries combined, these statistics bring to light the harsh reality that pedestrians and cyclists are at constant risk when operating on the same roadways as motorists.

Worcester is the second largest city in Massachusetts with approximately 181,000 residents; compared to the Commonwealth's largest city of Boston, which ranks in the top 5 most walkable cities (US Census Bureau, 2010). Worcester does not even list within the top 20 cities of Massachusetts alone. Worcester's walkability is substantially below expectations, which is a great concern to the Worcester community because it hinders the livability of the city, and generates limitations to its residents.

Partly due to these inadequacies, Worcester, Massachusetts is home to the 6th top pedestrian crash cluster in Massachusetts, and currently holds 21 different intersections on the 2006-2008 Statewide Top 200 Intersection Crash List (2008 Top Crash Locations). As evidenced by the statistics, Worcester is a city where efforts should be directed to increase the safety and suitability for both pedestrians and cyclists. Strides have been made to work on advocating for the improvement of roads and streets. We facilitated this implementation by working with the City of Worcester to create safe access for pedestrians, cyclists, and motor vehicles through Newton Square. By designing and engineering a street design for a particular region, we can increase the likelihood of its application within the City of Worcester. In addition, this project created Geographic Information System (GIS) maps of roads identified as candidates for bike lanes for sharrows for the Worcester Bike Working Group to be submitted to the Worcester Department of Public Works and Parks (DPW&P).

2.1 Background

For the first phase of our project, our efforts mainly focused on the safety and accessibility of bikers and pedestrians in Worcester. As our research developed, our group discovered the Complete Streets philosophy, as well as the working group of WalkBike Worcester; the combination of these two programs provides a strong desire in the area of biker and pedestrian safety implementation.

2.1.1 Complete Streets Philosophy

Massachusetts Department of Transportation (MassDOT) recently adopted the Complete Streets Primer, an independent program that provides states with a guideline for creating safe, usable transportation for all users. The state of Massachusetts is actually a leader in this area, having previously developed their own Baystate Roads Program in 2006 to improve the quality of roadways in the state. Their mission statement and sustainability commitment declares, “Our mission is to deliver excellent customer service to the people who travel in the Commonwealth and to provide our nation’s safest and most reliable transportation system in a way that strengthens our economy and quality of life” (Complete Streets Workshop). Using a combination of the two programs, Massachusetts has targeted many roads in the greater Boston area and has begun construction to modify streets. The Complete Streets program is unique in that it is a public program and therefore the model ordinances and bylaws are readily available for municipalities to view online.

The concept of Complete Streets is to allow the safest and most easily interpreted mode of transportation for all users, including motorists, cyclists and pedestrians. This is not to say that there is one particular model that applies to every possible street; in fact, the guideline is just that: a guideline. It serves as a resource for developers to think about different ways to use the area available to them. For instance, some streets may be wide enough to accommodate both motorist lanes and a bike lane, while others may only have the lane width for a sharrow (a shared bike lane). In order to be considered a Complete Street, it is not necessary for it to contain all modes of use for every type of transportation. (Complete Streets Workshop) In Massachusetts, the focus for analyzing streets for completeness has been mostly focused in Boston and the surrounding suburbs; however, MassDOT District 3 is hoping to make use of the Complete Streets model on their future projects.

On Wednesday, August 14th, 2013 Doug Prentiss, a transportation engineer from Fay, Spofford & Thorndike, presented a Complete Streets Workshop at Worcester City Hall open to all interested parties. Our group attended this presentation and gained a variety of useful resources and contacts. During this workshop, the main topic of conversation was about integrating cyclists and pedestrian transportation into existing roadways. This could be as simple as adding paint to the road, or more complicated, such as retiming of signalized intersections to accommodate pedestrians. When planning for a redesign of Newton Square, it is advantageous to consider the impacts of pedestrian traffic due to the public elementary and high schools on the two streets leading to the intersection. Using this knowledge of Complete Streets, we considered the safety of all users at Newton Square and created our recommendations accordingly.

2.1.2 WalkBike Worcester

WalkBike Worcester is a project of the Worcester Food and Active Living Policy Council. WalkBike Worcester aims to make walking and biking in the city more safe, pleasant, and convenient. They work with city officials, community groups, hold community events, and research local conditions. WalkBike Worcester attends public meetings and provides input on project designs and plans, giving a consistent and clear voice for pedestrians and cyclists in the city. They also aim to educate residents regarding current legislation that supports a transition to a pedestrian and cyclist friendly community. While involvement and activism are great means of employing change, the process of implementation is a difficult path to venture through. So far, the organization has demonstrated strong efforts in building partnerships with other organizations to help further their progress. In order to continue to solidify the strong foundation that is currently established, WalkBike Worcester is looking to make concrete changes to specific streets in the city of Worcester (WalkBike Worcester).

WalkBike Worcester was put into contact with a group of students from Worcester Polytechnic Institute (WPI) in 2012 for the Interactive Qualifying Project (IQP) that helped to identify areas for potential bike routes in the City of Worcester. When the project team presented their plans to Robert Moylan, Worcester Public Works and Parks Commissioner, their recommendations led to the formation of the Worcester Bike Working Group. The working group consists of department officials, members of the Central Massachusetts Regional Planning Commission (CMRPC), WalkBike Worcester, as well as general community members. The main purpose of the working group is to set obtainable goals for road improvement to create safe travel for bicyclists in Worcester. This working group continued through to 2013, when our current project team became involved.

On September 9th, 2013, our group had the opportunity to sit down with the working group and talk about their goals, possible additions to the current suggestions for the outlined roadways with the potential for bike lanes, and general suggestions for the group. CMRPC reviewed the list of potential streets to be improved given to them by WalkBike Worcester and the IQP group, and provided a tiered recommendation for possible implementation. In addition to the current working group goals, several suggestions were made about general ideas for road enhancement, such as restriping, additional signage, and further connection of the bike paths.

2.2 Methodology

Through our various meetings and interviews, our project group received a few different responsibilities to assist with WalkBike Worcester's project mission of improving safety for pedestrians and cyclists. These assignments included creating a compiled map, as well as establishing a street profile. With these two tasks, we were able to advance the work of WalkBike Worcester, making them one step closer to achieving their goals.

2.2.1 Maps for WalkBike Worcester

In July 2013, Worcester DPW&P asked WalkBike Worcester and the working group to create a list of arterial and residential streets to be considered for restriping. The groups identified arterial streets based upon their connectivity to existing bike paths, college campuses, and downtown. WalkBike Worcester asked us at the September working group meeting to create GIS Maps for their memo to the DPW&P for October 1st. On September 19th, we met with two members of WalkBike Worcester to further discuss their expectations of the GIS maps and received additional direction on the type of deliverable they anticipated. Using this information, we took the layers that had already been created by CMRPC for the arterial roadways, and added to them the residential streets that have been identified by the City of Worcester for repaving (please see Appendix B for a full list of the residential streets). CMRPC and WalkBike Worcester identified roads that would be ideal to add striped lanes, or sharrows. These layers also identified projects as either short-term or long-term recommendations. We went through the list of residential streets to be paved during the next construction season and identified the street segments that would benefit from having either a bike lane or sharrow. Those streets, along with all future Transportation Improvement Program (TIP) projects, and existing bike lanes were added to a map of the city that was used by WalkBike Worcester to create their "Recommendations for Initial Bike Lane Striping FY15 Construction Season", located in Appendix C.

2.2.2 Street Profile of Highland Street

At the Worcester Bike Working Group meeting held on September 9th, it was discussed that the stretch of Highland Street between Park Avenue and Newton Square was repaved within the last few years. However, additional striping was not completed. Currently, the only marking on this stretch of Highland Street is a double yellow center line. We were tasked with analyzing the street and its traffic patterns to come up with a striping solution that would accommodate motorists, pedestrians, and cyclists. We completed this task through a combination of visual data collection, as well as GIS analysis and interpretation, as outlined at the Complete Streets Workshop in August. We visited the street segment at various periods of congestion to gain a better understanding of the needs for all three types of roadway users; in addition, our group also utilized GIS data to determine the exact street width and potential design limitations. The street profiles were created using AutoCAD software; the dimensions of the road were taken from ArcGIS using the MassGIS DOT road file. This file provided the sidewalk widths, surface width of the road, and segment lengths of the road.

Figure 2: View of Highland Street

2.3 Deliverables

This portion of our project resulted in two distinct deliverables: the maps that display the potential roads to be marked during repaving, as well as a street profile for a well-known and frequented area of Worcester.

WalkBike Worcester received our maps and was pleased when they illustrated their thoughts of where the city would benefit from adding bike lanes to the roadways (please see Appendix C for maps). Unfortunately, for many of the residential streets, adding bike lanes were not practical given their limited accessibility and short length. We provided these maps in a readable manner so that all viewers, not just those familiar with GIS software, could gather information from looking at them.

Figure 3: Existing Street Profile of Highland Street between Park Avenue and Newton Square

The street profile, completed for Highland Street, was our second deliverable. The AutoCAD drawing our group created identified the entire segment of the road along with a cross-section, which displayed the dimensions of the travel lane, parking lane, sidewalks, and grass from each edge of the sidewalks. Figure 3 is not entirely consistent with the observations we made during our sight visit on September 12th, 2013. During that visit, we observed that the paved roadway was much wider than one car's width, and could likely accommodate an additional transportation lane. Upon closer inspection, we realized that the roadway is so wide to accommodate for a parking lane in addition to the single travel lane. We determined that due to many of the parking spaces in this street segment being designated for short-term parking or bus lanes, the road almost certainly appears artificially wide during periods where those spaces are not occupied. Toward the ends of the street segment, at the Park Avenue and Newton Square ends, the road does widen, but restriping narrower lanes here would not help the flow of traffic when the road width decreases again toward the middle of the segment.

Our suggestions for striping are to define the edge of the parking lane, thereby clearly labeling the available travel lane through this segment of Highland Street. The GIS files and our field measurements confirmed that the travel lane for this segment is only twelve feet wide, which is not wide enough to accommodate both a bike lane and a motorist travel lane. Assuming removing this temporary parking lane is not an option, this segment is a good example of where implementation of a sharrow could be beneficial.

2.4 Conclusion

Bicycle and pedestrian safety has become a prominent part of transportation engineering due to high pedestrian and bicycle accident rates, in order to help mitigate these safety issues. The City of Worcester is behind many cities in Massachusetts alone in its walk and bike-ability. Due to these higher crash rates, organizations such as WalkBike Worcester have been created to improve bicycle and pedestrian safety within the city. Our project worked with WalkBike Worcester along with The CMRPC to address bicycle and pedestrian issues in the city. We evaluated current major arterial streets in order to select streets that would benefit from sharrows or bike lanes, we also reviewed current repaving projects on arterial streets in Worcester to identify projects that could benefit from adding a bike lane, and we evaluated Highland Street from Newton Square to Park Avenue and designed a street profile that showed the actual dimensions of Highland Street and identified ways that it could be improved for bicycle safety. This project outlined different ways to improve bicycle safety throughout Worcester, and helped to begin a process that allows for improved bicycle and pedestrian safety throughout the city.

3 Newton Square Design Alternatives

Throughout the country, increasingly more modern roundabouts have been designed and constructed with safety being the key factor in mind; with these roundabouts, vehicle speeds have been decreased, there is a reduction in crashes, traffic flows more efficiently, there are significantly reduced costs on a long-term scale, and the aesthetics of the roundabout provides more of a landscaping opportunity. Worcester, Massachusetts is home to several newly designed and implemented roundabouts. These roundabouts have received very positive feedback from the Worcester community; however, there are still some intersections in Worcester that have yet to be modernized.

Near central Worcester, Newton Square is a rotary with five approaches, and has not been updated in a significantly long amount of time. This intersection sees a heavy amount of traffic each day from both the commuters entering the city, as well as students attending the nearby high school and elementary school. With such great levels of not only vehicle traffic but also pedestrian traffic, this intersection is a leading example of an outdated rotary that should be updated as a modern roundabout. As it currently stands, traffic queues are lengthy, the intersection becomes frequently congested, and any sort of pedestrian traffic could easily be viewed as dangerous. A redesign of Newton Square will make the vehicles move more efficiently throughout the roundabout, as well as increase pedestrian safety.

3.2 Background

For thorough context of our project and its applications, our group used multiple means of acquiring background information on roundabouts and their uses. Not only did we look into different manuals and various documents pertaining to roundabout design, but we also were able to sit down and discuss roundabouts with a few professionals that have specialized experience with our topics. Our group interviewed employees from different branches of transportation, which gave us a multi-viewed perspective on our project and its importance.

3.2.1 Massachusetts Department of Transportation

MassDOT was formed in 2009 in an effort to modernize the transportation systems in the commonwealth. MassDOT combined the Massachusetts Bay Transportation Authority, Executive Office of Transportation and Public Works, Massachusetts Turnpike Authority, the Massachusetts Highway Department (MassHighway), and the Registry of Motor Vehicles. The Secretary of Transportation administers the organization, a position appointed by the Governor (90 Day Integration Report). MassHighway oversees all state owned highways and interstates. The division is divided into six districts, seen in Figure 4. (MassDOT, Highway Division).Worcester is in District Three, and therefore under the jurisdiction of their district office in Worcester.

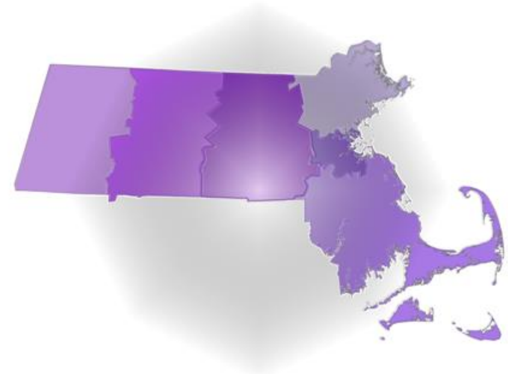


Figure 4: Map of Massachusetts Department of Transportation division distribution

On Thursday October 3rd the project team met with Joseph Frawley, the District Three Traffic Engineer with MassDOT. The meeting was scheduled to discuss Mr. Frawley's experience with designing roundabouts in Worcester, existing traffic count data for the intersection or other similar intersections, general roundabout design, the history of Newton Square, and additional data that should be collected with the traffic count.

Mr. Frawley has ample experience with roundabouts, particularly in the Worcester area. He designed the Washington Square roundabout in Worcester, along with roundabouts in Fitchburg, Lancaster, and Hudson (Frawley). We discussed the standards for roundabout design, and he recommended we use the National Cooperative Highway Research Program (NCHRP) Report 672, a federal guide for roundabout design. According to this guide, there are different ranges for lane widths and types of roundabouts. A single lane roundabout would have a diameter around 140 feet or smaller, while a double lane roundabout would be larger with 160-200 foot diameter with circulating widths of approximately 16-18 feet. These widths are based upon the width for a school bus to get through, while most roundabouts utilize a truck apron for large trucks that are sized based upon a tractor-trailer truck (NCHRP; Roundabouts: An Informational Guide). Mr. Frawley pointed out that the most important purpose of a roundabout is deflection. Roundabouts are meant to slow down the fastest path through the intersection in order to help with vehicle, pedestrian, and bicycle safety. He said that currently, the fastest path has a radius of about 600 feet, which is much larger than the ideal radius for the intersection; the biggest challenge would be to decrease the radius as much as possible while still allowing for efficient traffic flow (Frawley).

Mr. Frawley made us aware of the history of projects in this intersection. In 2007, MassDOT completed a study of the intersection including a complete turning movement count, crash analysis, and potential designs for changing the intersection. The study included data involving pedestrians, cyclists, and heavy vehicles, and therefore he suggested we include all types of transportation in our turning movement count. He provided us with the data MassDOT had from their study and included PDF files of the designs that they considered. A major concern that Mr. Frawley addressed with us was the cost and implications of the project. Due to public opinion, it generally becomes difficult to invest large sums of money into projects that will slow down traffic and in turn increase congestion. Therefore, the projects that are considered should include mitigation measures for additional traffic problems (Frawley).

The design process in 2007 didn't extend past preliminary conceptual designs; they created more than fifty designs and narrowed it down to four alternatives that they presented to the State. The first alternative increased the size of the breakdown lanes in every direction in order to decrease the radius of the circle, but continue to have one travel lane. The second alternative was to add an additional westbound travel lane through the intersection from Highland Street to Pleasant Street. This design was considered in order to account for the high influx of travelers utilizing the intersection during the evening commute.

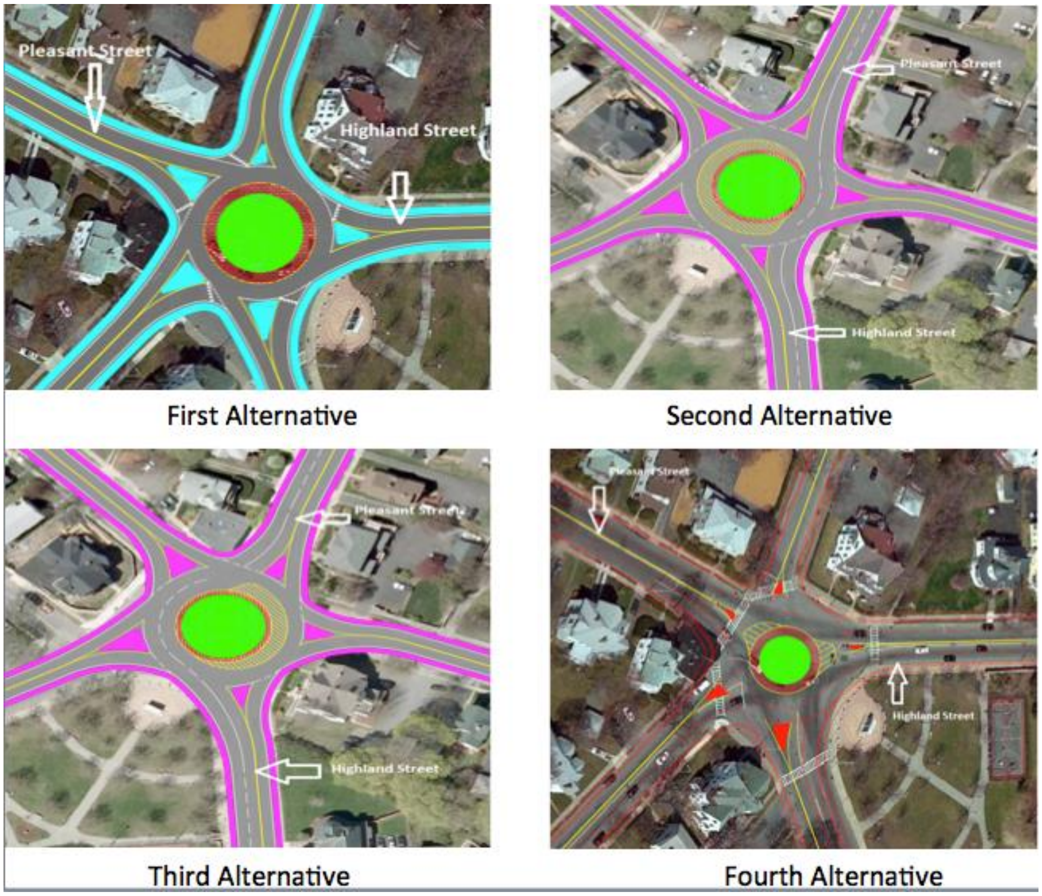


Figure 5: Design Alternatives Presented by MassDOT, 2007

MassDOT also considered an additional eastbound travel lane from Pleasant Street to Highland Street. Similar to the previous design, this alternative accounted for the high number of commuters entering the square during the morning commute. The flaws of both of these solutions were that they only accounted for the increased level of traffic during one of the peak traffic times, not both. A fourth alternative that was considered included additional travel lanes in both of these directions to accommodate both the AM peak and PM peak traffic. The three alternatives that were considered with an extra travel lane were the options they focused on, because of the high peak hour traffic volumes. According to their traffic study, during the AM peak hour, 1,704 cars entered the intersection from Pleasant Street and 1,205 cars exited at Highland Street. During the PM peak hour 1,057 cars entered the intersection from Highland Street and 1,129 cars exited via Pleasant Street (MassDOT Traffic Count). The major issue with adding an additional travel lane was the area available in the intersection. In order to have enough space for two travel lanes and a breakdown lane, MassDOT would have needed to acquire land adjacent to the intersection and increase the paved area. This would have added significant costs to the project.

On December 18th, 2013, we met with Mr. Frawley again to discuss similar issues and update him on our progress. The purpose of the meeting was to gain more information about the process and steps taken in 2007 and why there was no action taken. We also wanted to identify any issues that we could potentially run into and receive suggestions from him on design criteria. In 2007, the State's preferred option was to create a complete two-lane roundabout, but the District office was concerned about the impact on Newton Park and the on-street parking for Newton Pizza abutting the intersection. Mr. Frawley told us that his preference was to create an additional travel lane from Pleasant Street to Highland Street in the eastbound direction in order to mitigate the increased morning traffic (Frawley).

When Mr. Frawley was designing Washington Square in Worcester, he needed to coordinate with City of Worcester. Certain design elements were more a focus for discussion, such as the exit speed from the intersection due to how the exit angles are designed. This is an important design consideration in order to slow down vehicles departing the intersection and allow for safer pedestrian access. Another concern regarding pedestrians was the type of crosswalk. The city wanted to have straight crosswalks through each exit, which made the length of time that the pedestrian was in the road much longer and the crosswalks needed to be farther from the roundabout (Frawley. Mr. Frawley suggested that we research rectangular rapid flashing pedestrian lights to help increase driver awareness of pedestrians. He also suggested that we get an idea of the extent of the queuing is during the peak hour and the traffic flow during off-peak times. He suggested potentially making Newton Avenue a one-way exit only street due to its access from Pleasant Street. He also suggested creating a signalized intersection that would join Newton Avenue and Pleasant Street before the light and create a four-way intersection. Mr. Frawley informed us that Ali Khorasani and Joe Borbone from the Worcester DPW&P are currently looking into the intersection as well, and recommended that we meet with them to discuss the City's involvement further.

3.2.2 Federal Highway Administration

After serving as a guest lecturer to our Transportation: Traffic Engineering course on Tuesday, December 10th 2013, our group met with Mr. Robert Michaud of MDM Transportation Consultants, Inc. to inform him of our MQP plans and how his profession related to our project, as well as to receive any type of information he would be kind enough to share. Mr. Michaud has been on the project team for a number of roundabout construction jobs, and offered us various roundabout design options that MDM has evaluated; these examples provided us with context of optimal design/layouts of roundabouts (Michaud). Additionally, Mr. Michaud shared his knowledge of the Federal Highway Administration (FWHA) and their involvement with roundabout designs. He then directed us to a guide published by the FWHA that outlined design regulations and equations for analysis. The guide, entitled "ROUNDABOUTS: An Informational Guide," offers general information, planning techniques, performance evaluation procedures, and design guidelines for roundabouts. While the FWHA released this informational guide, their involvement in roundabout design goes beyond that; they also produced a technical summary of roundabouts for the specific purpose of safety considerations (Federal Highway Administration Manual). Mr. Michaud discussed these resources with us and explained their importance and relevance to our project and its success. Further, Mr. Michaud recommended a number of computer models that are used to analyze roundabouts, and even offered his personal recommendations based on an approved modeling method under current MassDOT policy.

3.3 Methodology

For our project, we were able to gather ample amounts of statistics to inform the selected Newton Square design alternative. Not only did we install a traffic counter along two high-volume approaches to Newton Square, but we also conducted two separate turning movement counts during both the morning and afternoon rush hour commutes. With this data, we determined the capacity and level of service of the intersection. Ultimately, our group gathered a significant amount of data that was beneficial to our analysis.

3.3.1 Methodology for Trial

On November 6th, 2013, our group visited the Newton Square site to conduct a trial run of the turning movement count, as well as to measure the roads and determine counting devices and tube locations for each of the streets. We decided to go on site during the same time frame that we would be running our turning movement counts so we could get a better feel for the traffic patterns and flow.

When we arrived on site, we measured the width of the entire street, including parking lanes, travel lanes and shoulders. We then measured the width of the crosswalks for each street; although we were not planning on placing a counting device on Newton Avenue, our group decided to measure its road width and crosswalk width regardless. After measuring the different streets, we then assessed the locations of where we would place the counting devices and tubes on each street based on driveways, bus stops, and various street poles.

When we ran our trial run of our turning movement count, we decided to measure by all counting the same street and finding the standard deviation from the numbers catalogued; afterwards, we tested counting individual streets to determine which would have the highest traffic flow, and therefore assign members of our team to specific locations based on accuracy and skill. Simulating the counting device software, we counted in 15-minute intervals. After a few trial runs, we found that the most efficient way to record data on the manual counters was to take a picture of the numbers and reset them as quickly as possible. In addition to the streets, cyclists, and pedestrians, we also logged U-turns.

After we concluded our trial run, we began to determine the logistics of our official turning movement count taking place on Wednesday, November 13, 2013. This included where we would set up our team members. It was decided that the team member counting Highland Street would also count Newton Avenue, with the exception of school departure times between 2:45 and 3:45 where we would have a fifth student assisting. We planned to have a member parked on Newton Avenue to conduct the turning movements of Highland Street and Newton Avenue, a member parked on Pleasant Street East, and two members located inside Newton Square Pizza to count turning movements for June Street and Pleasant Street West. We have extended the time to 1:45 to 6PM in order to accommodate Doherty High School's pedestrian increase for when school lets out. Due to the lengthy time of the study, we scheduled a 15-minute break for each counter throughout the day.

3.3.2 Installing Automatic Traffic Counters

On Wednesday, November 13th, our group assembled the traffic counters to collect data on the flow of vehicles during a prolonged period of time. We went on-site at 9:00AM; an immediate error that occurred upon arrival was two of our traffic counters were defective; initially, we thought it was a low battery issue. However, when our advisor Professor Suzanne LePage took the two inoperative counters back to check their charge, they were unresponsive. This led to having only two traffic counters available for data collection. After deciding which streets we wanted data on, our group selected Highland Street and Pleasant Avenue East to install the tubes. When setting up the tubes, our group utilized Officer Patrick Moran as a Police Detail on-site for safety precautions. We first untied the tubes and attached the "clips" which held the tube in place when we hammered the loop into the ground. We then secured the tube on the other end of the street by looping a thick cloth around it, then nailing that down as well. "Outdoor tape" was put down in the center of the road to ensure minimization of the tube's movement. We placed them eight feet apart to receive volume, speed, and direction from the counters.

3.3.3 Turning Movement Count

Using the information and observational data we took on November 6th, 2013 (as noted in Section 3.3.1), our group conducted two separate turning movement counts. Our first took place in the afternoon on Wednesday, November 13th to see the traffic volumes that occur during both the release of the nearby public schools, as well as the rush hour traffic taking place later on in the day. Our second turning movement count was on January 22nd, 2014 during the early hours of the day; we added this turning movement count to our methodology to account for the morning rush hour traffic from vehicles traveling into the city, as well as the school's traffic. Having both the morning and afternoon turning movements and traffic counts, we were able to determine which time of day saw the intersection saw the highest amount of volume, and factored that into our design alternative decision.

3.3.3.1 Morning

On Wednesday, January 22nd, our group revisited the site and conducted a second traffic count, this time during the morning commute hours (7:00AM-9:00AM). There were only three of us as we were unable to acquire additional help; one member counted for both June Street and Pleasant Street East, another for Highland Street and Newton Avenue, and the last group member counted for Pleasant Street West. We noticed a few different things from the morning commute versus the afternoon rush hour; first, the congestion from the school buses and car drop-offs for the high school located on Highland Street would cause significant backups through the rotary. Next, because of this backup, many parents would drop off their children either right in the rotary or on the "exit streets", which would not only increase the pedestrian traffic but also add to the congestion of the intersection. Some of the more general traffic problems aligned with what our group had witnessed in the afternoon commute times, such as additional lanes being created by drivers, the issue of which vehicle had the right of way, and even drivers simply using the rotary improperly. Determining the traffic counts for both the morning and afternoon commute hours was beneficial in evaluating which setting would receive the most value to a redesign of Newton Square, based on which time of day witnessed a worse level of service based on the traffic volume. To further develop our case for a design alternative to be implemented, our group went back to Newton Square around 5:00PM on January 22nd and tabulated the traffic queues that occur during rush hour traffic; using this information, we can see the significance of the backup that the day-to-day commuters experience when entering the intersection and determine the best fit solution to mitigate the traffic.

3.3.3.2 Afternoon

At 1:00PM the same day, our group revisited the site to conduct our turning movement count. The counters for June Street and Pleasant Street West stationed themselves in the Newton Pizza restaurant, the counter for Pleasant Street East was located in a parked car on the street facing the rotary, and the counter for both Highland Street and Newton Avenue was located in a parked car on Newton Avenue. At 1:30PM, the turning movement count started. We counted each car that entered from our street and where it went. We also counted pedestrians, cyclists, multi-axle vehicles, U-turns, as well as wrong turns. The manual counters were being used for the Pleasant Street West and June Street locations, and do not have a manual tracker for 15-minute intervals; the counters for these streets took pictures of their numbers every 15 minutes before resetting them for the next segment of time. The Pleasant Street East counter took a 15-minute break at 3:45PM, whereas the Pleasant Street West, June Street, Highland Street, and Newton Avenue counters took a break at 4:00PM. At 4:15PM, The Highland Street and Newton Avenue counter moved inside Newton Pizza because there was impairment in the view of Highland Street from Newton Avenue due to the sun setting. The turning movement count ended at 6:00PM. The raw data from each of the counters was entered in to a spreadsheet, denoting the time intervals, the items counted, and the street from which those items were tracked. After analyzing the data, the hourly totals were calculated, as well as the total volume and two-way volume of each street.

3.3.4 Determining Capacity and LOS

Once the data had been collected under assumed normal circumstances, the data was analyzed using Highway Capacity Software, commonly known as HCS. Highway Capacity Software, HCS, is a program used to model both real and simulated traffic situations. The software has been available for several years to demonstrate how roadway improvements could alleviate congested intersections. Differentiating between different signalization patterns and lane turning movements at typical four way intersections is standard, however the addition of rotaries and roundabout was not implemented until the 2010 update. Roundabout schematics and calculations are comprised of different components than typical four way intersections, and therefore requires a unique model. This HCS software was used to model various design alternatives that have been created by the project team. These design alternatives include a single lane roundabout, double lane roundabout, combination single/two lane roundabout from Highland Street to Pleasant Street West as well as a combination single/two lane roundabout from Pleasant Street West to Highland Street and a signalized intersection.

The drawbacks to the HCS software is that it can only accommodate four entrance/exits, for both roundabouts and signalized intersections, therefore limiting the accuracy of the model. This shortcoming however is considered negligible because the volume of traffic entering/exiting the intersection from Newton Ave is far less than the volumes entering/exiting from the other four streets. For the sake of consistency and to minimize the impact on the model, the project group included the vehicles associated with Newton Ave to the data for Pleasant Street West. This was to account for an accurate vehicle volume, even if the location of those contributions is not correct. Even in doing this, turning vehicles that would cause a U-turn result were neglected.

In addition to creating HCS models for roundabout solutions for Newton Square, we also used the software to create models for a traditional signalized intersection. Again, HCS signalized intersections can only accommodate four streets, causing the Newton Avenue volumes to be included with Pleasant Street West, just like the roundabout models. Without a signal currently at the intersection, some amount of estimation was necessary to determine how long the signals should be in each direction and which turning lane should be included for each street entrance (see Figure 6). In order to achieve the best result, we tested both a traditional east-west/north-south light cycle as well as an option where each street is allowed to move in their own turn, thereby allowing more turns to occur (see Figure 7).

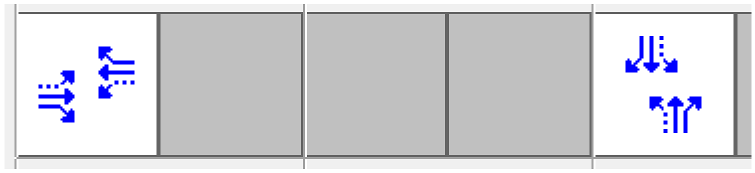


Figure 6: Simulated Schematic of Traditional East-West and North-South Signalization

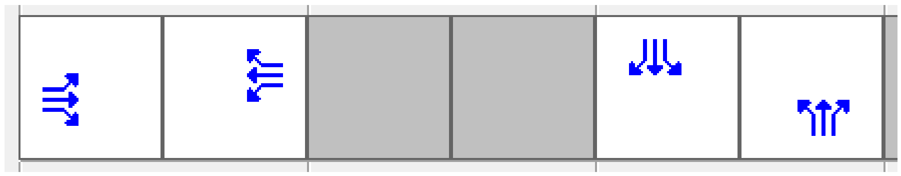


Figure 7: Simulated Schematic of Four Individual Signalized Streets

The length of these signals is also variable. We determined how to best demonstrate the inefficiency of a signalized intersection at Newton Square by testing different timings on the HCS program. The results of these models can be seen in the Analysis Section, 3.5.2.

3.3.5 Design Components

The best design was determined by five different factors: pedestrian and cyclist friendliness, safety, constructability, political implication, and cost. Our decision was informed based upon prior knowledge of the intersection that we gained from meeting with MassDOT and the City of Worcester. When MassDOT evaluated the intersection in 2007, they considered many design alternatives. After our first meeting with Joe Frawley, we obtained the top five design alternatives, as discussed in Section 3.2.1.

Our meeting with the Worcester DPW&P allowed us to have more access to background information regarding the square. They also informed us that they were currently completing a study of the intersection and provided us with their 25% designs. Their current design increased the radius of the inner circle, and created a truck apron. They left more space coming from Pleasant Street on the Western side of the intersection in order to allow for cars to exit via Pleasant Street or continue through the intersection to Highland Street.

Our design alternative was confirmed by the design that was already completed by the Worcester DPW&P. Their design met our criteria by increasing driver awareness and safety in the intersection, shortening the lengths of cross-walks in order to increase pedestrian safety. They also accomplished this with low cost, relatively easy constructability and minor political implications.

On Friday, January 24th, 2014 our group met with Joseph F. Borbone and Ali R. Khorasani, Director and Assistant Director of Engineering in the Worcester DPW&P, respectively. When setting up this meeting, our group really wanted to hear the city's take on Newton Square, and to see if there was any additional information that could be provided to us regarding its design, inefficiencies, and any potential redesign opportunities that have recently been brought to light.

We sat down with them and first went over the history of Newton Square. When this area was initially designed and created, it took fashion of an old style rotary that could accommodate various modes of transportation, previously including cable cars. However, with the traffic volume increases that the rotary is witnessing today, there are more complications that ensue with day-to-day use. For example, there is currently too much pavement surrounding the rotary, which allows for cars to move too freely in too many directions; the deflection is barely existent. Another issue with this deflection is that it makes it more difficult for the motorists to decide who has the right of way; many cars have the dilemma of who arrived to the intersection first. Overall, the accident rate is minor due to the lack of high speeds. However, this does not mean that they should be discounted.

After we discussed logistical problems with the rotary, our group was informed that the DPW&P recently started to look into redesigning Newton Square. They have been collaborating with Howard/Stein-Hudson Associates in creating plans for the intersection. Currently, the designs are at about a 25% drawing level, so both Mr. Borbone and Mr. Khorasani noted that it was in the relatively early design phase. They were hoping to bring the plans to the city council and look for funding the advance the design, or head straight into construction. The gentlemen also stated either avenue would be pursued depending on the amount of funding granted to the project (Borbone & Khorasani). On a traffic-engineering standpoint, one of the main concerns about the design to date was trying to determine if two lanes were necessary; another main issue was deflection. The redesigned circle should have reduced speeds and less conflict points. In addition, the new roundabout should also be designed for the critical peak period; as determined by our groups turning movement count, this period is between 4:30 and 5:30 PM rush hour traffic.

Moving deeper into the analysis of the rotary, Mr. Borbone and Mr. Khorasani started giving different recommendations about the roundabout designs we were going to create for our project. They offered ideas such as finding out the historic trends with the traffic volumes, to keep in mind the circle sizes, and determine differences in volumes of different times of day. The two employees also discussed that it is not typical to design for congestion. Mr. Borbone and Mr. Khorasani also gave us other roundabouts that had been recently redesigned to look into and assess the changes made and their efficiency levels. (Borbone & Khorasani)

3.4 Results

The results of our two turning movement counts are displayed in tables in the following sections, accompanies by a brief description of the data for both the morning and afternoon counts.

3.4.1 Turning Movement Counts

Once the turning movements were completed for both the morning and afternoon periods, the data needed to be organized into readable tables. In order to do this, we first organized the data first by street entrance, and then combined the data into one table. The results of the individual entrance street tables are listed in Appendices D & E. A summary of the entire intersection data for both the afternoon and morning counts is listed in the following sections.

3.4.1.1 Morning Volumes

The combined intersection table for the morning data is shown below in Table 1. The overall total number of vehicles that exited the intersection during each fifteen-minute interval is displayed in the column labeled 'total'. This total is a summation of the first five columns labeled with the street names. The following columns labeled 'heavy' and 'ped' represent the number of heavy vehicles and pedestrians that utilized the intersection during each interval. These numbers are not included in the vehicular totals or peak hour factor. A full table of all the entering street volumes is included in Appendix E. The peak hour was determined by summing the total number of vehicles that utilized the intersection every four intervals, and then the hour with the highest volume of vehicles in the intersection is the peak hour. For the morning count, the peak hour is from 7:30 to 8:30 am.

Table 1: Morning Exiting Volumes (Peak Hour Shaded)

	Intersection									
	Newton	Pleasant W	June	Pleasant E	Highland	Heavy	Ped	Total	Hour Total	
7:00	11	66	62	99	164	2	35	402		
7:15	13	59	81	130	161	0	5	444		
7:30	7	55	110	111	242	2	13	525		
7:45	14	59	137	108	228	2	22	546	1,917	
8:00	38	90	144	97	219	0	10	588	2,103	
8:15	27	82	121	107	214	0	3	551	2,210	
8:30	15	67	71	130	208	2	0	491	2,176	
8:45	2	80	79	111	165	0	0	437	2,067	
Total	127	558	805	893	1,601	8	88	3,984		
Peak Hour	86	286	512	423	903	4	48	2,210	Peak Hour Factor	0.94

The number of vehicles that exited onto each street during the entire count as well as during the peak hour is displayed in the bottom two rows. Using the peak hour total, the peak hour factor can be determined. The calculation for the afternoon PHF is shown in Equation 1.

Equation 1: Peak Hour Factor Calculation for Morning Count

$$PHF = \frac{Peak\ Hour\ Volume}{4 * Highest\ 15\ \text{min}\ Interval\ Volume} = \frac{2{,}210}{4 * 588} = 0.940$$

Comparing this data to the 2007 MassDOT study data, the same pattern emerges. During the previous study, 1,704 vehicles entered the intersection from Pleasant Street West and 1,205 exited via Highland Street during the morning peak hour. Our turning movement count resulted in 1,605 vehicles observed entering from Pleasant Street West and 903 vehicles exiting via Highland Street. It is important to note that these two counts did occur at different times of the year, which likely accounts for the decrease in volume. MassDOT conducted their study in the beginning of October, and our data was collected in the end of January.

3.4.1.2 Afternoon Volumes

The combined intersection table is shown below in Table 2. The overall total number of vehicles that exited the intersection during each fifteen-minute interval is displayed in the column labeled 'total', just as in the morning volumes table. A full table of all the entering street volumes is included in Appendix E. The peak hour was determined by summing the total number of vehicles that utilized the intersection every four intervals, and then the hour with the highest volume of vehicles in the intersection is the peak hour. For the afternoon count, the peak hour is from 4:15 to 5:15 pm.

Table 2: Afternoon Exiting Volumes (Peak Hour Shaded)

	Intersection Totals							
	Highland	Newton	Pleasant West	June	Pleasant East	Total	Hour Total	
1:30	179	27	100	94	73	473		
1:45	174	33	111	110	79	507		
2:00	166	46	140	98	75	525		
2:15	171	50	172	103	68	564	2,069	
2:30	192	22	134	115	104	567	2,163	
2:45	139	29	168	128	103	567	2,223	
3:00	159	21	182	102	56	520	2,218	
3:15	180	19	166	128	66	559	2,213	
3:30	183	22	186	106	75	572	2,218	
3:45	147	18	180	112	77	534	2,185	
4:00	163	19	170	126	70	548	2,213	
4:15	180	22	176	147	63	588	2,242	
4:30	149	18	211	149	70	597	2,267	
4:45	160	33	210	159	53	615	2,348	
5:00	142	36	207	168	55	608	2,408	
5:15	119	29	196	163	58	565	2,385	
5:30	137	21	201	129	66	554	2,342	
5:45	167	33	179	120	63	562	2,289	
Total	2,907	498	3,089	2,257	1,274	10,025		
Peak Hour	631	109	804	623	241	2,408	PHF	0.979

The number of vehicles that exited onto each street during the entire count are displayed in the second to last column, so for the whole intersection, 10,025 cars entered and exited Newton Square. The last row of Table 1 shows the number of cars that exited on to each street during the peak hour. For example, 631 vehicles exited onto Highland Street during the afternoon peak hour. Using the peak hour total, the peak hour factor can be determined. The peak hour factor (PHF) is a measure of how consistent the flow of vehicles is in the intersection. To find the PHF, first find the sum of the vehicles in the intersection during the peak hour, and then divide that by four times the highest volume fifteen-minute interval during the peak hour. The calculation for the afternoon PHF is shown in Equation 2.

Equation 2: Peak Hour Factor Calculation for Afternoon Count

$$PHF = \frac{Peak\ Hour\ Volume}{4 * Highest\ 15\ \text{min}\ Interval\ Volume} = \frac{2{,}408}{4 * 615} = 0.979$$

Comparing this data to the 2007 MassDOT study data, the similar pattern emerges. During the previous study, 1,057 vehicles entered the intersection from Highland Street and 1,129 exited via Pleasant Street West during the afternoon peak hour. Our turning movement count resulted in 987 vehicles observed entering from Highland Street and 804 vehicles exiting via Pleasant Street West.

3.5 Analysis

The most essential portion of our project was the analysis of the large amounts of data collected. To reach this decision, we solved volume capacity equations for roundabouts based on our turning movement data, assessed the different capacities of Newton Square, and also took into consideration our observations while present on-site. Culminating all of these evaluations, we were able to successfully finalize a design alternative for Newton Square.

3.5.1 Observations

On September 17th, 2013 we began observing the intersection by visiting it at an off-peak time to observe traffic flow. We realized the incredible difficulty of being a pedestrian in the intersection when we were almost struck by an oncoming vehicle while in the crosswalk. We also witnessed a near accident in the intersection where the entire intersection came to a complete stop because there was confusion about which vehicle had the right of way.

Figure 8: Congestion in Newton Square, showing vehicles forming two lanes in roundabout.

We conducted our turning movement count on November 13, 2013 from 1 pm until 6 pm. During the count we found many causes for traffic problems, many of which related to the school. At 3:15 pm a school bus stopped in the middle of the roundabout. This caused backups on every street because no one was able to enter the intersection during this time, while the students exited the bus and departed the intersection. We also noticed that there was a crossing guard present at this time. Another observation we had in terms of pedestrian utilization of the intersection was that pedestrians rarely used the cross walks when approaching the intersection from Doherty High School, they tended to cross beforehand. During the peak hour, when the intersection is filled mainly with commuters who use it every day, the intersection functioned efficiently with very few issues. The queues on Highland Street were longest when the high school was being let out, and during the peak hour. We also noticed that there must have been an easier way to get from June to Pleasant Street, in both directions, because the number of cars that were travelling in these directions was minimal.

During our morning traffic count on January 23, 2014 we noticed a few patterns that were different from our afternoon traffic count. The largest congestion problem took place when school was starting at the high school. Traffic was backed up on Highland Street through the intersection onto Pleasant Street West; this made it difficult for any cars to move in any direction during that time. We hypothesized that this back up was due to people being dropped off at the High School in the street. In order to avoid this confusion, some parents dropped their children off on Pleasant East and they walked from there to the High School. Some parents even took U-turns on Pleasant Street after dropping their children off at the intersection in order to avoid entering the roundabout, which created a dangerous situation for everyone involved. Another trend that we noticed was an issue with drivers entering the intersection from Coolidge Road. Vehicles entered the roundabout directly from Coolidge Road instead of merging onto Pleasant Street and then entering the intersection. There was a crossing guard in place during our morning traffic count, however they were only monitoring Pleasant Street West and June Street for the Elementary school students for approximately twenty minutes.

We also visited on January 23, 2014 and January 30th, 2014 to view afternoon and morning queuing, respectively. During the afternoon, we found that there were approximately 12-20 cars in the queue on Highland Street at 5:15 during the peak hour, and this number was largely dependent on the Park Avenue and Highland Street intersection light cycle. In our morning visit we found out that the problems in the intersection are resulting from the High School. Due to the width of Highland Street, parents are pulling over and dropping students off in the street, which causes stop and go traffic, especially since the students were not utilizing the crosswalks efficiently and there were no crossing guards at any of the crosswalks to help direct traffic. The backups on Pleasant Street West during the morning went as far as Howard Terrace, approximately 1,000 ft from the intersection, and the queuing in the morning was significantly worse than in the afternoon.

3.5.2 Volume/Capacity Calculations

Before the Highway Capacity Software was updated to include roundabout models, volume capacity calculations had to be done out by hand, using equation found in the Federal Highway Administration, FHWA, Manual. In order to solve for the capacity for roundabout, you need to first find the circular volume of the intersection in addition to the entering and exiting volumes. As seen in Figure 9 below, the circular volume is the number of cars that pass through a circular section of the roundabout. (Roundabouts FHWA, 85) For ease of understanding, the streets in the diagram have been labeled with the corresponding streets in Newton Square.

The circular volumes include all vehicles that enter a street before the fixed circular point, and exit after the fixed point. For instance, the east bound circular volume would include vehicles that entered from Pleasant Street West and exited on either Pleasant Street East, or Highland St, but not those that exited onto June Street, as well as all the vehicles that enter from June Street and those entering from Highland and exiting onto Pleasant East. The equations provided to calculate circular volumes are shown below. (FHWA. 84)

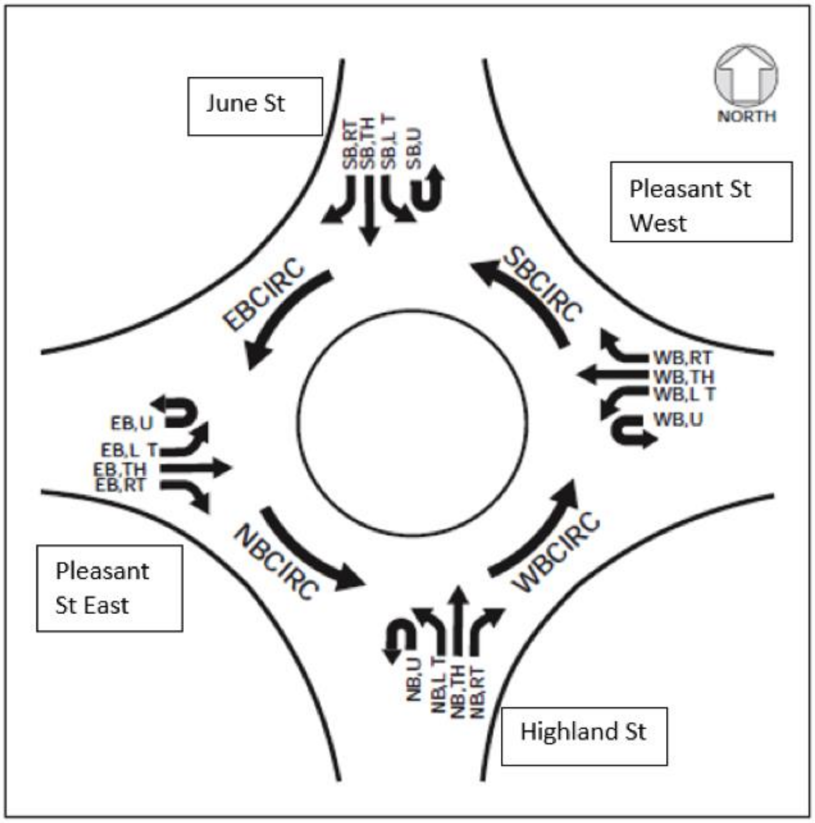


Figure 9: Circular Volume Diagram

Equation 3: Circular Volume Equation

$$V_{EB,circ} = V_{WB,LT} + V_{SB,LT} + V_{SB,TH} + V_{NB,U\text{-}turn} + V_{WB,U\text{-}turn} + V_{SB,U\text{-}turn}$$

$$V_{WB,circ} = V_{EB,LT} + V_{NB,LT} + V_{NB,TH} + V_{SB,U\text{-}turn} + V_{EB,U\text{-}turn} + V_{NB,U\text{-}turn}$$

$$V_{NB,circ} = V_{EB,LT} + V_{EB,TH} + V_{SB,LT} + V_{WB,U\text{-}turn} + V_{SB,U\text{-}turn} + V_{EB,U\text{-}turn}$$

$$V_{SB,circ} = V_{WB,LT} + V_{WB,TH} + V_{NB,LT} + V_{EB,U\text{-}turn} + V_{NB,U\text{-}turn} + V_{WB,U\text{-}turn}$$

Unfortunately, the equations only include four streets, however the project group modified the equations, using the same method of entering and exiting cars to incorporate Newton Ave into the calculations in order to achieve a more accurate result. The circular volumes below were solved using the peak hours for both the morning and afternoon turning movement count data. The results of these modified equations are shown in the following sections, along with the calculations for both morning and afternoon circular volumes. The volume labels have been abbreviated.

The first label is the street from which the cars entered the roundabout, and the second label is the street at which the vehicles exited the roundabout. The abbreviations are decoded in Table 3.

3.5.2.1 Intersection Morning Peak Hour Volume Calculations

Table 3: Circular Volume Abbreviations

Abbreviation	Street Name
High	Highland Street
New	Newton Avenue
PLW	Pleasant Street West
June	June Street
PLE	Pleasant Street East
Circ	Circular Volume

In order to complete the circular volume calculations for the morning peak hour, the volume of cars that entered the intersection and where they exited needed to be found. Based on the peak hour volumes for the entire intersection described in Section 4.1, the values used for these calculations are displayed in Table 4, followed by the calculations.

Table 4: Peak Hour Volumes used for Morning Circular Volume Calculations

Peak Hour Volumes						
		Exit Street				
		Highland	Newton	Pleasant West	June	Pleasant East
Entrance Street	Highland St	2	33	198	445	20
	Newton	40	0	6	20	69
	Pleasant West	548	1	0	32	276
	June	272	17	7	0	58
	Pleasant East	41	35	75	15	0

Equation 4: Morning Circular Volume Equations

$$V_{HIGH,CIRC} = V_{PLE,JUNE} + V_{PLE,PLW} + V_{PLE,NEW} + V_{JUNE,PLW} + V_{PLW,NEW} + V_{JUNE,NEW}$$

$$V_{HIGH,CIRC} = 15 + 75 + 35 + 7 + 1 + 17 = 150$$

$$V_{PLE,CIRC} = V_{PLW,NEW} + V_{JUNE,PLW} + V_{JUNE,HIGH} + V_{NEW,HIGH} + V_{PLW,HIGH} + V_{JUNE,NEW}$$

$$V_{PLE,CIRC} = 1 + 7 + 272 + 40 + 548 + 17 = 885$$

$$V_{PLW,CIRC} = V_{PLE,JUNE} + V_{HIGH,PLE} + V_{HIGH,JUNE} + V_{NEW,HIGH} + V_{NEW,JUNE} + V_{NEW,PLE}$$

$$V_{PLW,CIRC} = 15 + 20 + 445 + 40 + 20 + 69 = 609$$

$$V_{JUNE,CIRC} = V_{PLW,HIGH} + V_{PLW,PLE} + V_{HIGH,PLE} + V_{PLW,NEW} + V_{NEW,HIGH} + V_{NEW,PLE}$$

$$V_{JUNE,CIRC} = 548 + 267 + 20 + 1 + 40 + 69 = 945$$

$$V_{NEW,CIRC} = V_{HIGH,PLW} + V_{HIGH,JUNE} + V_{HIGH,PLE} + V_{JUNE,PLW} + V_{PLE,PLW} + V_{PLE,JUNE}$$

$$V_{NEW,CIRC} = 198 + 445 + 20 + 7 + 75 + 15 = 760$$

The results of these circular volumes was as expected based on the observations made during the morning turning movement count. The majority of vehicles enter from Pleasant Street West and June Street and exit onto Highland Street, so therefore it stands to reason that the highest circular volume would be highest at June Street and Pleasant East. Conversely, the number of vehicles passing Highland Street and exiting onto Newton or Pleasant Street West is very low, confirming the low Highland circular volume.

3.5.2.2 Intersection Afternoon Peak Hour Volume Calculations

In order to complete the circular volume calculations for the afternoon peak hour, the volume of cars that entered the intersection and where they exited needed to be found. Based on the peak hour volumes for the entire intersection described in Section 4.1, the values used for these calculations are displayed in Table 2, followed by the calculations.

Table 5: Peak Hour Volumes Used for Afternoon Circular Volume Calculations

		Peak Hour Volumes				
		Exit Street				
		Highland	Newton	Pleasant West	June	Pleasant East
Entrance Street	Highland	0	42	442	467	36
	Newton	18	0	7	24	26
	Pleasant West	204	0	0	56	140
	June	351	18	34	1	38
	Pleasant East	58	49	321	75	1

Equation 5: Afternoon Circular Volume Equations

$$V_{HIGH,CIRC} = V_{PLE,JUNE} + V_{PLE,PLW} + V_{PLE,NEW} + V_{JUNE,PLW} + V_{PLW,NEW} + V_{JUNE,NEW}$$

$$V_{HIGH,CIRC} = 75 + 321 + 49 + 34 + 0 + 18 = 497$$

$$V_{PLE,CIRC} = V_{PLW,NEW} + V_{JUNE,PLW} + V_{JUNE,HIGH} + V_{NEW,HIGH} + V_{PLW,HIGH} + V_{JUNE,NEW}$$

$$V_{PLE,CIRC} = 0 + 34 + 351 + 18 + 204 + 18 = 625$$

$$V_{PLW,CIRC} = V_{PLE,JUNE} + V_{HIGH,PLE} + V_{HIGH,JUNE} + V_{NEW,HIGH} + V_{NEW,JUNE} + V_{NEW,PLE}$$

$$V_{PLW,CIRC} = 75 + 36 + 467 + 18 + 24 + 26 = 646$$

$$V_{JUNE,CIRC} = V_{PLW,HIGH} + V_{PLW,PLE} + V_{HIGH,PLE} + V_{PLW,NEW} + V_{NEW,HIGH} + V_{NEW, PLE}$$

$$V_{JUNE,CIRC} = 204 + 140 + 36 + 0 + 18 + 26 = 424$$

$$V_{NEW,CIRC} = V_{HIGH,PLW} + V_{HIGH,JUNE} + V_{HIGH,PLE} + V_{JUNE, PLW} + V_{PLE, PLW} + V_{PLE,JUNE}$$

$$V_{NEW,CIRC} = 442 + 467 + 36 + 34 + 321 + 75 = 1{,}375$$

The results of these circular volumes was as expected based on the observations made at the time of the afternoon traffic count. The majority of vehicles are entering from Highland Street and exiting onto Pleasant Street West and June Street, so therefore it stands to reason that the highest circular volume would be at Newton Street.

3.5.3 Capacity Analysis

In addition to providing the circular volume equations, the FHWA Roundabout Manual also provides a chart by which the circular volumes and entering volumes can be compared in order to determine the flow capacity of a roundabout. (Roundabout FHWA, 87)

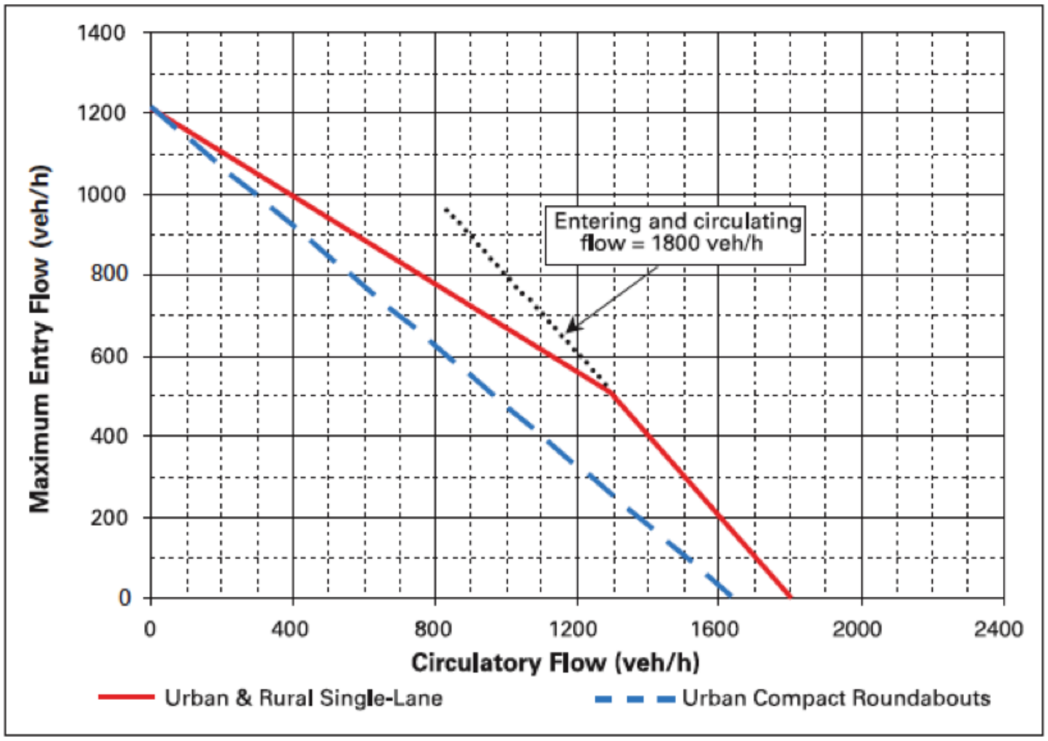


Figure 110: Circular Volume/Entry Flow Capacity Chart

There are several different charts based on the geographic location and size of the roundabout. For Newton Square, chart for "Urban & Rural Single-Lane and Urban Compact Roundabouts" seemed the most reasonable because the roundabout is in fact single lane, and Worcester Massachusetts is considered an urban environment.

In addition to this chart, the manual also states, "Roundabouts should be designed to operate at no more than 85 percent of their estimated capacity. Beyond this threshold, delays and queues vary significantly from their mean values." (Roundabouts FHWA, 86) Using this information, we can get a better idea of how Newton Square is functioning, even if a particular street is not running at capacity.

3.5.3.1 Morning Capacity Analysis

This chart is read using the circular volume and entering volumes for each street. In Figure 11 below, the same chart is shown, now including the circular entering volumes for each of Newton Square. The numerical values are also listed in Table 6.

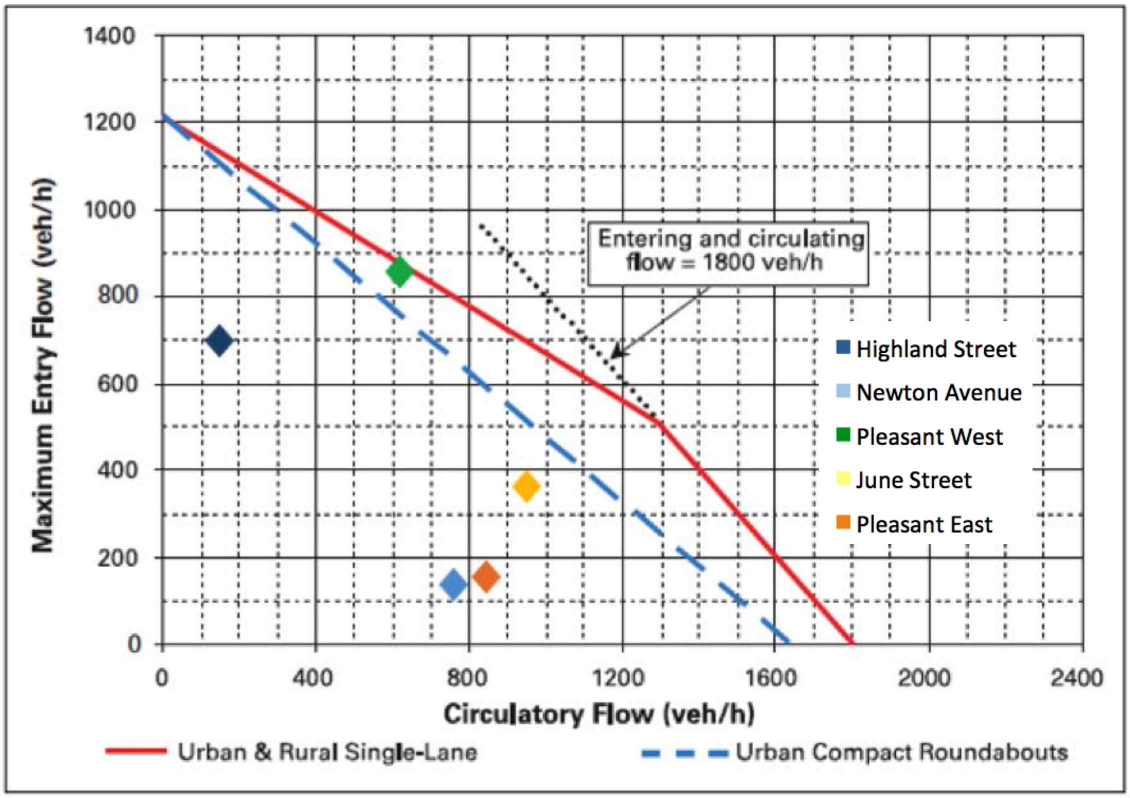


Figure 121: Flow Capacity Chart with Newton Square Morning Overlay

Table 6: Volume/Capacity Results Used for Figure 11

	Circulatory Flow	Current Entry Flow	Max Entry Flow Urban & Rural	Max Entry Flow Urban Compact
Highland Street	150	698	1,100	1,150
Newton Ave	760	135	650	800
Pleasant Street West	609	857	775	875
June Street	945	354	500	700
Pleasant Street East	885	166	600	750

Based on these results, only Pleasant Street West is running over capacity during the morning peak hour. However June Street is not too far from the Urban & Rural Single-Lane flow capacity line, which correlates with the observations made during the morning turning movement count. Although June Street is running at a high capacity compared to the other three approaches, it is running at 70% capacity during the peak hour, which is still within a reasonable range according to the FHWA. Interestingly, Newton Avenue and Pleasant Street East are located very close to each other on this chart. This is consistent with the gathered data as neither Pleasant Street East nor Newton Ave are common exits out of Newton Square.

3.5.3.2 Afternoon Capacity Analysis

This chart is read using the circular volume and entering volumes for each street. In Figure 12 below, the same chart is shown, now including the circular entering volumes for each of Newton Square. The numerical values are also listed in Table 7.

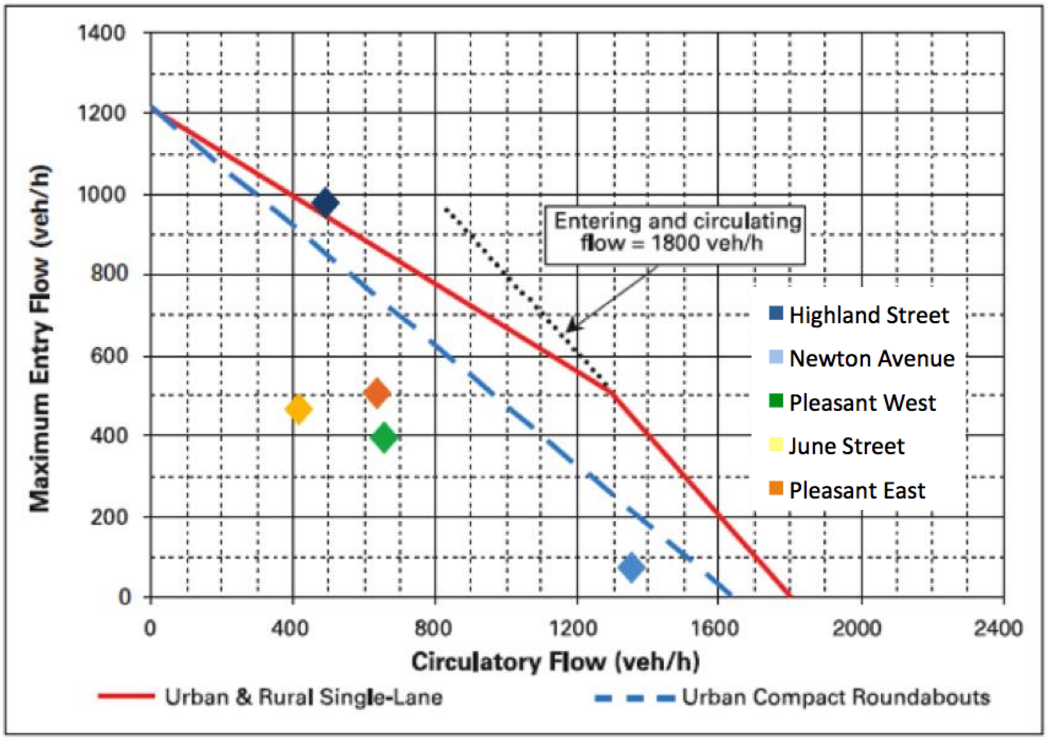


Figure 132: Flow Capacity Chart with Newton Square Afternoon Overlay

Table 7: Volume/Capacity Results Used for Figure 12

	Circulatory Flow	Current Entry Flow	Max Entry Flow Urban & Rural	Max Entry Flow Urban Compact
Highland Street	497	987	850	925
Newton Ave	1,375	75	200	450
Pleasant Street West	646	400	725	850
June Street	424	442	900	975
Pleasant Street East	625	504	750	875

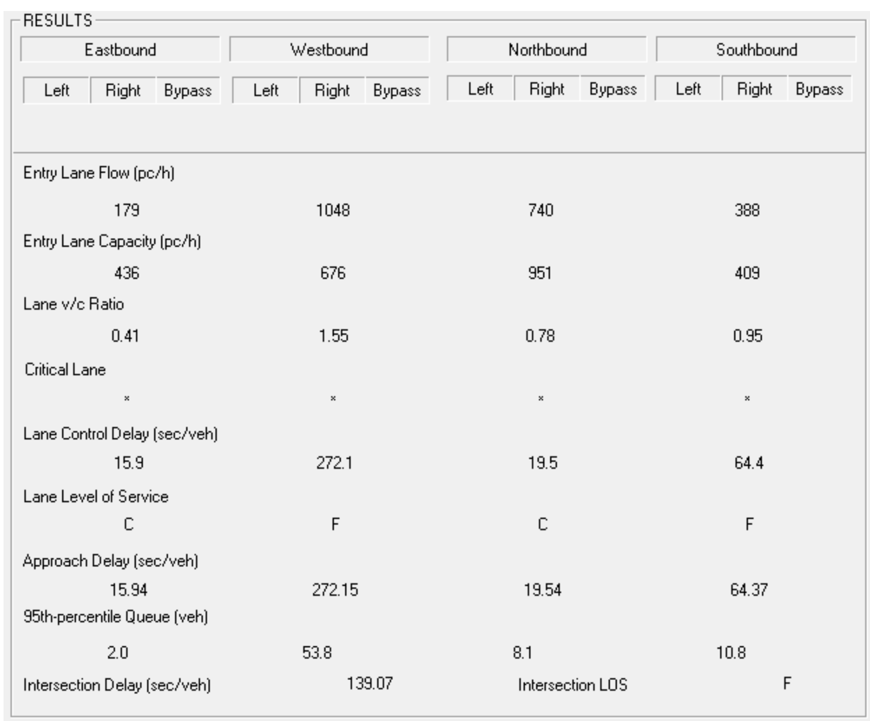
Based on these results, only Highland Street is running over capacity during the afternoon peak hour. It is also interesting to see that Pleasant Street West, Pleasant Street East and June Street contain similar flows rates. None of the other streets are close to the 85% capacity benchmark outlined by the FHWA.

3.5.4 HCS Models

Using Highway Capacity Software, our project group created six models to demonstrate both current conditions of Newton Square as well as models of selected proposed design alternatives. HCS, as described in Section 3.3.5, compiles the entered data and along with preprogramed formulas and assumptions to create a level of service analysis of a given intersection. In the case of Newton Square, the current conditions model produced results correlating with the capacity calculations.

3.5.4.1 Current Conditions, Single Lane Roundabout

Using the data we collected for both the morning and afternoon peak hours, we have created HCS models to demonstrate the current conditions of the single lane roundabout.



RESULTS

	Eastbound	Westbound	Northbound	Southbound
	Left / Right / Bypass	Left / Right / Bypass	Left / Right / Bypass	Left / Right / Bypass
Entry Lane Flow (pc/h)	179	1048	740	388
Entry Lane Capacity (pc/h)	436	676	951	409
Lane v/c Ratio	0.41	1.55	0.78	0.95
Critical Lane	x	x	x	x
Lane Control Delay (sec/veh)	15.9	272.1	19.5	64.4
Lane Level of Service	C	F	C	F
Approach Delay (sec/veh)	15.94	272.15	19.54	64.37
95th-percentile Queue (veh)	2.0	53.8	8.1	10.8

Intersection Delay (sec/veh) 139.07 Intersection LOS F

Figure 13: HCS Morning Results for Current Conditions Model

RESULTS

	Eastbound	Westbound	Northbound	Southbound
	Left / Right / Bypass	Left / Right / Bypass	Left / Right / Bypass	Left / Right / Bypass
Entry Lane Flow (pc/h)	515	478	964	461
Entry Lane Capacity (pc/h)	591	625	672	732
Lane v/c Ratio	0.87	0.76	1.43	0.63
Critical Lane	x	x	x	x
Lane Control Delay (sec/veh)	38.3	25.8	222.2	16.1
Lane Level of Service	E	D	F	C
Approach Delay (sec/veh)	38.31	25.82	222.22	16.05
95th-percentile Queue (veh)	9.9	7.1	44.6	4.5
Intersection Delay (sec/veh)	104.92		Intersection LOS	F

Figure 14: HCS Afternoon Current Conditions Model

In both level of service tables of the current conditions models, the Newton Square is failing as an intersection during both morning and afternoon peak hours. The Intersection LOS is displayed in the bottom right hand corner of each figure. In this same line, we can see that the average vehicle is delayed 105 seconds before proceeding through the intersection. The individual street's level of service is shown in the row labeled "Lane Level of Service". This row shows how each individual street contributes to the intersection as a whole. After seeing this visual representation, we decided to test five other proposed design alternatives:

- Double Lane roundabout from Pleasant Street West to Highland Street
- Double Lane roundabout from Highland Street to Pleasant Street West
- Full Double Lane roundabout for intersection
- Two-Phase Signalized option
- Four-Phase Signalized option

3.5.3.2 Double Lane Roundabout from Pleasant Street West to Highland Street

The first design alternative we tested was a double lane roundabout from Pleasant Street West to Highland Street. This design was proposed to account for the increase in traffic driving in this direction during the morning peak hour. The results of the HCS models are seen below. This design would increase the LOS from an F to a C and decrease the average wait time to 18 seconds during the morning peak hour.

RESULTS

	Eastbound			Westbound			Northbound			Southbound		
	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass
Entry Lane Flow (pc/h)	135	44		492	555			740		327	62	
Entry Lane Capacity (pc/h)	553	580		769	789			951		527	409	
Lane v/c Ratio	0.24	0.08		0.64	0.71			0.78		0.62	0.15	
Critical Lane		x		x	x			x		x	x	
Lane Control Delay (sec/veh)	9.8	7.1		15.9	18.3			19.5		20.5	11.1	
Lane Level of Service	A	A		C	C			C		C	B	
Approach Delay (sec/veh)	9.15			17.21			19.54			18.97		
95th-percentile Queue (veh)	1.0	0.2		4.7	6.0			8.1		4.2	0.5	

Intersection Delay (sec/veh) 17.62 Intersection LOS C

Figure 15: HCS Morning Results for Double Lane Roundabout PLW-High Model

The same design did not produce the same results in the afternoon however, because the greater volume of traffic is headed from Highland Street towards Pleasant Street West and June Street. The resulting LOS was still an F, and the delay time was increased to 111 seconds. The delay increase is not significant, but it reiterates the point that this model does not relieve any of the congestion caused during the afternoon peak hour.

RESULTS

	Eastbound			Westbound			Northbound			Southbound		
	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass
Entry Lane Flow (pc/h)	456	59		396	82			1007		422	39	
Entry Lane Capacity (pc/h)	695	717		724	746			672		816	834	
Lane v/c Ratio	0.66	0.08		0.56	0.11			1.50		0.54	0.05	
Critical Lane		*		*	*			*		*	*	
Lane Control Delay (sec/veh)	17.8	5.9		14.2	6.1			250.8		12.5	5.0	
Lane Level of Service	C	A		B	A			F		B	A	
Approach Delay (sec/veh)		16.47			12.83			250.77			11.87	
95th-percentile Queue (veh)	4.9	0.3		3.5	0.4			49.6		3.3	0.2	

Intersection Delay (sec/veh) 110.77 Intersection LOS F

Figure 16: HCS Afternoon Results for Double Lane Roundabout PLW-High Model

5.3.3 Double Lane Roundabout from Highland Street to Pleasant Street West

The second design alternative we tested was a double lane roundabout from Highland Street to Pleasant Street West. This design was proposed to account for the increase in traffic driving in this direction during the afternoon peak hour. The results of the HCS models are seen below. This design maintains a LOS of F during the morning peak hour, and increases the delay to an average of 135 seconds per vehicle.

RESULTS

	Eastbound			Westbound			Northbound			Southbound		
	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass
Entry Lane Flow (pc/h)		179			1048		495	246			388	
Entry Lane Capacity (pc/h)		436			676		993	1002			409	
Lane v/c Ratio		0.41			1.55		0.50	0.25			0.95	
Critical Lane		*			*		*				*	
Lane Control Delay (sec/veh)		15.9			272.1		9.7	6.0			64.4	
Lane Level of Service		C			F		A	A			F	
Approach Delay (sec/veh)		15.94			272.15			8.44			64.37	
95th-percentile Queue (veh)		2.0			53.8		2.9	1.0			10.8	

Intersection Delay (sec/veh) 135.53 Intersection LOS F

Figure 17: HCS Morning Results for Double Lane Roundabout High-PLW Model

The same design did produce a positive result in the afternoon however, because the greater volume of traffic is headed from Highland Street towards Pleasant Street West and June Street. The resulting LOS was still a C, and the delay time was decreased to an average of 19 seconds. This delay decrease from 105 seconds to 19 seconds is huge and would have a significant impact on the afternoon commute.

RESULTS

	Eastbound			Westbound			Northbound			Southbound		
	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass
Entry Lane Flow (pc/h)		515			478		513	494			461	
Entry Lane Capacity (pc/h)		717			746		672	672			834	
Lane v/c Ratio		0.72			0.65		0.77	0.74			0.56	
Critical Lane		x		x	x		x	x		x	x	
Lane Control Delay (sec/veh)		20.3			16.5		24.6	22.7			12.5	
Lane Level of Service		C			C		C	C			B	
Approach Delay (sec/veh)		20.33			16.47			23.68			12.48	
95th-percentile Queue (veh)		6.2			4.8		7.2	6.5			3.5	

Intersection Delay (sec/veh) 19.48 Intersection LOS C

Figure 148: HCS Afternoon Results for Double Lane Roundabout High-PLW Model

3.5.3.3 Full Double Lane Roundabout

The next design alternative we tested was a double lane roundabout for the entire intersection. This design was proposed to dramatically decrease congestion during both peak hours. The results of the HCS models are seen below. This design raises the morning level of service from an F to a B, and decreases the average wait time to 14 seconds.

RESULTS

	Eastbound			Westbound			Northbound			Southbound		
	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass
Entry Lane Flow (pc/h)	135	44		492	555		495	246		327	62	
Entry Lane Capacity (pc/h)	553	580		769	789		993	1002		527	409	
Lane v/c Ratio	0.24	0.08		0.64	0.71		0.50	0.25		0.62	0.15	
Critical Lane		x		x	x		x	x		x	x	
Lane Control Delay (sec/veh)	9.8	7.1		16.2	18.9		9.7	6.0		20.9	11.1	
Lane Level of Service	A	A		C	C		A	A		C	B	
Approach Delay (sec/veh)		9.16			17.65			8.47			19.36	
95th-percentile Queue (veh)	1.0	0.2		5.2	6.8		2.9	1.0		4.7	0.5	

Intersection Delay (sec/veh)	14.40	Intersection LOS	B

Figure 1915: HCS Morning Results for a Double Lane Roundabout

This combined with the results of the afternoon model, make this design alternative the most efficient solution in terms of eliminating congestion. The afternoon LOS is raised to a C and the average delay is decreased to 18 seconds per vehicle.

RESULTS

	Eastbound			Westbound			Northbound			Southbound		
	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass	Left	Right	Bypass
Entry Lane Flow (pc/h)	456	59		396	82		513	494		422	39	
Entry Lane Capacity (pc/h)	695	717		724	746		672	672		816	834	
Lane v/c Ratio	0.66	0.08		0.56	0.11		0.77	0.74		0.54	0.05	
Critical Lane		×		×	×		×	×		×	×	
Lane Control Delay (sec/veh)	17.8	5.9		14.2	6.1		24.6	22.7		12.5	5.0	
Lane Level of Service	C	A		B	A		C	C		B	A	
Approach Delay (sec/veh)		16.47			12.83			23.68			11.87	
95th-percentile Queue (veh)	4.9	0.3		3.5	0.4		7.2	6.5		3.3	0.2	

Intersection Delay (sec/veh) 17.85 Intersection LOS C

Figure 160: HCS Afternoon Results for a Double Lane Roundabout

3.5.3.5 Two Phase Signalized Design

The first signalized situation we tested for the morning peak hour data was a traditional two-phase control, described in Section 3.3.5. The results of this model are seen below in Figure 21.

Lane Grp	Group Capacity	Flow Rate (s)	v/c	g/C	Delay	LOS	Delay	LOS
Eastbound								
LT	630	1750	0.21	0.36	28.5	C	28.0	C
R	581	1615	0.08	0.36	26.6	C		
Westbound								
L	718	1805	0.87	0.56	45.5	D		
TR	671	1863	0.63	0.36	37.5	D	42.3	D
Northbound								
LT	664	1845	0.74	0.36	42.4	D	39.1	D
R	581	1615	0.42	0.36	32.5	C		
Southbound								
L	207	574	0.13	0.36	28.1	C		
TR	666	1850	0.53	0.36	34.6	C	34.1	C

Intersection Delay = 38.9 (sec/veh) Intersection LOS = D

Figure 171: HCS Morning Results for Two-Phase Signalized Model

For this signalized situation, the LOS would be a level D in the morning. This result estimates that the average vehicle would be delayed 38.9 seconds before continuing through to their desired destination. The most congested approach would be the westbound direction, or Pleasant Street West, which remains consistent with our data collection.

Cycle Length: 172.0 secs

Intersection Performance Summary

Appr/ Lane Grp	Lane Group Capacity	Adj Sat Flow Rate (s)	Ratios v/c	Ratios g/C	Lane Group Delay	Lane Group LOS	Approach Delay	Approach LOS
Eastbound								
LT	384	1889	0.35	0.20	61.2	E	60.1	E
R	329	1615	0.13	0.20	56.9	E		
Westbound								
L	367	1805	1.71	0.20	397.5	F		
TR	379	1863	1.11	0.20	149.1	F	297.5	F
Northbound								
LT	386	1896	1.28	0.20	213.0	F	168.4	F
R	329	1615	0.75	0.20	78.7	E		
Southbound								
L	367	1805	0.07	0.20	55.7	E		
TR	376	1850	0.93	0.20	99.7	F	96.6	F

Intersection Delay = 206.4 (sec/veh) Intersection LOS = F

Figure 192: HCS Afternoon Results for Two-Phase Signalized Model

It is interesting to note that while the street with the most delay is Pleasant Street West, the intersection in general accommodates a more consistent vehicle volume during the morning peak hour than during the afternoon peak hour. While Newton Square is not currently controlled by signalization, similar patterns still emerge in the LOS. For this signalized situation, the LOS would be a level F in the afternoon. This result estimates that the average vehicle is delayed 66.1 seconds before continuing through to their desired destination. The most congested street approach would in the northbound direction, or Highland Street, which remains consistent with our results of the roundabout turning movements.

3.5.3.6 Four Phase Signalized Design

Figures 23 and 24 show the results of a four phase signalized option where each of the approaches receives their own light phase to accommodate left-turning vehicles. The LOS for the intersection would be F during both peak periods, and the average vehicle delay would be268 seconds in the morning and 206 seconds in the afternoon. This more than doubles the existing intersection delay.

Control Delay and LOS Determination

Appr/ Lane Grp	Ratios v/c	Ratios g/C	Unf Del d1	Prog Adj Fact	Lane Grp Cap	Incremental Factor k	Del d2	Res Del d3	Lane Group Delay	Lane Group LOS	Approach Delay	Approach LOS
Eastbound												
LT	1.12	0.20	87.5	1.000	385	0.50	248.3	0.0	335.8	F	269.9	F
R	0.16	0.45	35.4	1.000	734	0.50	0.5	0.0	35.9	D		
Westbound												
L	0.50	0.20	77.6	1.000	369	0.50	4.9	0.0	82.5	F		
TR	0.76	0.20	82.4	1.000	352	0.50	15.5	0.0	97.9	F	91.6	F
Northbound												
LT	1.34	0.20	87.5	1.000	387	0.50	631.7	0.0	719.2	F	392.7	F
R	0.68	0.45	47.3	1.000	734	0.50	5.1	0.0	52.5	D		
Southbound												
L	0.14	0.20	71.6	1.000	369	0.50	0.8	0.0	72.4	E		
TR	0.99	0.20	87.2	1.000	383	0.50	80.4	0.0	167.6	F	156.3	F

Intersection delay = 268.0 (sec/veh) Intersection LOS = F

Figure 203: HCS Morning Results for Four-Phase Signalized Model

Sum of flow ratios for critical lane groups, Yc = Sum (v/s) = 0.00
Total lost time per cycle, L = 0.00 sec
Critical flow rate to capacity ratio, Xc = (Yc)(C)/(C-L) = 0.00

Control Delay and LOS Determination

Appr/ Lane Grp	Ratios v/c	Ratios g/C	Unf Del d1	Prog Adj Fact	Lane Grp Cap	Incremental Factor k	Del d2	Res Del d3	Lane Group Delay	Lane Group LOS	Approach Delay	Approach LOS
Eastbound												
LT	0.84	0.35	39.1	1.000	514	0.50	16.9	0.0	56.1	E	50.5	D
R	0.22	0.35	30.0	1.000	559	0.50	0.9	0.0	30.9	C		
Westbound												
L	0.35	0.54	30.8	1.000	531	0.50	1.8	0.0	32.6	C		
TR	0.45	0.35	32.9	1.000	596	0.50	2.4	0.0	35.3	D	34.2	C
Northbound												
LT	1.01	0.35	42.5	1.000	512	0.50	93.3	0.0	135.8	F	100.5	F
R	0.89	0.35	40.2	1.000	559	0.50	23.5	0.0	63.7	E		
Southbound												
L	0.29	0.35	30.9	1.000	177	0.50	4.1	0.0	35.0-	C		
TR	0.58	0.35	34.8	1.000	648	0.50	3.9	0.0	38.7	D	38.2	D

Intersection delay = 66.1 (sec/veh) Intersection LOS = E

Figure 214: HCS Afternoon Results for Four-Phase Signalized Model

3.6 Recommendations

After careful consideration of the data collected by both this project group as well as the 2007 MassDOT traffic study, we can conclude that the most effective design alternative to Newton Square will be a partial two lane roundabout extending from Pleasant Street West to Highland Street. This design closely resembles the third design alternative presented by MassDOT at the conclusion of their traffic study. Please see Section 3.2.1 for more details. Before making this recommendation, we considered the four existing design alternatives, as well as a signalized intersection. Based on our personal observations made at the intersection during our turning movement studies, the HCS models, and input from MassDOT and DPW&P, we determined the third design alternative addresses the major concerns of the intersection.

3.6.1 Design Alternative

During our morning turning movement count conducted on January 23rd, 2013, we noticed that drivers on Pleasant Street West aligned themselves into two lanes, despite the fact that those lane designations are not painted on the street. The extra space that allows them to do so is unavailable in the afternoon because where the vehicles were driving over is actually parking spaces for Newton Square Pizza, and are occupied during business hours. By labeling a two lane entrance on Pleasant Street West and two travel lanes extending to Highland Street, this will facilitate a significant decrease in confusion among drivers. Although there is a higher volume of vehicle entering Newton Square from Highland Street during the afternoon peak hour, this additional volume does not impede the flow of the entire intersection compared to the morning peak hour. A schematic of our suggested design alternative is provided in Appendix F.

Based on the HCS models and the constraints of the site, the most feasible design alternatives are to have a double lane from either Pleasant Street West to Highland Street, or from Highland Street to Pleasant Street West. The entire intersection being a double lane roundabout is not feasible because the space a double lane roundabout requires is not available for use within the parameters of the intersection. Looking at the two options for partial double lanes, compared to the current conditions, the two design alternatives are fairly comparable.

Table 8: Comparison of PLW-High and High-PLW Design Alternatives

	Current Conditions	PLW-High	High-PLW
Morning LOS	F	C	F
Afternoon LOS	F	F	C
Morning Delay	139 sec	17 sec	135 sec
Afternoon Delay	105 sec	111 sec	19 sec

Based on the level of service and delay results produced from the HCS models, there is not a clear favorite between the two design alternatives, as shown in Table 8. In both cases, the double lane only reduces congestions during one of the peak hours. Because of this, the determination of which design alternative to recommend is left to other factors besides traffic volumes. These factors include personal observations on severity of congestion and confusion in the intersection as well as the physical constraints of the intersection.

During our December 18th, 2013 discussion with Joe Frawley we presented to him our design alternatives, as well as our specific selection as the best option for Newton Square. He agreed with our rationale for selecting a double lane roundabout from Pleasant Street West to Highland Street. He concurred with our reasoning that this pattern is already occurring during the morning commute and would not create a significant change to the current operation to the intersection while allowing for clarity in driver understanding of the function of the intersection.

Upon Joe Frawley's consensus, we met with Joe Borbone and Ali Khorasani of the Worcester DPW&P to discuss the view point of the City of Worcester at Newton Square. During this meeting, we found that they have begun to move forward with architectural designs and have commissioned schematics of the third design alternative, therefore confirming our choice that this design alternative is the best fit for the intersection. The drawing is available in Appendix F. They agreed with Mr. Frawley's assessment that the entrance and exit angles, along with the turning radii are an important factor in slowing motorists down. They were also satisfied that even with the medians and increased center island diameter, accommodations for heavy vehicles, including WB-60s, are being met with this design.

In addition to the larger concern of travel lanes, we also recommend that medians be put in at each street. Pleasant St East is the main concern due to vehicles assuming that Newton Square can function as a six-way intersection and entering the intersection directly from Coolidge Street. The median would force these vehicles to enter the intersection appropriately. Additionally medians would adjust the entrance angle in order to decrease vehicular speeds. A safety concern for all streets leading to the intersection is the length of the crosswalks. Currently, the crosswalks are placed directly at the entrance to the roundabout, causing pedestrians to be vulnerable in the street for longer than necessary. Realigning the crosswalks farther from the intersection would decrease the cross time and improve pedestrian safety.

Along with the design that Worcester DPW&P provided, we suggest adding signalized pedestrian cross-walk signs in order to improve pedestrian safety. These signs would be placed at each entrance and exit of the roundabout in order to warn vehicles that a pedestrian is utilizing the crosswalk. In 2010 The Federal Highway Administration did a study of these types of Rectangular Rapid-Flashing beacons and every type of beacon that they tested increased driver's yielding compliance (Evans, FHWA). We believe that these beacons would help notify drivers in the roundabout of pedestrians and allow for safer pedestrian access during the times that the crossing guard is not in the intersection.

3.6.2 Newton Square Neighborhood

According to the Worcester DPW&P, the Newton Square redesign is considered a separate entity from the surrounding area. However, the adjacent streets should still be looked at as well because they contribute to the significant congestion occurring in Newton Square; specifically on Highland Street, in the morning when the nearby high school beings session. We observed many vehicles taking turns into the parking lot which caused delays in both the east and west directions. Additionally, due to the width of Highland Street, many cars pulled over to the curb to let students out instead of driving into the parking lot. While this was a good idea in theory, the vehicles did not always pull over far enough to keep the travel lane clear and students often cross the street right at the car instead of continuing to a crosswalk. Because of this heavy congestion in front of the high school, many parents avoided the drop off area on Highland Street and instead chose to drop their students off in the intersection itself, adding to the confusion of Newton Square. Due to these complications, it is highly recommended that this issue be addressed in addition to the Newton Square redesign to alleviate the resulting traffic problems.

A major safety concern that we noticed during the morning traffic count was vehicles entering the intersection directly from Coolidge Road instead of merging and entering via Pleasant Street, due to the proximity of Coolidge Road to the intersection. Our design alternative eliminates this problem by creating a median between June Street and Pleasant West, narrowing the entrance on Pleasant Street, and blocking drivers from entering the intersection incorrectly. Drivers will be forced to take a left onto Pleasant Street, merge with the oncoming traffic, and enter Newton Square via Pleasant Street. Although this eliminates the safety issue, it also creates more difficulty for vehicles coming from Coolidge Road. However, given the nature of the neighborhood between Pleasant and June Streets, these vehicles could find alternate ways to enter the intersection if making the left turn onto Pleasant Street causes backups on Coolidge and Pleasant Streets.

3.6.3 Cost Considerations

According to the FHWA guide on roundabouts, there are different major costs associated with a signalized intersection and a roundabout. A signalized intersection attributes the majority of its costs to installing the signal as well as upkeep and maintenance, and the costs are increased significantly if the pavement area needs to be increased to add an additional travel lane. The majority of costs when designing a roundabout are due to increasing the pavement area of the intersection (Roundabouts FHWA, 36). Therefore four of the six alternatives would be relatively low cost since they stay within the original layout of the intersection.

There would only be high costs associated with the fourth alternative, which adds two lanes in both directions and increases the layout of the intersection. The second alternative, that we chose to be the best alternative, would be a relatively low cost project. The majority of the costs would come from increasing the size of the center island, and the additional landscaping that would go along with it, along with adding medians at the entrances. There are also low maintenance costs associated with a roundabout, these would be attributed to landscaping, and restriping. These maintenance costs are already going on at the intersection, and would not be significantly increased by completing this project.

There have been many projects, similar to Newton Square across the country that update roundabouts to make them safer and more effective. For example in 1993, the Los Alamitos Traffic Circle in Long Beach, California was updated with lane widening, and restriping. Between the engineering and construction, this project cost approximately $400,000, which would amount to around $750,000 today, assuming 3% inflation (NCHRP). Another example is the Cearfoss Roundabout in Maryland, which was created to decrease accidents and speeds at the intersection in order to improve safety. This project was completed in 1995 for $386,145, which amounts to $675,000 today (FHWA, Safety). Both of these projects were much more elaborate than our intended project, and therefore we do not foresee that the project will exceed $600,000.

3.7 Conclusions

Our project sought to improve roadway safety for all users in the designated location of Newton Square in Worcester Massachusetts. We began this project by completing a turning movement count of the intersection to compare with past data compiled by MassDOT. After initial analysis of our data, we determined that it was advantageous to conduct an additional turning movement count in order to gain a better understanding of traffic patterns at this intersection throughout the day. Based upon these two traffic counts, we considered six design alternatives, including the current conditions, for Newton Square and determined the optimal solution given the constraints of intersection. Some of the constraints we encountered were the amount of land available within the layout of the intersection, costs of different changes and fluctuating level of service throughout the day. The design alternative that we are recommending addresses the aforementioned considerations and will deliver a higher overall level of service compared to current conditions of the roundabout. With this redesign, traffic flow will be increased, the capacity of the intersection improved, and the overall safety of motorists, bicyclists and pedestrians alike will be significantly enhanced.

Appendix A: Project Proposal, Submitted October 17th, 2013

Redesign of Newton Square

Major Qualifying Project

Project Proposal

Civil Engineering Department

Margaret Corrigan

Meghan Hennessey

Susan Stukas

October 17, 2013

Professor Suzanne LePage

Table of Contents

Table of Figures

Table of Tables

Capstone Design Statement

This Major Qualifying Project looks to present design alternatives to Newton Square, located in Worcester, Massachusetts. The square is a five-road intersection that is organized through use of a rotary, not signalization and has been an area of previous study by the Massachusetts Department of Transportation (MassDOT). We seek to continue their efforts in creating a beneficial design alternative. The current intersection is very congested, and motorists are able travel through at a higher than expected speed due to the width of the travel lane. In creating our design alternatives, we will first need to conduct a traffic count of the intersection to determine its capacity. In combination with the previous data collected by MassDOT, we will develop several design alternatives with consideration paid to the following eight constraints of Capstone Design.

Economics- This Major Qualifying Project will consider the financial constraints facing the city of Worcester in our potential designs of Newton Square. We will keep our expectations of our design in a realistic scope that could be achieved within the budget allocated to the City of Worcester. For this reason, cost will be one of the higher ranking factors in determining which design to present as a best option.

Environmental- In any form of construction, environmental concerns are taken into consideration during both the design and execution phases. We will consider the environmental impacts of tearing up the Square and the surrounding streets, as well as laying new pavement.

Sustainability- Once the new Newton Square design is implemented, if updating the striping is the only change that is made, the intersection's upkeep will be no more taxing than the current square. However, if a signalized solution is deemed best, the intersection will require more attention than its current design.

Constructability- In order to create an engineered redesign of Newton Square, naturally constructability has to be considered, such as the amount of effort and temporary rerouting that needs to occur in order for the new final design to be implemented. The ease of construction is just as important as the cost of a particular project and the impact it will have on the community, therefore we anticipate this will be highly considered in the redesign of Newton Square.

Ethical- We will consider the ethical implications of our redesign of Newton Square using the ASCE Code of Ethics standard across all types of construction projects.

Health & Safety-Safety will be very highly considered in creating a redesign. We will consider the safety for all who utilize Newton Square for transportation including motorists, cyclists, and pedestrians. All of the designs will have the goal of improving safety for all users.

Social- It is one thing to change the design, but quite another to convince the public to make use of those changes. The social implications of any design alternative will need to be considered with high importance; it is the people who will be using the intersection who will determine if the design is in fact more functional. The impact of the residents and local businesses in and around the area will also be taken into consideration.

Political- Similar to economics, because this project is dealing with a city right-of-way, any changes would need to be approved by the city offices. Politics may not be the biggest consideration for the functional design of the square. However, it will be an important factor in whether or not this design will be implemented.

1 Introduction

In the United States, pedestrians and cyclists are vulnerable users of our transportation system due to the lack of abundant designated bike paths and safe sidewalks provided to them. Pedestrian and bicycle accidents in the United States are remarkably high; in 2011, 4,432 pedestrians were killed, and an estimated 69,000 were injured in traffic crashes across the country. On average, a pedestrian was killed every two hours and injured every eight minutes in traffic crashes within the United States[1]. Additionally, 677 pedal cyclists were killed and an additional 48,000 were injured[i]. With over 5,000 fatalities and more than 117,000 injuries combined, these statistics bring to light the harsh reality that pedestrians and cyclists are at constant risk when operating on the same roadways as motorists.

Worcester is the second largest city in Massachusetts with approximately 181,000 residents (US Census Bureau); compared to the Commonwealth's largest city of Boston, which ranks in the top 5 most walkable cities. Worcester does not even list within the top 20 cities of Massachusetts alone. Worcester's walkability is substantially below expectations, which is a great concern to the Worcester community because it hinders the livability of the city, and generates limitations to its residents. Partly due to these inadequacies, Worcester, Massachusetts is home to the 6th top pedestrian crash cluster in Massachusetts, and currently holds 21 different intersections on the 2006-2008 Statewide Top 200 Intersection Crash List[ii]. As evidenced by the statistics, Worcester is a city where efforts should be directed to increase the safety and suitability of both pedestrians and cyclists alike. Strides have been made to work on advocating for the improvement of roads and streets. We will facilitate this implementation by working with the City of Worcester to create safe access for pedestrians, cyclists, and motor vehicles through Newton Square. By designing and engineering a street design for a particular region, we increase the likelihood of its application within the City of Worcester.

1.1 Scope of Work

For this project, our team will coordinate with a few different key players involved in the transportation field, including MassDOT, the City of Worcester, WalkBike Worcester Working

Group, as well as various community members willing to share input. We will be evaluating the Newton Square neighborhood, specifically Highland Street from Park Avenue to Newton Square (pictured below) as well as the configuration of Newton Square itself. Through this evaluation, we will determine what changes are feasible to make in order to better accommodate pedestrians, cyclists and motorists alike.

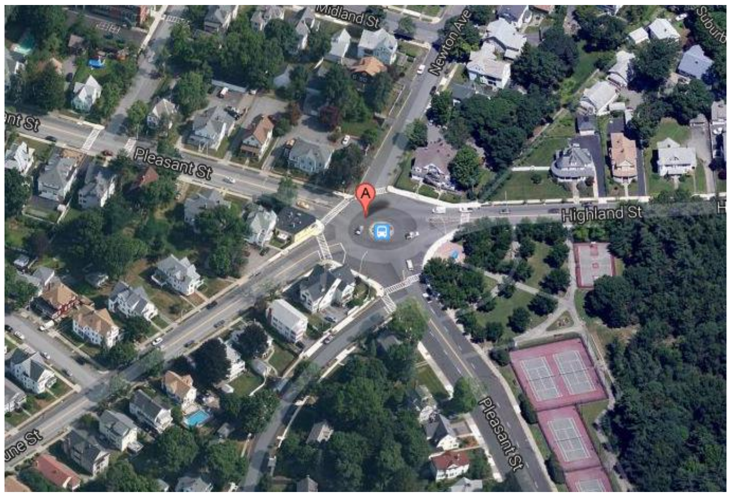


Figure 1: Aerial View of Newton Square

The assessment will consist of traffic counting around Newton Square to see the common traffic flow patterns that are produced, as well as taking measurements of roadways surrounding the rotary. This information will be gathered in the upcoming months, and the data analysis will take place in succession. The analysis of the data to be collected will help our group determine the best course of action with the current layout and surrounding area. Most likely to be provided will be recommendations on new paint striping for the streets, as well as to reconstruct Newton Square for a more pedestrian and cyclist friendly path that will ultimately simplify travel for these groups. We will do this by suggesting new striping on the roadways, and incorporating methods of slowing down traffic and potentially increasing the capacity of the intersection in our design alternatives.

2 Background

There are many alternatives to consider when designing a circular intersection such as a roundabout, mini-roundabout, neighborhood traffic-calming circle, or a rotary. A commonly used option is a roundabout, which is often used for smaller circular intersections, channelized in order to create slower entry and circulating speeds. Some roundabouts have only one lane and others have multiple lanes, based upon the area available. Another option is a neighborhood traffic-calming circle. However, these are often used in four-way intersections to replace stop signs and reduce speeds in small residential neighborhoods and do not accommodate trucks. Rotaries are commonly used in high-speed intersections where area is available for a larger diameter circle in order to allow for higher entry and circulating speeds. [2]

2.1 Complete Streets Philosophy

MassDOT has recently adopted the Complete Streets Primer, an independent program that provides states with a guideline for creating safe, usable transportation for all users. The state of Massachusetts is actually a leader in this area, having previously developed their own Baystate Roads Program in 2006 to improve the quality of roadways in the state. Their mission statement and sustainability commitment states "Our mission is to deliver excellent *customer service* to the people who travel in the Commonwealth and to provide our nation's *safest* and most reliable transportation system in a way that strengthens our economy and quality of life."[3] Using a combination of the two programs, Massachusetts has targeted many roads in the greater Boston area and has begun construction to modify streets. The Complete Streets program is unique in that it is a public program and therefore the model ordinances and bylaws are readily available for municipalities to view online.[4]

The concept of Complete Streets is to allow the safest and most easily interpreted mode of transportation for all users, including motorists, cyclists and pedestrians. This is not to say that there is one particular model that applies to every possible street; in fact the guideline is just that, a guideline. It serves as a resource for developers to think about different ways to use the area available to them. For instance, some streets may be wide enough to accommodate

[2] Transportation Research Board, National Cooperative Highway Research Program (NCHRP) Report 672: Roundabouts: An Informational Guide—Second Edition, Chapter 3, Washington, D.C. 2010.
[3] Prentiss, Doug. "MassDOT Design Guide and Complete Streets Primer." Complete Streets Workshop. Worcester City Hall, Worcester MA. 14 Aug. 2013. Lecture.
[4] "MMA Model Complete Streets Ordinances/Bylaws" The Massachusetts Municipal Association. Online PDF. 15 Sep. 2013.

both motorist lanes and a bike lane, while others may only have the lane width for a sharrow, or shared bike lane. In order to be considered a Complete Street, it is not necessary for it to contain all modes of use for every type of transportation.[5] In Massachusetts, the focus for analyzing streets for completeness has been mostly focused in Boston and the surrounding suburbs, however MassDOT District 3 is hoping to make use of the Complete Streets model on their future projects.

On Wednesday August 14th, 2013 Doug Prentiss, a transportation engineer from Fay, Spofford & Thorndike, presented a Complete Streets Workshop at Worcester City Hall open to all interested parties. We attended this presentation and gained a variety of useful resources and contacts. During this workshop the main topic of conversation was about integrating cyclists and pedestrian transportation into existing roadways. This could be as simple as adding paint to the road, or more complicated to require retiming of signalized intersections to accommodate pedestrians.[6] When planning for a redesign of Newton Square, it is advantageous to consider the impacts of pedestrian traffic due to the public elementary and high schools on the two streets leading to the intersection. Using this knowledge of Complete Streets, we will consider the safety of all users at Newton Square and will create our recommendations accordingly.

2.2 WalkBike Worcester

Walk Bike Worcester (WBW) is a project of the Worcester Food and Active Living Policy Council. WBW aims to make walking and biking in the city more safe, pleasant, and convenient. They work with city officials, community groups, hold community events, and research local conditions. WBW attends public meetings and provides input on project designs and plans, giving a consistent and clear voice for pedestrians and cyclists in the city. WalkBike Worcester aims to educate residents regarding current legislation that supports a transition to a pedestrian and cyclist friendly community. While involvement and activism are great means of employing change, the process of implementation is a difficult path to venture through. So far,

---

[5] MassDOT Design Guide & Complete Streets

[6] MassDOT Design Guide & Complete Streets

the group has demonstrated strong efforts in building partnerships with other organizations to help further their progress. In order to continue to solidify the strong foundation that is currently established, the working group is looking to make concrete changes to specific streets in the city of Worcester.

WalkBike Worcester was put into contact with a group of students from Worcester Polytechnic Institute (WPI) in 2012 for the IQP that helped to identify areas for potential bike routes in the City of Worcester. When the project team presented their plans to Robert Moylan, Worcester Public Works and Parks Commissioner, their recommendations led to the formation of the Worcester Bike Working Group. The working group consists of department officials, members of the Central Massachusetts Regional Planning Commission (CMRPC), WalkBike Worcester, as well as general community members. The main purpose of the working group is to set obtainable goals for road improvement to create safe travel for bicyclists in Worcester. This working group continued through to 2013, where our current project team has become involved.

On September 9th, 2013, we had the opportunity to sit down with the working group and talk about their goals, possible additions to the current suggestions on roadway with the potential for bike lanes, and general suggestions for the group. CMRPC reviewed the list of potential roadways to be improved given to them by WBW and the IQP group, and provided a tiered recommendation for possible implementation. In addition to the current working group goals, several suggestions were made about general ideas for road enhancement, such as restriping, additional signage, and further connection of the bike paths.

2.3 Massachusetts Department of Transportation

MassDOT was formed in 2009 in an effort to modernize the transportation systems in the commonwealth. MassDOT combined the Massachusetts Bay Transportation Authority (MBTA), Executive Office of Transportation and Public Works (EOT), Massachusetts Turnpike Authority (MTA), the Massachusetts Highway Department (MassHighway), and the Registry of Motor Vehicles (RMV). The Secretary of Transportation administers the organization, a position appointed by the Governor.[7] The highway department of MassDOT oversees all state owned highways and interstates. The division is divided into six districts, seen in Figure 2.[8] Worcester is in District Three, and therefore under the jurisdiction of their district office in Worcester.

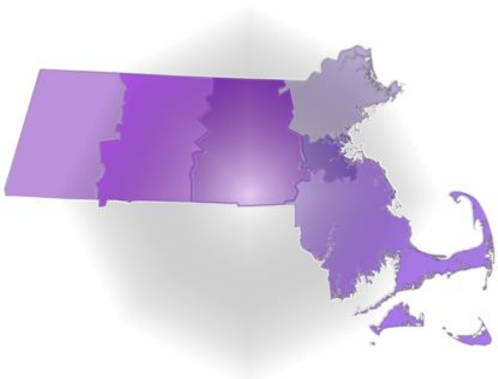


Figure 2: Map of Massachusetts Department of Transportation division distribution

[7] Kirwan, Leslie, James A. Aloisi, Jr., and Jeffery B. Mullan. "90 Day Integration Report." Massachusetts Department of Transportation, Sept. 2009.

[8] "Highway Division." *MassDOT*. The Commonwealth of Massachusetts, Jan. 2012. Web. 04 Nov. 2013.

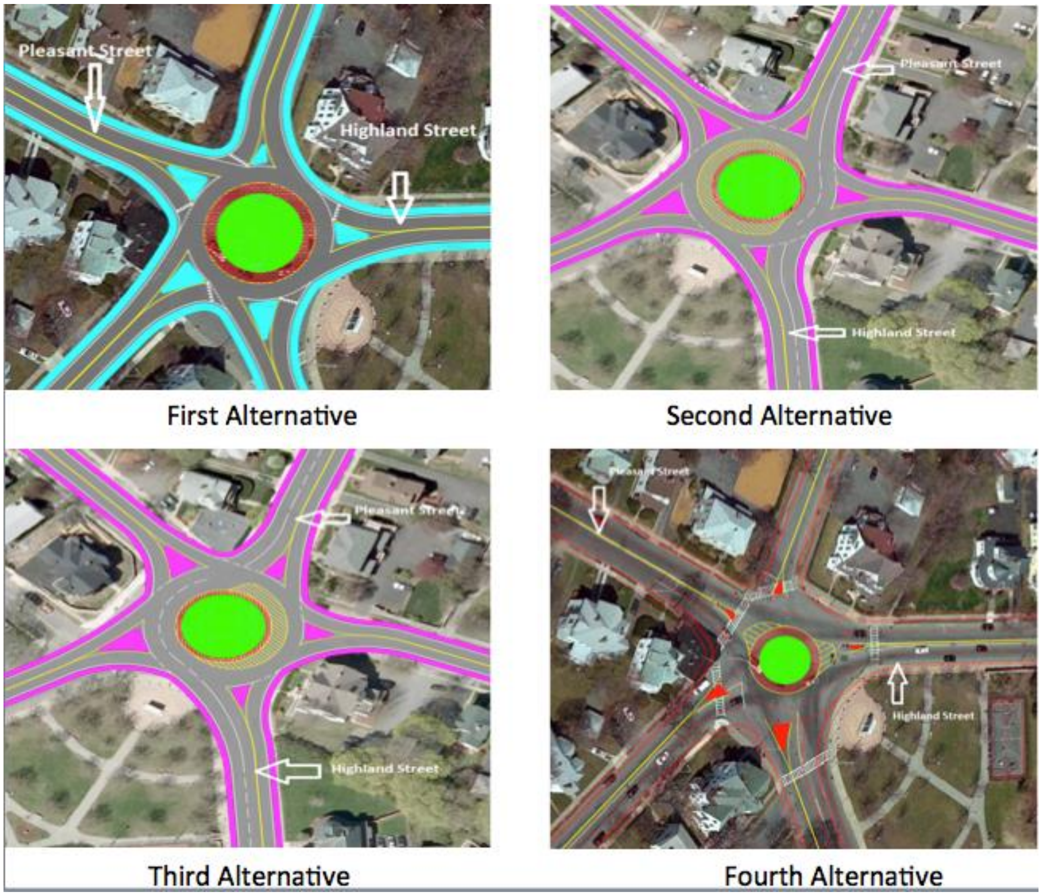


Figure 3: Redesign options considered by MassDOT

We met with the MassDOT traffic engineer Joe Frawley, in District Three on October 3rd, 2013 to discuss their involvement in past projects involving Newton Square. In 2007, they reviewed the intersection and designed multiple alternative intersection plans. In 2007, MassDOT considered redesigning Newton Square in order to allow for more efficient traffic flow. They completed a detailed study of the intersection, including a complete traffic count, and considered many redesign options. They considered a signalized intersection, which proved to be inefficient because of predicted increased traffic delays. They also considered adding additional lane markings, but according to the Federal Highway Administration guidelines, lane lines are not encouraged for a circular roadway because they can often be misleading. They considered four different design alternatives, seen in Figure 3. The first alternative increased the size of the breakdown lanes in every direction in order to decrease the radius of the circle but continue to have one travel lane. The second alternative was to add an additional westbound travel lane through the intersection from Highland Street to Pleasant Street. This design was considered in order to account for the high influx of travelers utilizing the intersection during the evening commute.

MassDOT also considered an additional eastbound travel lane from Pleasant Street to Highland Street. Similar to the previous design, this alternative accounted for the high number of commuters entering the square during the morning commute. The flaws of both of these solutions were that they only accounted for the increased level of traffic during one of the peak traffic times, not both. A fourth alternative that was considered included additional travel lanes in both of these directions to accommodate both the AM peak and PM peak traffic.

The three alternatives that were considered with an extra travel lane were the options they focused on, because of the high peak hour traffic volumes. According to their traffic study, during the AM peak hour, 1,704 cars entered the intersection from Pleasant Street and 1,205 cars exited at Highland Street. During the PM peak hour 1,057 cars entered the intersection from Highland Street and 1,129 cars exited via Pleasant Street. The major issue with adding an additional travel lane was the area available in the intersection. In order to have enough space for two travel lanes and a breakdown lane, MassDOT would have needed to acquire land adjacent to the intersection and increase the paved area. This would have added significant costs to the project. The engineers working for MassDOT were unable to come to a conclusion on the optimal way for redesigning the intersection and no further improvements were made.

3 Methodology

3.1 Street Maps for WalkBike Worcester

As a result of our September 19th meeting with WalkBike Worcester, they requested that we create a series of maps for them to present to the DPW on October 1st, 2013. These maps are to combine data from several sources into one document to ease viewing and understanding of their compatibility. The sources of this data is provided by previous IQP groups, roads selected by the Worcester Bike Working Group, as well as the residential streets to be repaved in the 2014 construction year identified by the Worcester City Councilmen. Please see Appendix A for a full list of the residential streets. In order to create one unified map, we will first acquire the ArcGIS files from CMRPC. Once we have access to these files, we will add markings for the residential streets to be repaved. We anticipate that this information will be presented in different colors in order to distinguish the information provided by CMRPC and the City Councilmen.

WalkBike Worcester hopes these maps will help illustrate their ideas of where the city would benefit from adding bike lanes to the roadways. For many of the residential streets, this will not be practical given their limited accessibility and their short length. We will provide these maps to them before the deadline of October 1st and present them in a readable manner so that information can be gathered by all viewers, not just those familiar with GIS software.

3.2 Street Profile of Highland St

At the Worcester Bike Working Group meeting held on September 9th, it was discussed that the stretch of Highland Street between Park Avenue and Newton Square was repaved within the last few years. However, additional striping was not completed. Currently the only marking on this stretch of Highland Street is a yellow double center line. We were tasked with analyzing the street and its traffic patterns to come up with a striping solution that will accommodate motorists, pedestrians, and cyclists. We will

Figure 4: View of Highland Street

complete this task through a combination of visual data collection as well as GIS analysis and interpretation, as outlined at the Complete Streets Workshop in August.[9] We will visit the street segment at various periods of congestion to gain a better understanding of the needs for all three types of roadway users. Our group will utilize GIS data to determine the exact street width and potential design limitations. We hope to suggest appropriate signage to include all types of traffic including moving vehicles, cyclists, and parked cars or public transportation channels.

3.3 Traffic Counts at Newton Square

The Worcester DPW has a comprehensive traffic count record for the majority of the streets and intersections across the city; however, their records fall short at rotaries. Rotaries pose a conundrum in traffic counts because of their complexity. At a typical intersection, a traffic counting device would be used to log vehicular traffic in all directions and their turning patterns, including straight motion and both turning directions if allowed. At an intersection with only two cross roads and a traffic light, there is a timed pattern to the traffic movements, allowing for easier counting due to the rhythm of movement. The concept of a circular intersection is improve traffic flow so that there are always cars entering and exiting the field of motion.

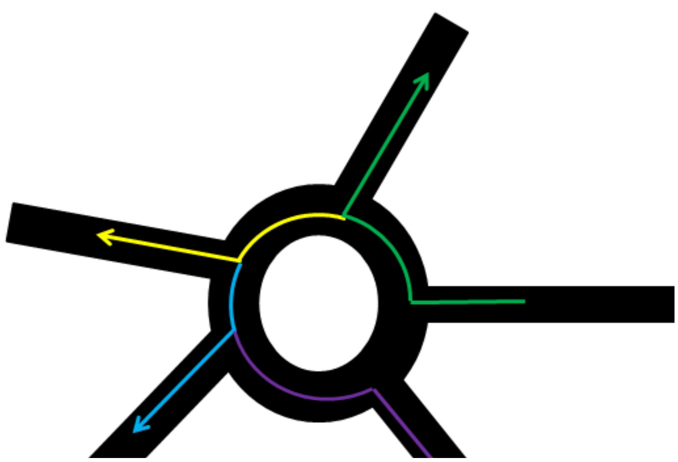


Figure 5: Traffic counting system for Newton Square

This being the case, extra caution needs to be taken when counting traffic patterns in Newton Square. In order to get an accurate count, we will systematically count the cars by focusing on one entrance at a time. Five students will need to participate in this traffic count, each one focusing on a single entrance. The students will follow cars from their designated entrance to the rotary and then mark which exit each car takes, demonstrated in Figure 7 left. Each student will be responsible for all four exits coming from their designated

[9] MassDOT Design Guide & Complete Streets

rotary entrance. This will require vigilant attention by all parties to ensure that all cars utilizing the rotary are accounted for.

The WPI Civil & Environmental Engineering Department has two intersection Traffic Data Collector Devices which can be used to count vehicular movements at typical four way intersections and can accommodate four traffic lanes in all directions. In the case of a rotary, these devices are not the ideal tool to use. The group will first test these devices in use at the rotary before conducting the official traffic count to see if they are a constructive use of technology. If it is determined that the devices are not as effective in this unconventional setting, hand tallies will be counted.

This traffic study will be conducted over the course of several hours at peak traffic times, on Wednesday, November 13th, and will count the turning movements of all cars that enter the intersection. We anticipate counting over a period of several hours, in which case the traffic counts will be divided into smaller time intervals to allow for more thorough analysis of the transportation patterns, most likely fifteen minute intervals. The group will also count pedestrians and cyclists that make use of Newton Square. This is important to note in order for our recommendations to align with the Complete Streets guidelines that have been adopted by MassDOT.

Before conducting the full traffic count, we will visit the square for a trial run on November 6th to practice our skills at tracking the turning movements of cars exiting the rotary. We will test both our individual and collective accuracies on this date and segment our data into fifteen minute time intervals. We hope that having a consistent time interval will aid the group in analyzing the data after the traffic count has been completed and should allow patterns to emerge.

3.4 Street Profiles for Newton Square Feeding Streets

As a result of the Newton Square traffic counts, we will produce street profiles for the five streets leading off the roundabout; Newton Avenue, Highland Street, Pleasant Street, June Street & the second Pleasant Street entrance. The street profiles for these five streets will focus on the entrances/exits from Newton Square and how those intersections could be improved.

Items that will be taken into account will include the location of the stop line, width of pedestrian crossing area and the width of the vehicular travel lane. A street profile will already have been completed for Highland Street, as requested by WBW. However, there will be a distinct difference in the information contained in these two street profiles. The first profile for Highland Street will focus on the entire length of the segment between Park Ave and Newton Square, while the second will specifically look at the intersection of Highland Street and Newton Square.

3.5 Newton Square Design Alternatives

In creating design alternatives for Newton Square, we will consider the data collected in our traffic count and compare it to the traffic count conducted six years ago by MassDOT. This information will be used to identify the most commonly traveled pathways through the intersection, and therefore determine the location in the intersection where the most mitigation needs to take place. We will begin by designing several alternatives including single lane, double lane and signalized solutions. These designs will be reviewed and assessed for their feasibility.

3.6 Criteria Determining Alternative for Recommendation

After determining the best options for the redesign of Newton Square, the design alternatives that we come up with will go through an evaluation process to analyze their fundamental effectiveness in different categories that are important for roadway modernization. To ultimately select the final design, we have created a rubric to evaluate each of the alternative designs using specifications to rank its acceptability. To fully assess each of the different designs, we are taking the following five different categories into consideration:

- Pedestrian/biker friendliness: This is given the utmost importance, because it is essentially the main goal of the reconstruction.
- Safety of the redesign: Safety should be highly considered because if a road design strategy is unsafe, it puts pedestrians, cyclists, and motorists in danger.
- Constructability: The feasibility of actually performing the work to its completion is significant to ensure it is achievable.

- Political Implication: This plays an important role in Worcester due to the city's long-standing history; there are many political factors to consider when redesigning an area that has much antiquity.
- Cost of the redesign: If the design fully encompasses all of the other aspects, yet it is out of the financial range of the city, the alternative selected will be unmanageable.

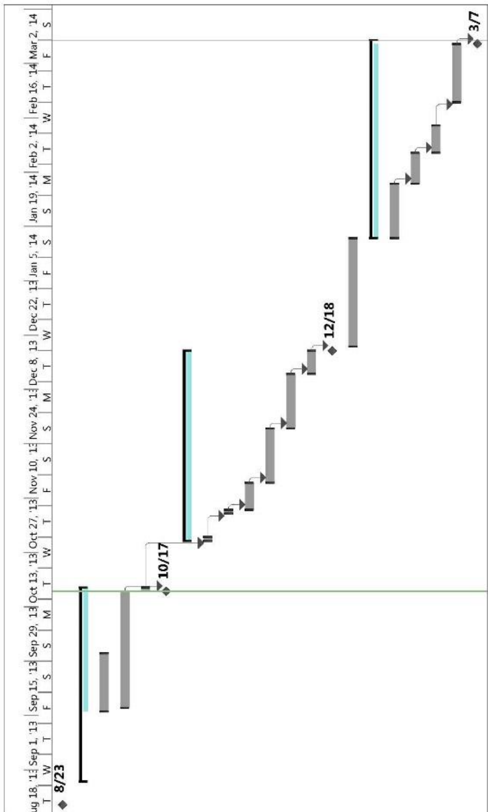
We will look at each of the design alternatives and appropriately rank them from the different groupings previously described on a qualitative scale; from the completed rubrics, we will select the one that is the all-inclusive frontrunner of the options.

Table 1: Preliminary Design Rubric - Grading Criteria

	Highly Unsatisfactory	Unsatisfactory	Satisfactory	Superior	Exceptional
Pedestrian/Biker Friendliness					
Safety					
Constructability					
Political Implication					
Cost					

3.7 Schedule

ID	Task Name	Duration	Start	Finish
1	Project Starts	0 days	Fri 8/23/13	Fri 8/23/13
2	**A Term**	**36 days**	**Thu 8/29/13**	**Thu 10/17/13**
3	Develop PDFs of Street Maps	11 days	Mon 9/16/13	Mon 9/30/13
4	Write Proposal Draft	22 days	Tue 9/17/13	Wed 10/16/13
5	Develop Street Profile of Highland	1 day	Thu 10/17/13	Thu 10/17/13
6	Complete Proposal Draft	0 days	Thu 10/17/13	Thu 10/17/13
7	**B Term**	**35 days**	**Wed 10/30/13**	**Wed 12/18/13**
8	Test Run of Traffic Count	1 day	Wed 10/30/13	Wed 10/30/13
9	Conduct Traffic Count	1 day	Wed 11/6/13	Wed 11/6/13
10	Evaluate Data From Traffic Count	5 days	Thu 11/7/13	Wed 11/13/13
11	Create 2-4 Alternatives for Newton Square	10 days	Thu 11/14/13	Wed 11/27/13
12	Solidify criteria for determining best alternative	10 days	Thu 11/28/13	Wed 12/11/13
13	Narrow selections down to one (using criteria	4 days	Thu 12/12/13	Tue 12/17/13
14	Finalize Selection	0 days	Wed 12/18/13	Wed 12/18/13
15	Christmas Break	20 days	Thu 12/19/13	Wed 1/15/14
16	**C Term**	**37 days**	**Thu 1/16/14**	**Fri 3/7/14**
17	Continue furthering selected Newton Square design	10 days	Thu 1/16/14	Wed 1/29/14
18	Determine final design of Newton Square	6 days	Thu 1/30/14	Thu 2/6/14
19	Draft Complete Street profiles of the feeding streets	5 days	Fri 2/7/14	Thu 2/13/14
20	Create final draft of report	11 days	Thu 2/20/14	Thu 3/6/14
21	Final Report Due	0 days	Fri 3/7/14	Fri 3/7/14



Project: FirstLaunch
Date: Thu 10/17/13

Task	Project Summary	Manual Task	Start-only	Deadline			
Split	Inactive Task	Duration-only	Finish-only	Progress			
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress			
Summary	Inactive Summary	Manual Summary	External Milestone				

Page 1

4 Preliminary Results

4.1 Maps for WalkBike Worcester

In July 2013, the Worcester Department of Public Works and Parks (DPWP) asked WalkBike Worcester and the working group to create a list of arterial and residential streets to be considered for restriping. The groups identified arterial streets based upon their connectivity to existing bike paths, college campuses, and downtown. The streets that were identified can be seen in the maps in Appendix B. WalkBike Worcester asked us at the September working group meeting to create GIS Maps for their memo to the DPWP for October 1st. On September 19th, we met with two members of WalkBike Worcester to further discuss their expectations of the GIS maps and received additional direction on the type of deliverable they anticipated. Using this information, we took the layers that had already been created by CMRPC for the arterial roadways, and added to them the residential streets that have been identified by the City of Worcester for repaving. CMRPC and WalkBike Worcester identified roads that would be ideal to add striped lanes, or sharrows. These layers also identified projects as either short-term or long-term recommendations. We went through the list of residential streets to be paved during the next construction season and identified the street segments that would benefit from having either a bike lane or sharrow. Those streets, along with all future Transportation Improvement Program (TIP) projects, and existing bike lanes were added to a map of the city that was used by WalkBike Worcester to create their “Recommendations for Initial Bike Lane Striping FY15 Construction Season.”

5.2 Newton Square Site Visit Findings

We first visited Highland Street leading into Newton Square on September 12th, 2013, to observe the intersection and gather an assessment of the current traffic flow conditions. At this time, we observed the on-street parking signage is confusing to the unfamiliar user, as the times and designations of parking change multiple times through the four-tenths of a mile street segment. On one side of the street, a short segment hosts three different types of parking designations including no parking anytime, two hour limit, and bus parking only. This is one complication we will face when creating this street profile. Even with the on-street parking, it was clear that the street width is more than adequate, as large trucks easily passed the parked cars with room to spare. This is evidence that there is potential to add a bike lane to this segment, or at least enough room to restripe the street to be more accommodating to the different types of users.

At the traffic circle, we clearly observed several of the flaws in the design of the intersection. The right-of-way is unclear and leads to motorist confusion, as observed by two near accidents where traffic came to a complete stop to avoid the collision. This is caused by a number of constraints, one being that the center of the traffic circle is very small, allowing for several travel lanes to be accessible by a straight line, and thereby not following the circular direction of a roundabout. We also tested the pedestrian accessibility by utilizing the crosswalks and walking around the perimeter of the Square. Crossing was very difficult, due in part to the confusion of motorist right-of-way as well as the speed with which motorists travel through the intersection. At multiple crossings, we would see cars stop for us in both directions, entering and exiting the intersection, but then a third car would try to pass the stopped cars, entering the field of motion in the crosswalk. Seeing as crosswalks are not a unique feature to Newton Square, we attributed this passing to the width of the rotary lane where two cars can comfortably fit, making it much easier to ignore a stopped car. These observations, as well as those made during our official traffic count on November 13th, 2013, will contribute greatly to our design alternatives for Newton Square.

5.3 Street Profile for Highland St

The street profiles were created using AutoCAD software. The dimensions of the road were taken from ArcGIS using the MassGIS DOT road file. This file provided the sidewalk widths, surface width of the road, and segment lengths of the road. The drawings identified the entire section of the road along with a cross-section which displayed the dimensions of the travel lane, parking lane, sidewalks, and grass from each edge of the sidewalks.

Figure 6: Street Profile of Highland Street between Park Ave and Newton Square

These drawings are not congruent with the observations we made during our sight visit on September 12th, 2013. During that visit we observed that the roadway was much wider than one car width and could likely accommodate a shared transportation lane. However, once the lanes had been drawn to scale, we can see that the travel lane is in fact within the normal range.[10] After considering why this may be the case, we determined that because many of the parking spaces in this street segment are designated for short term parking or bus lanes, the road most likely appears artificially wide during periods where those spaces are not occupied. Toward the ends of the street segment, at the Park Avenue and Newton Square ends, the road does widen, but a lane shift here would not help the flow of traffic when the road narrows again toward the middle.

Our suggestions for striping would be to define the edge of the parking lane, thereby defining true width of Highland Street through this segment. The GIS files confirmed that the travel lane for this segment is only twelve feet wide, which is not wide enough to accommodate both the bike lane and a motorist travel lane. However, it could be a good implementation of a sharrow.

[10] MassDOT Design Guide & Complete Streets

5 Deliverables

5.1 Street Profile for Highland Street

In talking with the Worcester Bike Working Group, it was decided that one of our contributions could be to complete a street profile for the stretch of Highland Street between Park Avenue and Newton Square. There are many factors that will contribute to the potential street profiles for this series of segments. Doherty High School is located on the west side of the street; behind the school is the public park, Newton Hill Park. For the convenience of both the high school and the park, there are several bus stops on both sides of the street, as well as large sidewalks and some on-street parking. This combination will require analysis of both the street's requirements and the physical limitations of the road width. We will include both reconfigurations of the entire street, including roadway and sidewalks, as well as recommendations for the roadway only.

5.2 Traffic Counts for Newton Square

Along with our analysis of Newton Square and the streets feeding into the roundabout, we will be conducting a traffic count of all vehicles that enter and exit the roundabout. This task will be conducted at a peak traffic time range in order to witness the roundabout's function when it is most crowded. The data collected during these counts will be available to be added to the city's log of traffic counts and GIS files. The goal of this traffic count is to determine where motorists are traveling to and what the target streets are for repair and potential restructuring. We will notify MassDOT and CMRPC about our data collection and provide that collected data to them if either party is interested.

5.3 Street Profiles for Newton Square Feeding Streets

Using the data collected from the traffic counts at Newton Square, we will construct street profiles for the four streets feeding into Newton Square in addition to Highland Street. We anticipate that these street profiles will realign the entrance and exit striping for the streets into Newton Square. The profiles will be provided in both GIS and CAD files to show the full extent of recommendations.

5.4 Design Alternatives for Newton Square

One of the products of the traffic count to be conducted at Newton Square is the creation of design alternatives for the intersection. We will use the data collected during our own count, as well as compare the data to that collected six years prior in 2007 for MassDOT. In order to create these alternative designs, we will first consider all types of solutions to this crowded intersection. These designs will include both single and double lane designs as well as signalized and non-signalized potential solutions. We plan to create between two and four design solutions that can be accommodated in the space allowed.

5.5 Final Design Alternative Criteria for Newton Square

Once the design alternatives have been created, we will use the design criteria described in Section 3.6 to determine the best design alternative. Before a design can be selected, we will first have to finalize the design criteria. We anticipate being able to do this after conducting the traffic count and consulting with MassDOT. We will also investigate holding a public forum where residents of the area along with city officials and members of MassDOT could share their opinions on the design alternatives. This meeting would likely be held in January, after the traffic count has been conducted and several alternatives created.

Works Cited

Fowley, Joseph. Transportation Engineer, Massachusetts Department of Transportation. Interview conduction on 3 October 2013.

Goins, Karen & Powers, Gerald. Members of WalkBike Worcester. Interview conducted 17 Sep 2013.

"Highway Division." *MassDOT*. The Commonwealth of Massachusetts, Jan. 2012. Web. 04 Nov. 2013.

Kirwan, Leslie, James A. Aloisi, Jr., and Jeffery B. Mullan. "90 Day Integration Report." Massachusetts Department of Transportation, Sept. 2009.

"MMA Model Complete Streets Ordinances/Bylaws" The Massachusetts Municipal Association. Online PDF. 15 Sep. 2013

Prentiss, Doug. "MassDOT Design Guide and Complete Streets Primer." Complete Streets Workshop. Worcester City Hall, Worcester MA. 14 Aug. 2013. Lecture.

Transportation Research Board, National Cooperative Highway Research Program (NCHRP) Report 672: Roundabouts: An Informational Guide—Second Edition, Chapter 3, Washington, D.C. 2010.

Appendix B: Worcester Residential Streets to be Repaved

(As identified by Worcester City Councilmen)

District 1	
Apollo Rd	Eagle Rd W to Romola Rd
Arbutus Rd	417 Burncoat E to Bluebell Rd
Audubon Rd	119 Richmond Ave NW to Flagg
Constitution Ave	182 Constitution Ave to Tacoma
Cranston St	17 Rockelle E to End
Eunice Ave	29 Clark N to 89 Brandon Rd
Hartford Rd	426 Burncoat E to End
Hingham Rd	Stoneleigh Rd SE to End
Leyton Rd	Spring Valley Rd N to End
Lull St	Richmond Ave to Vassar
Oak Hill Rd	Easterly 1100 ft to Aylesbury Rd
Purchase St	Clark N to Quinapoxet La
Waring Cir	Leyton Rd E to End
District 2	
Ashburnham Rd	65 Kenwood Ave S&W to End
Bates (#2) Ave	Greenhill Ave to End
Buckingham St	Entire
Hackfeld Rd	Entire
Oriol Dr	Lincoln S to Cul De Sac
Eastern Ave	355' N of Catharine St to N of Catherine St
Eastern Ave	Belmont St to 355' N of Catharine St
Eastern Ave	Belmont St to Prospect St
Mount Vernon St	Windsor St to Prospect St
Mount Vernon St	Westminster E to Windsor St
Stanton St	710' N of Belmont to Break St

Atlanta	Entire
Tampa St	Entire
Merrifield	Belmont to Elliott St
District 3	
Dearborn St	Heywood S to Crowningshield
Denver Terrace	Fenwood Rd S to End
Derby St	#63 to Everton
Hyannis Pl	649 Grafton NE to 270' E of Grafton
Ida Rd	Dolly Dr to Sandra Dr
Indiana St	Brightwood Ave to Everton St
Koping St	Loxwood St to Wabash Ave
McGill St	110' W of McKeon Rd SW to Bothnia St
Midgely La	Entire
North Steele St	Whipple N to Oscar
Oswald St	39 Stebbins S to Snyder Ct
Pioneer Rd	Westborogh E to Pineland
Spurr St	105 Vernon E to Providence
Tiffany Ave	Entire
Vincent Cir	Massasoit Rd Westerly
West Upsala St	182 Vernon W to 64 Fairfax Rd
Gambier Ave	13 Acton to End
District 4	
Camp St	Cambridge St to End
Davis St	41 Peidmont W to 33 Queen
Gardner St	Hollis St to Tainter St
Hollywood St	May St to Oberlin St
Jaques Ave	67 Wellington W to Piedmont St
Lodi St	Lamartine St to Lafayette St
Oread Pl	812 Main NW to Alden

Elm St	Linden to Park Ave (reduced by $277,000 due to side walk allocation)
Russell St	Elm to Pleasant St
District 5	
Clover St #2	South Ludlow St to 173' S of Pine View
Circuit Ave West	Circuit Ave S NW to End
Dellwood Rd	1000 Pleasant St to End
Hillcrest Ave	Penhallow Rd E to End
Hunthurst Cir	560 Chandler SW to 1819' SW
Isabella St	7 Englewood Ave W to 14 Circuit Ave
Maxdale Rd	Cardinal Rd S to Pinnacle
Morningside Rd	5 Chamberlain Pkwy S to Morningside Ter
Oak Knoll Rd	Hillcrest Ave to 643' N (remove per RLM 5/3/13)
Orrison St	Moreland E to End
Paradox Dr	Beaconsfield Rd NE to Wrentham Rd
Sorrento St	Grenada N to End
Sweetbriar Ln	Mill E to End
Wrentham Rd	(added per RLM 5/3/13)

Appendix C: WalkBike Worcester Submission Maps & Cover Letter to Worcester DPW&P

Suzanne LePage, AICP
Department of Civil and Environmental Engineering
Worcester Polytechnic Institute (WPI)
100 Institute Road
Worcester, MA 01609

October 3, 2013

Robert L. Moylan, Jr.
Commissioner
Worcester Department of Public Works & Parks
20 East Worcester Street
Worcester, MA 01604

Dear Mr. Moylan:

On behalf of the Worcester Bikeways Working Group, please find enclosed future recommendations for roadway striping to accommodate bicyclists within the City of Worcester. A technical memorandum is included herein, documenting the development process and detailing the proposed actions. We have also included maps showing our recommendations for short-term implementation as well as a future bikeway system map illustrating connectivity opportunities.

As you may recall, a team of WPI students hosted a workshop last spring to discuss future bicycle facility opportunities. As you suggested at that meeting, some of the attendees have since formed a Working Group to identify short and long-term project ideas. The enclosed materials represent the first product born out of that effort. In addition, a team of three WPI civil engineering students are working on a redesign of Newton Square and its feeder streets, with a particular emphasis on pedestrian and bicycle accommodations. We anticipate continued discussions and coordination with Worcester's other colleges and universities as well.

In summary, we are very appreciative of your attendance at last spring's workshop and your stated commitment to improving bicycle travel within the City. We very much look forward to a continued working relationship.

Sincerely,

Suzanne LePage, AICP
Worcester Bikeways Working Group Chair
Instructor, Civil & Environmental Engineering, WPI (slepage@wpi.edu)

RECOMMENDATIONS FOR INITIAL BIKE LANE STRIPING FY15 CONSTRUCTION SEASON

PREPARED FOR WORCESTER DEPARTMENT OF PUBLIC WORKS AND PARKS BY THE WORCESTER BICYCLE WORK GROUP OCTOBER 3, 2013

PROCESS

Two groups have proposed roadways for bike lane striping in Worcester. Worcester Polytechnic Institute students produced recommendations for linking Worcester's college campuses and downtown as part of two Individual Qualifying Projects (IQPs). WalkBike Worcester produced recommendations that take advantage of recent and upcoming capital improvements and resurfacing with a focus on linking downtown to surrounding areas. In July 2013 the Worcester Department of Public Works and Parks (DPWP) tasked the two groups to jointly produce a list of arterial and residential streets for initial striping in the FY 15 construction season based on streets already selected for resurfacing. The group would submit this list to DPWP by early October, followed by negotiation with DPWP and final selection by the end of 2013.

The work group requested the lists of arterials and residential streets in July. DPWP provided the 2014-2016 list of residential streets, but said arterials would not be selected soon and the group should consider all arterials. WPI students and Central Massachusetts Regional Planning Commission provided GIS mapping assistance. CMRPC overlaid the recommendations of the IQPs and WalkBike Worcester and added existing bike lanes (Lake Ave and Canal District) plus upcoming federal aid projects on the Transportation Improvement Program (TIP) to demonstrate potential connectivity. WalkBike Worcester reviewed all residential streets designated for resurfacing and selected a small number for striping. Most of the residential street segments slated for resurfacing do not merit striping as they are short, disconnected and quiet enough to allow comfortable bicycle travel without dedicated lanes.

RECOMMENDED ROADWAYS FOR BIKE LANE STRIPING AND SHARROWS

We have included two GIS maps to illustrate roadways the work group recommends for striping:

Worcester Bikeways Striping during 2014 Construction Season: This map shows recommended streets for bike lanes and sharrows during the upcoming construction season. It is expected this striping would require little engineering design to accomplish.

Worcester Bikeways Planning Map: This map includes all streets on the 2014 map, additional streets that could be striped within 1-2 years based on further study or engineering design, and upcoming TIP projects. The purpose of this map is to demonstrate connectivity and highlight missing links.

Following is a list of the streets recommended for striping in the upcoming construction season.

Bike lanes:

- *Southbridge Street (McKeon Road to intersection of McGrath and Hermon Streets)*
- *Greenwood Street (US-20 to Wiser Ave)*
- *Harding Street (Winter Street to Kelley Square) *2015CMMPO TIP**
- *Temple Street/Winter Street (Alternate One-Way)*

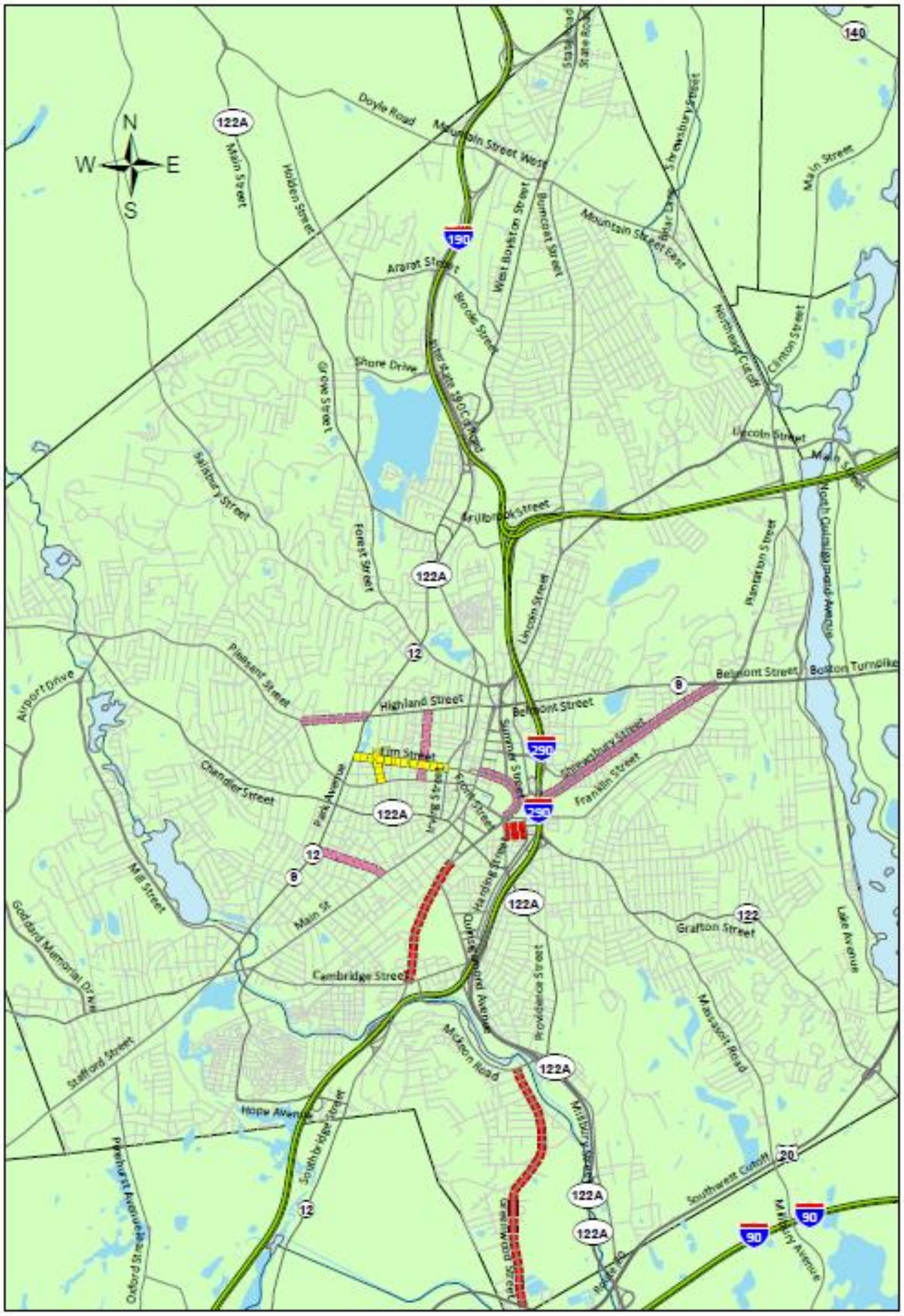
Sharrows:

- *Shrewsbury Street (Washington Square to Belmont Street)*
- *Foster Street (Franklin Street to Main Street)*
- *Greenwood Street / Blackstone River Road (Wiser Ave to McKeon Rd)*
- *May Street (Main Street to Park Avenue)*
- *Highland Street (Lincoln Square to Newton Square)*

Striping during residential resurfacing:

- *Elm Street*
- *Pleasant Street*

Worcester Bikeways 2014 Project Map



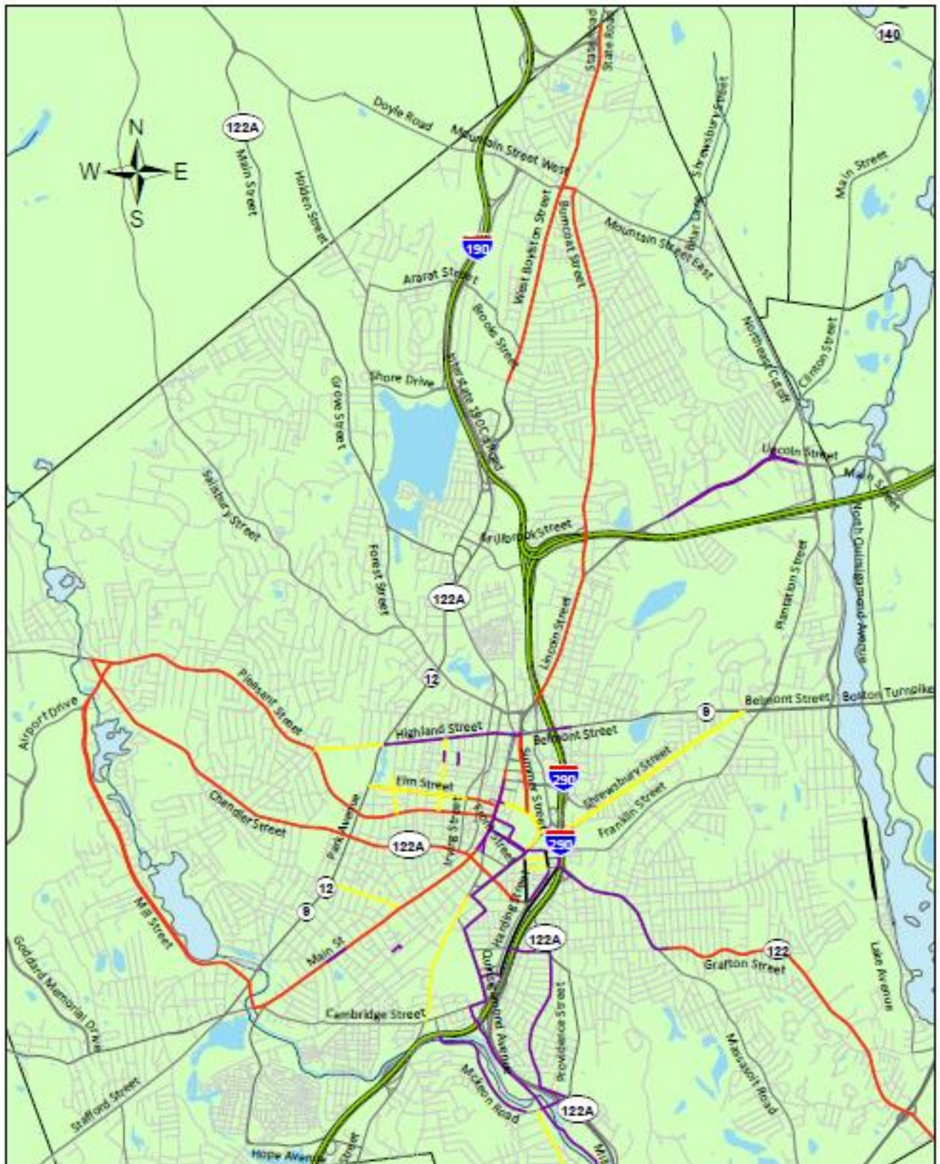
Recommendations

- Striped Lanes
- Sharrows
- Striping on Scheduled Resurfacing Projects

0 0.375 0.75 1.5 2.25 3 Miles

Information Provided by WalkBike Worcester & CMRPC
Compiled by Worcester Polytechnic Institute
Major Qualifying Project Civil Engineering Students

Worcester Bikeways Planning Map



Bikeway System

- Future TIP Projects
- Short-Term (Recommended for Striping in 2014)
- Longer-Term (1-2 Years)
- Existing Bike Lanes

Miles
0 0.375 0.75 1.5 2.25 3

WPI

Information Provided by WalkBike Worcester & CMRPC
Compiled by Worcester Polytechnic Institute
Major Qualifying Project Civil Engineering Students

Appendix D: MQP Turning Movement Data. Morning Count, January 23rd, 2014

	Highland							Total	Hour Total
	Newton	Pleasant W	June	Pleasant E	Highland	Heavy	Ped		
7:00	5	57	51	13	0	0	0	126	
7:15	3	45	69	17	0	0	0	134	
7:30	5	41	98	5	0	1	0	149	
7:45	5	41	126	2	0	2	0	174	583
8:00	12	61	128	6	2	0	0	209	666
8:15	11	55	93	7	0	0	0	166	698
8:30	7	53	53	8	1	2	0	122	671
8:45	0	57	53	10	1	0	0	121	618
Total	48	410	671	68	4	5	0	1201	
Peak Hour	33	198	445	20	2	3	0	698	

	Newton							Total	Hour Total
	Newton	Pleasant W	June	Pleasant E	Highland	Heavy	Ped		
7:00	0	2	8	8	6	0	3	24	
7:15	1	4	5	5	5	0	0	20	
7:30	0	2	5	18	8	0	1	33	
7:45	0	1	1	18	5	0	0	25	102
8:00	0	1	8	13	17	0	0	39	117
8:15	0	2	6	20	10	0	1	38	135
8:30	0	0	2	12	6	0	0	20	122
8:45	0	0	6	10	8	0	0	24	121
Total	1	12	41	104	65	0	5	223	
Peak Hour	0	6	20	69	40	0	2	135	

	Pleasant West							Total	Hour Total
	Newton	Pleasant W	June	Pleasant E	Highland	Heavy	Ped		
7:00	1	0	3	57	62	0	1	123	
7:15	0	1	6	83	95	0	0	185	
7:30	0	0	5	71	153	1	0	229	
7:45	1	0	5	68	141	0	1	215	752
8:00	0	0	8	68	122	0	1	198	827
8:15	0	0	14	69	132	0	1	215	857
8:30	2	0	12	100	123	0	0	237	865
8:45	0	0	13	76	114	0	0	203	853
Total	4	1	66	592	942	1	4	1605	
Peak Hour	1	0	32	276	548	1	3	857	

	June							Total	Hour Total
	Newton	Pleasant W	June	Pleasant E	Highland	Heavy	Ped		
7:00	1	1	0	21	51	2	2	74	
7:15	2	1	0	25	37	0	1	65	
7:30	1	0	0	17	67	0	0	85	
7:45	2	1	0	20	73	0	5	96	320
8:00	9	3	0	10	68	0	8	90	336
8:15	5	3	0	11	64	0	1	83	354
8:30	3	2	0	10	67	0	0	82	351
8:45	2	0	0	15	35	0	0	52	307
Total	25	11	0	129	462	2	17	627	
Peak Hour	17	7	0	58	272	0	14	354	

	Pleasant East							Total	Hour Total
	Newton	Pleasant W	June	Pleasant E	Highland	Heavy	Ped		
7:00	4	6	0	0	45	0	29	55	
7:15	7	8	1	0	24	0	4	40	
7:30	1	12	2	0	14	0	12	29	
7:45	6	16	5	0	9	0	16	36	160
8:00	17	25	0	0	10	0	1	52	157
8:15	11	22	8	0	8	0	0	49	166
8:30	3	12	4	0	11	0	0	30	167
8:45	0	23	7	0	7	0	0	37	168
Total	49	124	27	0	128	0	62	328	
Peak Hour	35	75	15	0	41	0	29	166	

Appendix E: MQP Turning Movement Data. Afternoon Count, November 13th, 2013

	Highland Street										
	Newton	Pleasant West	June	Pleasant East	Pedestrian Crosses	Cyclist Entrances	Multi Axle Vehicles	Highland		Totals	Hour Totals
1:30	8	50	67	6	3	0	1	4		131	
1:45	11	61	77	13	12	0	0	0		162	
2:00	11	82	73	18	8	0	2	3		184	
2:15	12	88	81	11	3	0	2	1		192	669
2:30	9	87	78	9	1	0	3	1		183	721
2:45	9	103	92	19	4	0	2	0		223	782
3:00	7	107	79	13	0	0	2	0		206	804
3:15	5	94	89	11	1	0	3	0		199	811
3:30	5	112	83	16	0	0	1	0		216	844
3:45	4	119	85	12	0	0	0	0		220	841
4:00	**5**	**110**	**98**	**11**						**224**	859
4:15	6	101	112	10	4	0	1	0		229	889
4:30	10	117	102	6	0	0	1	0		235	908
4:45	15	118	127	12	0	0	1	0		272	960
5:00	11	106	126	8	3	0	0	0		251	987
5:15	8	98	112	11	0	1	1	0		229	987
5:30	4	110	95	10	0	0	0	0		219	971
5:45	12	93	85	10	0	2	0	3		200	899
Totals	152	1756	1661	206	39	3	20	12		3775	
Peak Hour	42	442	467	36	7	0	3	0	0	987	

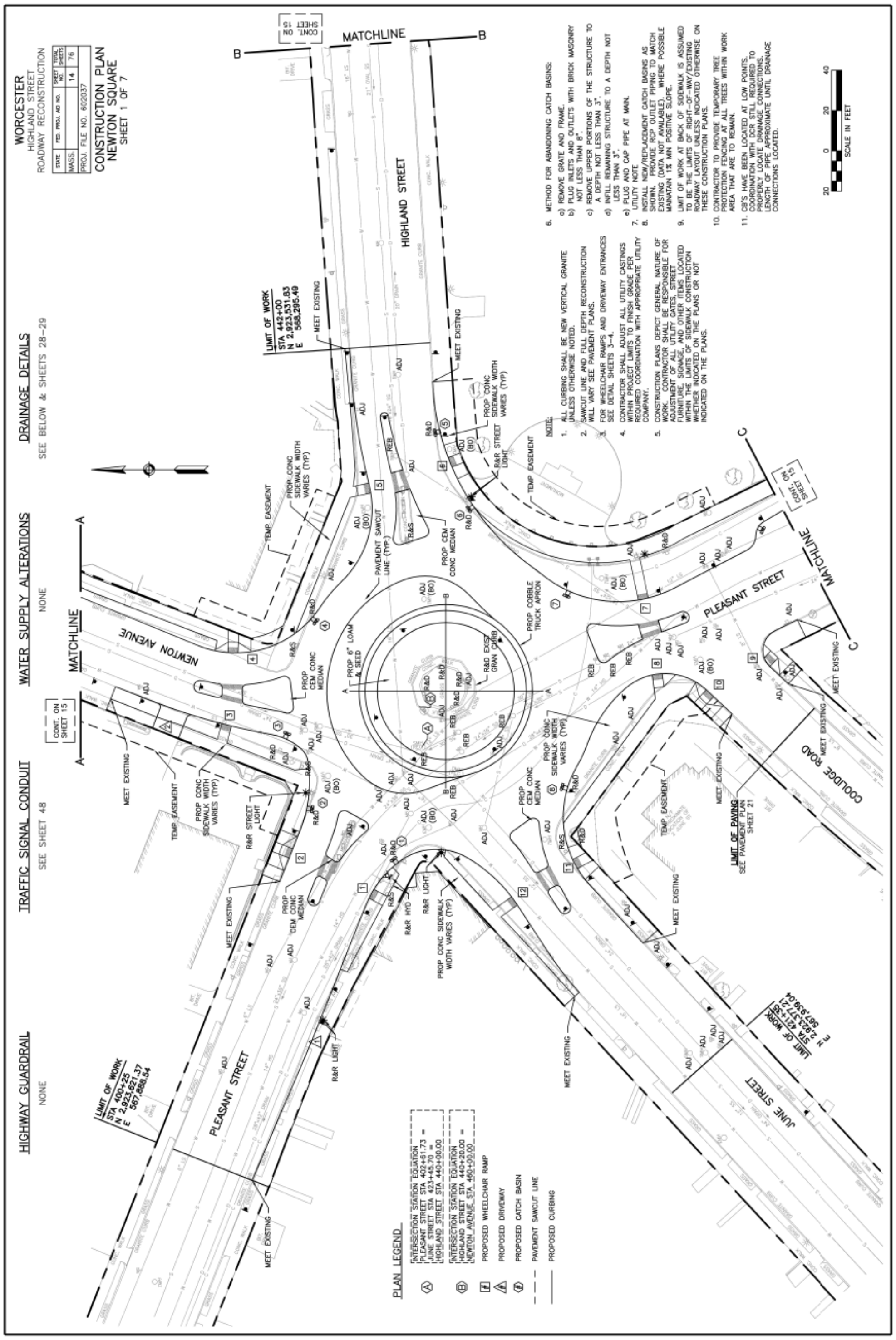
	Newton St										
	Pleasant West	June	Pleasant East	Highland	Pedestrian Crosses	Cyclist Entrances	Multi Axle Vehicles	Newton		Vehicular Totals	Hour Totals
1:30	0	4	5	3	6	0	0	0		12	
1:45	2	10	11	2	19	0	1	0		25	
2:00	3	4	8	5	13	0	0	0		20	
2:15	3	2	10	4	9	0	1	0		19	76
2:30	0	8	24	13	2	0	0	0		45	109
2:45	1	10	8	3	6	0	0	0		22	106
3:00	1	2	7	2	3	1	1	0		12	98
3:15	1	7	8	2	6	1	0	0		18	97
3:30	2	1	6	5	0	0	0	0		14	66
3:45	0	5	12	8	2	0	2	0		25	69
4:00	**1**	**4**	**9**	**6**						**20**	77
4:15	2	4	7	5	4	0	0	0		18	77
4:30	1	5	10	5	10	0	0	0		21	84
4:45	2	8	2	3	0	0	0	0		15	74
5:00	2	7	7	5	1	0	0	0		21	75
5:15	3	10	9	7	0	0	1	0		29	86
5:30	1	5	7	4	2	0	0	0		17	82
5:45	1	4	5	7	4	2	0	0		17	84
Totals	26	100	155	89	87	4	6	0		370	
Peak Hour	8	24	53	24	43	0	2	0	0	109	

	Pleasant St West										
	June	Pleasant East	Highland	Newton	Pedestrian Crosses	Cyclist Entrances	Multi Axle Vehicles	Pleasant West		Vehicular Totals	Hour Totals
1:30	9	51	73	2	1	0	1	0		135	
1:45	12	45	65	2	5	0	1	0		124	
2:00	8	43	61	5	3	1	4	0		117	
2:15	8	38	63	1	0	0	1	0		110	486
2:30	22	62	64	1	1	0	3	1		149	500
2:45	14	62	54	0	2	0	0	0		130	506
3:00	12	29	41	2	3	1	2	0		84	473
3:15	13	38	50	0	19	1	1	2		101	464
3:30	6	45	57	0	2	0	4	1		108	423
3:45	6	39	43	0	1	0	2	1		88	381
4:00	**8**	**39**	**56**	**0**						**103**	400
4:15	10	39	69	0	4	0	0	0		118	417
4:30	19	44	60	0	3	0	4	0		123	432
4:45	8	30	36	0	0	0	0	0		74	418
5:00	19	27	39	0	4	0	1	0		85	400
5:15	22	32	25	0	0	0	2	0		79	361
5:30	13	39	33	0	2	0	1	0		85	323
5:45	9	38	56	0	2	0	3	0		103	352
Totals	218	740	945	13	52	3	30	5		1916	
Peak Hour	52	205	242	7	6	1	8	1	0	506	

	June St										
	Pleasant East	Highland	Newton	Pleasant West	Pedestrian Crosses	Cyclist Entrances	Multi Axle Vehicles	June		Vehicular Totals	Hour Totals
1:30	11	84	3	8	1	0	1	2		106	
1:45	10	94	8	11	6	0	0	0		123	
2:00	6	80	14	8	10	0	0	0		108	
2:15	8	90	18	16	3	0	0	0		132	469
2:30	8	103	2	7	36	0	2	0		120	483
2:45	13	72	8	11	2	0	0	0		104	464
3:00	7	98	5	3	1	0	0	0		113	469
3:15	8	113	4	10	13	1	0	2		135	472
3:30	8	106	8	8	3	0	1	0		130	482
3:45	14	82	4	2	8	1	2	0		102	480
4:00	**10**	**87**	**4**	**5**			**0**	**0**		106	473
4:15	7	91	5	7	3	0	0	0		110	448
4:30	9	78	3	8	8	0	0	0		98	416
4:45	9	92	5	11	3	0	0	0		117	431
5:00	13	90	5	8	1	0	0	1		116	441
5:15	5	71	3	6	0	0	1	0		85	416
5:30	10	82	1	11	0	0	0	0		104	422
5:45	10	79	4	7	0	0	0	0		100	405
Totals	166	1592	104	147	98	2	7	5		2009	
Peak Hour	32	367	42	42	55	0	2	0	0	483	

	Pleasant St East										
	Highland	Newton	Pleasant West	June	Pedestrian Crosses	Cyclist Entrances	Multi Axle Vehicles	Pleasant East		Vehicular Totals	Hour Totals
1:30										0	
1:45	13	12	37	11	49	0	0	0		73	
2:00	17	16	47	13	23	0	1	0		93	
2:15	13	19	65	12	11	0	0	1		109	
2:30	11	10	39	7	6	0	0	1		67	342
2:45	10	12	53	12	4	0	1	1		87	356
3:00	18	7	71	9	1	0	1	0		105	368
3:15	15	10	59	17	3	0	0	1		101	360
3:30	15	9	63	16	2	0	0	0		103	396
3:45	**14**	**10**	**58**	**16**						**98**	407
4:00	14	10	54	16	0	0	1	1		94	396
4:15	15	11	66	21	1	0	0	0		113	408
4:30	6	5	85	23	0	0	0	1		119	424
4:45	29	13	79	16	0	0	1	0		137	463
5:00	8	20	91	15	1	0	0	0		134	503
5:15	16	18	89	19	0	0	1	1		142	532
5:30	18	16	79	16	1	0	0	0		129	542
5:45	22	17	78	22	0	2	0	0		139	544
Totals	254	215	1113	261	102	2	6	7		1843	
Peak Hour	64	71	337	72	2	2	1	1	0	544	

Appendix F: Recommended Roundabout Re-Design. CAD Drawing provided by Worcester DPW&P



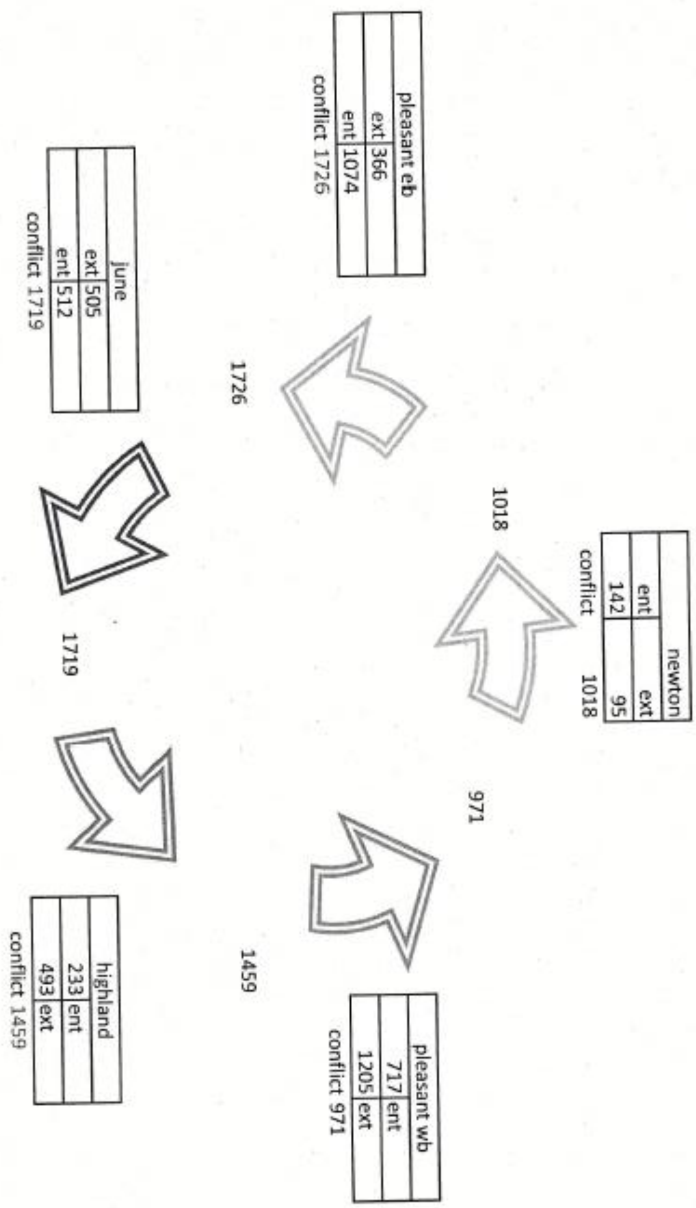
Appendix G: Massachusetts Department of Transportation 2007 Turning Movement Count Data

Newton Square, Worcester: AM Peak Hour

Entering / Exiting / Circulating Flow Rates

	highland	pleasant wb	newton	pleasant eb	june
rights	26	9	9	0	36
thru	57	226	24	339	435
lefts	113	451	87	722	16
lefts	37	31	22	13	18
entering flow	233	717	142	1074	505
exiting flow	493	1205	95	366	512

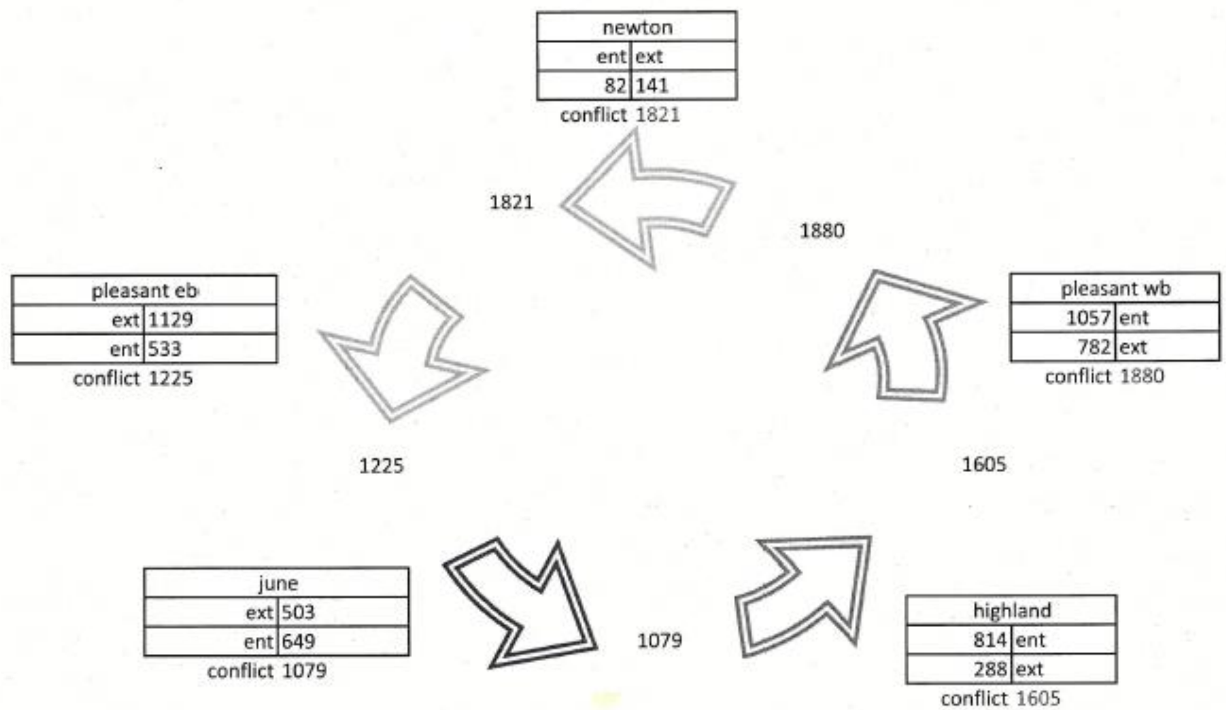
	circulating flow
highland/pleasant	1459
pleasant/newton	971
newton/pleasant	1018
pleasant/june	1726
june/highland	1719



Newton Square, Worcester: PM Peak Hour
Entering / Exiting / Circulating Flow Rates

	highland	pleasant wb	newton	pleasant eb	june
rights	61	33	7	48	23
thru	78	486	31	189	417
lefts	596	491	29	289	23
lefts	79	47	15	7	40
entering flow	814	1057	82	533	503
exiting flow	288	782	141	1129	649

	circulating flow
highland/pleasant	1605
pleasant/newton	1880
newton/pleasant	1821
pleasant/june	1225
june/highland	1079



Works Cited

"2010 Interactive Population Search". United States Census Bureau. 2010 https://www.census.gov/2010census/popmap/ipmtext.php?fl=25:25027:2502782000

Borbone, Joseph & Khorasani, Ali. Worcester Department of Public Works. Director and Assistant Director of Engineering. Interviewed Jan 24, 2014.

Evans, Monique R. "Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks." *Federal Highway Administration.* US Department of Transportation, Sept. 2010.

Frawley, Joseph. Transportation Engineer, Massachusetts Department of Transportation. Interviews conduction on 3 October 2013 & 19 December 2013

Goins, Karen & Powers, Gerald. Members of WalkBike Worcester. Interview conducted 17 Sep 2013.

"Highway Division." *MassDOT*. The Commonwealth of Massachusetts, Jan. 2012. Web. 04 Nov. 2013.

Kirwan, Leslie, James A. Aloisi, Jr., and Jeffery B. Mullan. "90 Day Integration Report." Massachusetts Department of Transportation, Sept. 2009.

"MMA Model Complete Streets Ordinances/Bylaws" The Massachusetts Municipal Association. Online PDF. 15 Sep. 2013

"Modern Roundabout Practice in the United States: A Synthesis of Highway Practice". National Cooperative Highway Research Program, Synthesis 264. 1998. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_264.pdf

Michaud, Robert. MDM Transportation Consultants. Transportation Engineering Class Lecture, Dec 10, 2013.

NCHRP Report 672. "Roundabouts: An Informational Guide". Second Edition. National Cooperative Highway Research Program. 2010

Prentiss, Doug. "MassDOT Design Guide and Complete Streets Primer." Complete Streets Workshop. Worcester City Hall, Worcester MA. 14 Aug. 2013. Lecture.

“Roundabouts- The Maryland Experiences: A Maryland Success Story.” Federal Highway Administration, Safety. Feb 2010. http://safety.fhwa.dot.gov/intersection/resources/casestudies/fhwasa09018/

“ROUNDABOUTS: An Informational Guide”. US Department of Transportation, Federal Highway Administration. June 2000. http://www.fhwa.dot.gov/publications/research/safety/00067/000671.pdf

“Traffic Counts.” Functional Design Report. MassDOT Intersection Improvement Plan. 2007

“Traffic Safety Facts: 2011 Data”. US Department of Transportation. National Highway Traffic Safety Administration. Aug 2013. http://www-nrd.nhtsa.dot.gov/Pubs/811748.pdf

Transportation Research Board, National Cooperative Highway Research Program (NCHRP) Report 672: Roundabouts: An Informational Guide—Second Edition, Chapter 3, Washington, D.C. 2010.