MQP-SL1-TK18

Intersection Redesign in Tewksbury, Massachusetts

A Major Qualifying Project Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In Partial Fulfillment of the Requirements for the
Degree of Bachelor of Science
In
Civil Engineering

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Date:
March 2, 2018

Submitted to:

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Abstract

The intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street in Tewksbury, Massachusetts can no longer provide safe and efficient travel due to poor design and increasing traffic. Utilizing traffic engineering data collection and design, problems that affect safety and throughput were identified, and a design to alleviate those problems was created. By using Highway Capacity Software analysis, AutoCAD modeling, and professional intersection design, this design sought to improve the health and wellbeing of the people of Tewksbury.

Capstone Design

This project involved analyzing and developing improvements for the intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street in Tewksbury, Massachusetts. As the culmination of undergraduate studies in Civil Engineering, WPI requires a Major Qualifying Project with a capstone design element to fulfill the Accreditation Board for Engineering and Technology (ABET) engineering requirements. The American Society of Civil Engineers (ASCE) suggests seven factors that must be considered by this project in order to meet the Capstone Design requirement. This project addressed the following constraining aspects, including:

- Economic: For the town to build any recommended improvements, this project took into account both the costs of construction and implementation as well as sources of funding. This team looked to identify the most beneficial and efficient improvements for a reasonable cost.
- Environmental: Suggested improvements to the intersection of Shawsheen Street, Beech Street, Patten Road, and Foster Road were designed with the intention of not adversely affecting the environment. The team also worked to promote alternative modes of transportation by incorporating the Complete Streets Program.
- Social: The intent of this project was to design improvements to benefit the community of Tewksbury, without negatively affecting the businesses and homes nearby. The team determined the most economic and effective solution to benefit the travel of the citizens of Tewksbury.
- Political: Throughout the completion of this project, the team collaborated with the town engineer and other representatives of the Town of Tewksbury, as necessary, to ensure they were informed of any actions taken. The team's suggested improvements were presented to the town engineer, town planner, and town police/fire improvements, in order to make the final decision and to decide if these changes would benefit the town.
- Ethical: The team did not threaten the reputation of WPI, nor did it put the Town of Tewksbury at risk. All decision-making was made in compliance with the ASCE Code of Ethics.
- Health & Safety: The improvements to the intersection of Shawsheen Street, Beech Street, Patten Road, and Foster Road serve to increase safety by addressing areas with increased crash rates and turning movements with acute or excessively wide angles.
- Constructability: In addressing improvements to the intersection of Shawsheen Street, Beech Street, Patten Road, and Foster Road the team presented the most effective option to the town engineer after assessing the overall cost, size and time needed to complete each alternative design option.
- Sustainability: The development of intersection improvements served the purpose of improving the intersection for both present and future needs. Final plans considered the future traffic demands of the intersection and population growth of the town of Tewksbury to prevent imminent changes following these improvements.

Professional Licensure

Professional engineers greatly influence the engineering community, and are imperative to protecting the health and safety of community members affected by any and all engineering projects. Obtaining the "Professional Engineer" (PE) license is a lengthy undertaking, meant to ensure that certified PE's are trained to "shoulder the responsibility for not only their work, but also for the lives affected by that work and must hold themselves to high ethical standards of practice" (National Society of Professional Engineers, 2017).

In order to earn a PE license, one must graduate from an accredited engineering university and pass the Fundamentals of Engineering (FE) exam in order to become an Engineer in Training (EIT). Following successful completion of the FE exam, one must accrue four years of professional experience at a minimum. Then, one must pass the Principles and Practice of Engineering exam in order to become a Professional Engineer (National Society of Professional Engineers, 2017).

Obtaining a professional engineering license is an important step for the continued learning of any engineer. It is often the primary goal of an engineer to obtain the PE license because it expands one's opportunities for career growth and affords the engineer new responsibilities in the workplace. This project allowed the team to learn the skills necessary to work as an effective engineering team and take an introductory step into an engineering career.

Acknowledgements

A huge thank you is owed to our advisor, Professor Suzanne LePage, as without her help this project would not have been possible. We would also like to thank the Town of Tewksbury, specifically Kevin Hardiman, P.E., for all of his support and assistance during the project period. Another thank you to Professor John R. Hall for providing us with the essential equipment to carry out our survey data collection. Additionally we want to thank the Northern Middlesex Council of Governments for all of their assistance in acquiring traffic data, as well as the Tewksbury Police Department for help obtaining crash data. Lastly, we would like to thank Worcester Polytechnic Institute for the ability to complete this project and gain incredible project experience to better prepare ourselves for our careers in the near future.

Authorship

The following report consists of work completed by Craig Barrett, Vanessa Beutel, James Macfarlane and Patrick Murphy. All group members contributed equally to this report, data collection and all presentations in order to successfully complete this project.

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Executive Summary

Tewksbury, Massachusetts is a moderately sized town that borders Lowell, Massachusetts. In one of the older parts of the town sits the intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street. Shawsheen Street is a fairly popular route for connection to Interstate 93, which provides access to Boston, Massachusetts and New Hampshire. The intersection in question has generated numerous complaints in the past, as relayed by the town's engineer. The complaints primarily consisted of safety concerns while traveling through the intersection.

The goal of this Major Qualifying Project (MQP) was to collect the necessary data to determine what design recommendations to provide to the town engineer. The team collected and analyzed the traffic data and were able to design geometric improvements to the intersection to address the concerns of the town.

Any geometric improvements to the five-way intersection in Tewksbury needed to follow the guidelines set forth by the Massachusetts Road Design Guidelines. Additionally, both state and government funding can be requested for the project if the designs meet the necessary requirements. When designing, the team kept these design elements in mind so that in the future the town may apply for additional funding for the construction of an improved intersection.

In order to determine the level of operation of the current intersection, the team collected various types of data to create a detailed depiction of the intersection. Vehicular traffic count data was obtained from the Northern Middlesex Council of Governments (NMCOG), an agency that, on the team's behalf, used road tubes to count the number of vehicles in the intersection. These counts were used to determine when the peak travel times were at the intersection. From there, the team conducted peak hour traffic counts. The data from the peak hour traffic counts were entered into Highway Capacity Software 2010 (HCS) to determine the Level-of-Service of each intersection and whether any signals would be warranted given the amount of traffic.

From the data collected and analyzed, the team was able to design various improvements to the intersection. These improvements included realigning Shawsheen Street to decrease the amount of pavement surface area and modifying turn radii at the corners of the intersection to more accurately reflect MassDOT design standards. The various design options were presented to the town engineer as well as the town planner, an officer on the Tewksbury Police Department, and a member of the Tewksbury Volunteer Fire Department. The feedback received from these individuals allowed the team to solidify one design option as the final recommendation for improvement in the intersection. The following are the recommendations from the team:

- Realigning the intersection of Patten Road and Shawsheen Street, making the intersection a right angle in order to improve visibility for cars leaving Patten Road.
- Narrowing turn radii at the intersection of Shawsheen Street, Foster Road, and Beech Street, reducing the speeds at which cars can make a turn, while making pedestrian crossings shorter and safer.
- Removing or narrowing the parking lot entrance from Shawsheen Street, to prevent conflict and confusion between cars entering and exiting the parking lot, and those traveling through the intersection.
- Realigning Shawsheen Street to maintain a consistent width through the intersection, drastically lowering the width of the pavement in the intersection, and decreasing the distance of pedestrian crossings.
- Making the intersection ADA compliant with the extension of sidewalks, addition of pedestrian ramps, and standardization of crosswalks.

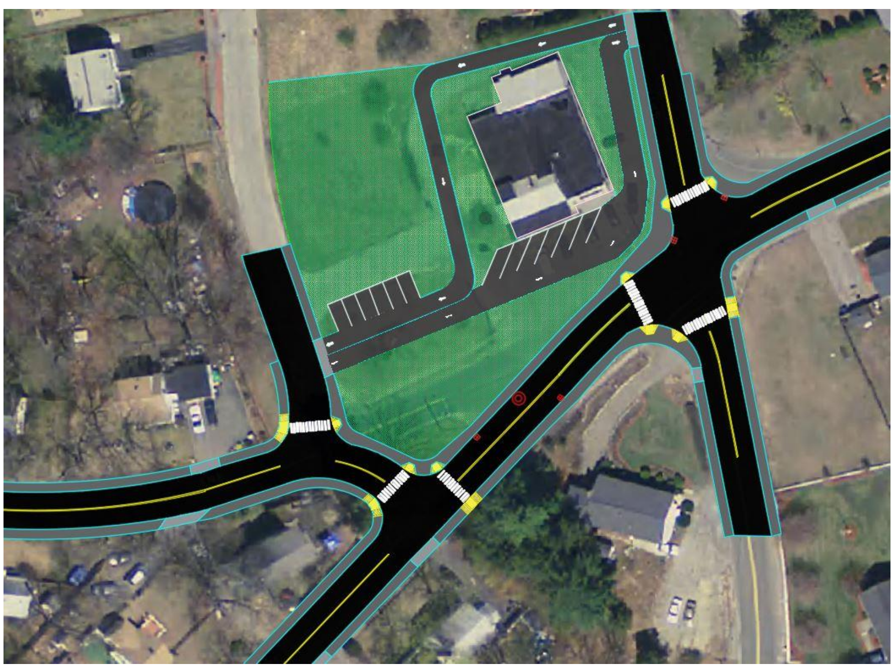

Figure 1: Final Design Alternative

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Acronyms

Acronym	Meaning
AADT	Annual Average Daily Traffic
ABET	Accreditation Board for Engineering and Technology
ADA	Americans with Disabilities Act
ADT	Average Daily Traffic
ATR	Automated Traffic Recorder
ASCE	American Society of Civil Engineers
CAD	Computer-Aided Design
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
DPW	Department of Public Works
FHWA	Federal Highway Administration
HCS	Highway Capacity Software
LOS	Level-of-Service
MassDOT	Massachusetts Department of Transportation
MPO	Metropolitan Planning Organization
MQP	Major Qualifying Project
MUTCD	Manual on Uniform Traffic Control Devices
NMCOG	Northern Middlesex Council of Governments
NMMPO	Northern Middlesex Metropolitan Planning Organizations
RPA	Rural Planning Agency
STIP	Massachusetts State Transportation Improvement Program
TIP	Transportation Improvement Program
TMC	Turning Movement Counter

1.0 Introduction

Tewksbury is a town located in Middlesex County within the northeastern corner of Massachusetts. It is considered part of Greater Lowell and is within commuting distance of Boston. Primarily a residential community, a large portion of community members travel elsewhere for their occupations.

In Tewksbury, Shawsheen Street provides a way for residents of surrounding communities to get to Interstate 93. The confluence of Patten Road, Foster Road, and Beech Street with Shawsheen Street is an intersection that the Town of Tewksbury believes would benefit from redevelopment. This Major Qualifying Project (MQP) provided recommendations on improvements to the five-way intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street in Tewksbury, MA.

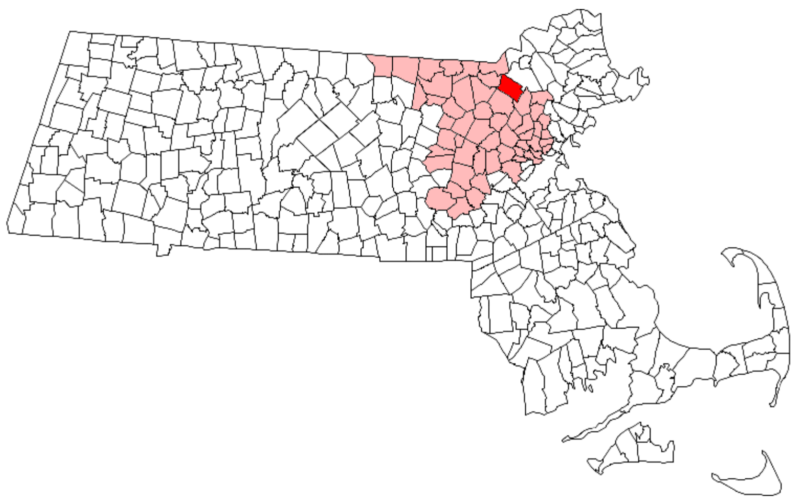

Figure 2: Tewksbury, MA highlighted (red) within Middlesex County (pink)

Currently, this intersection has generated many complaints from members of the community, who consider the intersection to be a nuisance and a danger (see Appendix B). Acute-angle and overly wide-angle turns as well as poor sight lines have caused confusion between drivers, increasing the likeliness of vehicle crashes occurring. The intersection has received no geometric changes in its history.

The team's objectives for this project were as follows:

- Collect data on existing intersection conditions
- Analyze data to determine problems in the intersection
- Create and model possible improvement options
- Assess each improvement option through an effectiveness and feasibility analysis

- Select preferred choice according to previous assessments and criteria provided by the town throughout the project
- Present and finish written report

Through these objectives and the methods contained within this project, recommendations were developed which the town can use to complete improvements to this intersection.

2.0 Background

The background section provides an overview of the Intersection of Shawsheen Street, Patten Road, Foster Road and Beech Street. It discusses the surrounding area, zoning and existing conditions. It also contains sections regarding Massachusetts Project Development and Design Guidelines, MassDOT's Complete Streets Program, and Massachusetts State Transportation Improvement Program.

Figure 3: Intersection Location

2.1 The Intersection

The intersection of Shawsheen Street, Patten Road, Foster Road and Beech Street has been a fixture in the town of Tewksbury. The 5-way intersection in its present form has not changed significantly since the 1970's. The intersection only receives routine maintenance, such as new stop signs, when necessary. The intersection exhibits both excessively acute and wide angle turns, as well as poor sight lines, leading to many complaints from the community members regarding the layout of the intersection and calls for improvements to be made to the location. The community recognizes that these issues impose potential safety risks and have asked that something be done to increase safety (see Appendix B).

The primary intersection, shown in Figure 4, consists of Shawsheen Street, Foster Road and Beech Street. A smaller, secondary intersection, shown in Figure 5, is where Patten Road merges with Shawsheen Street. The intersection has stop signs and flashing red stop light on Beech Street, Foster Road, and Patten Road. Shawsheen Street is controlled by a flashing yellow stop light.

Currently the intersection does not adequately accommodate those with disabilities. Sidewalks are only available on one side of the road and are extremely narrow, which limits where people in wheelchairs can travel. The intersection lacks warnings for people with visual impairments that are reaching the intersection. There are no pedestrian push buttons to signal designated times for people to safely cross the street and there are no indicators for cars to yield for pedestrians, which may make it more difficult for them to cross.

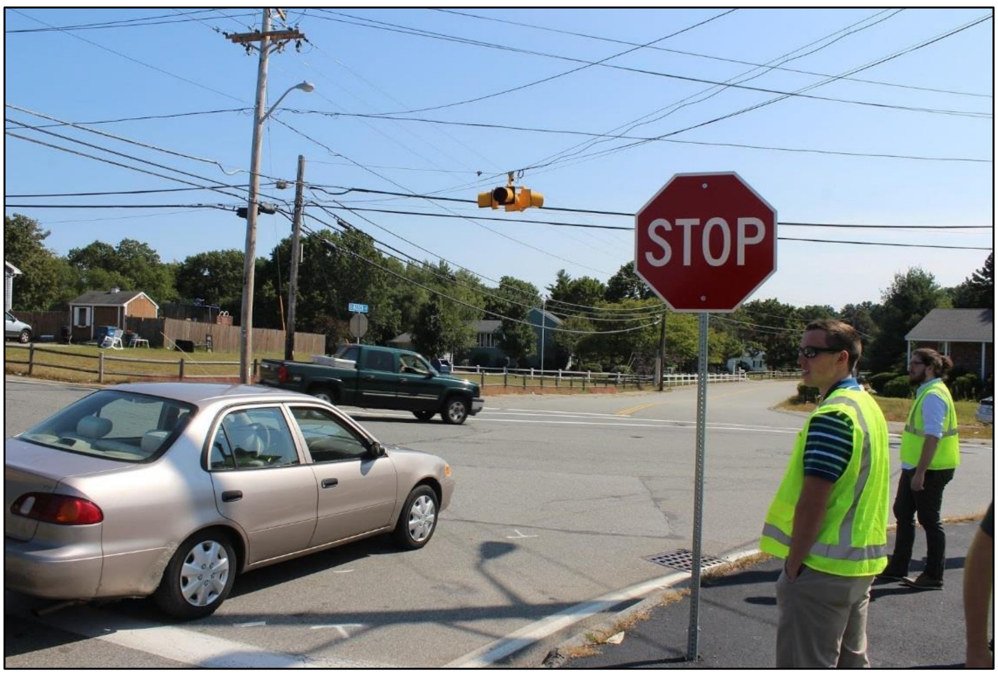

Figure 4: The primary intersection of Shawsheen Street, Foster Road, and Beech Street

Figure 5: The secondary intersection between Shawsheen Street & Patten Road (Shawsheen Street runs along the left and Patten Road runs to the right)

2.2 Surrounding Neighborhood

According to the Tewksbury Zoning Bylaws dated October 2015 the highlighted area of the intersection is zoned as "Limited Business." On the northeastern corner of Foster Road and Shawsheen Street is a convenience store known as Tewksbury Market. It is the only business at the intersection. When designing geometric improvements to the intersection, it was beneficial to know how the surrounding areas are zoned. This assisted in determining the type of vehicles that utilize the intersection, for example, commuter travelers in residential zones or heavy vehicles in commercial zones.

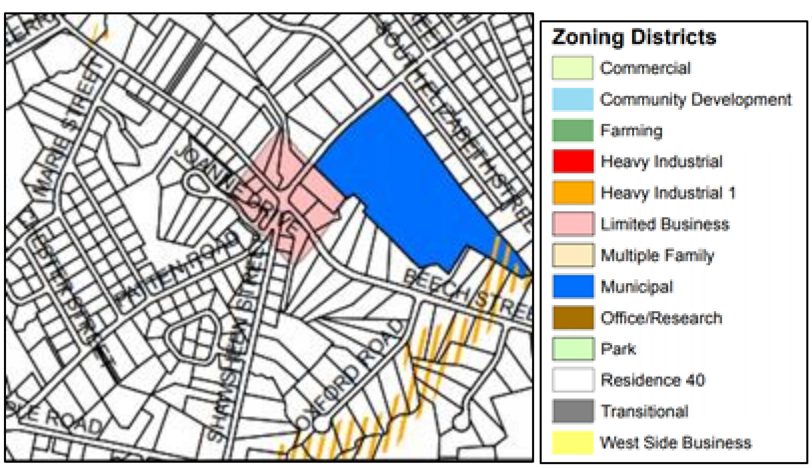

Figure 6: Google Maps Satellite Image of the intersection

The area surrounding the intersection is residential. Beech Street continues south and leads to a dead end. Foster Road travels north from the intersection through a residential area and connects to Chandler Street. Patten Road merges with Shawsheen Street from Whipple Road, forming a triangle, providing an alternate route to connect to Shawsheen Street. Shawsheen Street provides direct access through Tewksbury to Interstate 93, which provides access to cities such as Boston, Massachusetts to the south and Manchester, New Hampshire to the north. Shawsheen Street is also used by residents of Billerica, Massachusetts for access to I-93. Approximately 500 ft from the intersection is the Heath Brook Elementary School, one of four primary schools in the town. The school requires a reduced speed limit of 20 mph when children are present. The Town of Tewksbury is looking to lower the speed limit on Shawsheen Street from 40 miles per to hour to 35 miles per hour, but anticipates making significant modifications to the intersection as well.

2.3 Massachusetts Roadway Design Guidelines

The planning process for transportation improvement projects in Massachusetts are subject to following the Project Development and Design Guidebook if the project receives state or federal funding. Its purpose is to provide a framework for planners when designing improvements for communities. The Guidebook describes project development procedures and design guidelines ranging from pavement design to highway interchange design.

The information provided in Chapter 6 of the Project Development and Design Guidebook directly relates to intersection improvements. Some of this information includes traffic control standards, pedestrian Level-of-Service, and intersection capacities. This chapter was consulted by the project team to ensure that every aspect of intersection design was considered throughout the duration of the project and that Massachusetts standards are being addressed correctly in the designs.

2.4 MassDOT: Complete Streets

As communities have re-urbanized within the past few decades comes the realization that roads are for more than just cars. More people are walking, biking, or taking public transportation, and often, these forms of transportation feel that they are not given priority in the limited road space. More attention has been drawn towards designs which share space on the road, and this is reflected in Massachusetts state policy through the development of the Complete Streets Program. Through MassDOT, the Complete Streets program intends to instruct and aid municipalities towards developing Complete Streets. Municipalities who choose to be included are given design training for city employees, as well as funding for technical assistance and construction. MassDOT hoped that these incentives, as well as the benefits for the community, would encourage municipalities to incorporate more comprehensive design for their roads.

The program begins with the writing of a commitment letter stating intent to develop a Complete Streets policy. The municipality must send at least one representative to a Complete Streets training workshop. The municipality must then develop a policy to guide future design to follow Complete Streets goals and processes. The policy must guide all municipal construction projects to serve the interest of Complete Streets, and support and encourage multiple modes of transportation. This policy must address certain aspects of the design process, and MassDOT awards points for the completeness of the policy. If the policy scores a minimum of 80 out of 100 points, and is passed by the highest elected official or board, the municipality would be complete with Tier 1 of the funding program (*Complete Streets Funding Program Guidance*). Currently, Tewksbury has submitted their letter of intent, and so is on their way to becoming a Complete Streets Eligible Municipality, and may seek technical assistance up to $50,000 (*Massachusetts Complete Streets Funding Program Participation*).

In Tier 2 of the program, the municipality must develop a prioritization of its Complete Streets projects. If awarded technical assistance, the $50,000 can be used in the development of this prioritization. Needs must be established and ranked from a number of municipal assessments, taking into account which areas would be benefited most by the addition of a Complete Street. This process may involve outside consultants and community involvement. For instance, Northampton, MA's prioritization plan, which has been approved, ranks fifteen potential projects and provides details about each, as well as desired funding sources (Northampton Complete Streets Prioritization Plan). Once this plan is approved, the municipalities enters Tier 3 of the program, and individual projects can be approved for funding and construction by MassDOT. Each project can receive up to $400,000 towards construction if it is eligible. Funding is prioritized by how well a project meets each of the program's goals.

When designing an intersection, Complete Streets design encourages support for multimodal transportation. This, as with any intersection design, is done through Level-of-Service (LOS), which measures usability of an intersection by average delay time. Unlike traditional design, however, Complete Streets design requires the measurement of LOS for pedestrians, bicycles and motor vehicles separately. In addition to calculating roadway LOS, Highway Capacity Software (HCS) is capable of calculating pedestrian/cyclist LOS. Design then becomes a balancing act between multiple

LOS's, and sacrificing the service of one to improve the capacity of another is generally not encouraged (*Project Development and Design*).

2.5 Northern Middlesex Transportation Improvement Program (TIP)

Tewksbury is part of the Northern Middlesex Council of Governments and the Northern Middlesex MPO (NMMPO). Each year, the NMMPO compiles its regional TIP from each municipal government to determine its highest priority projects. From 2017 to 2021, Northern Middlesex will receive about $42.2 million each year (*State Transportation Improvement Program*).

NMMPO prioritizes projects based on a large number of criteria. Performance measures are set for project safety, efficiency, and bridge and pavement performance, among others. Projects which work towards MassDOT development goals are also given priority, if they promote positive community development through planning, or protect the environment. Additionally, the TIP takes into account public involvement. When assessing the needs of each project, public opinion is an important factor, and public review and comment on the TIP is encouraged before it is officially submitted to MassDOT (*Northern Middlesex Regional Transportation Improvement Program*). In order to seek TIP funding for this project, the intersection alternatives are required to meet MassDOT intersection standards.

2.6 Intersection Design Aspects

A large portion of the project involved understanding the components necessary in intersection design. When approaching intersection design a number of factors need to be considered to ensure safety and functionality.

2.6.1 Automated Traffic Recorder Counts & Turning Movement Counts

Conducting turning movement counts are crucial to determining the volume of traffic at a location. The first part of conducting a count is to determine when a count should take place. Typically, counts are not done between Friday and Monday because traffic conditions fluctuate greatly due to weekends. Counts should also not be done on or around holidays, as this is not an accurate depiction of traffic volumes. For example, a large influx of traffic may occur on the Wednesday before the Thanksgiving holiday and therefore should not be used to represent the average daily traffic at an intersection.

Automated traffic counters in the form of rubber tubing are often laid out across a road for the duration of one week in order to track the number of drivers that cross into an intersection. This data is collected and can be reviewed to find an optimal time to conduct a manual traffic count.

From this data, the Average Daily Traffic (ADT) can be calculated by averaging the daily volume over at least two days. Additionally, the Annual Average Daily Traffic can be calculated, taking into account adjustments for variances by month, with the equation:

$$AADT=V24ij^{*}\ DFi^{*}MFj$$

Where V_{24ij} is the 24 hour volume for day i and month j, DF_i is the daily adjustment factor for day i, and MF_j is the monthly adjustment factor for month j. Adjusting for the variances by month incorporated times of the year where there is more or less average daily traffic (Pande, 2016).

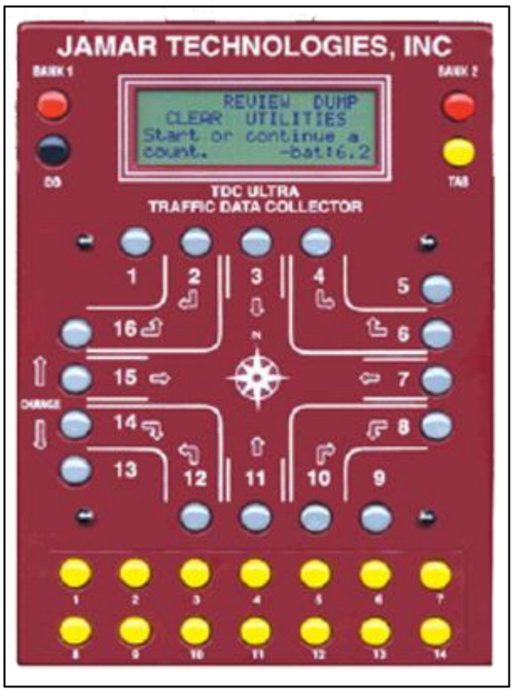

Figure 7: Turning movement counter (Jamar TDC Ultra, 2017)

A manual traffic count requires an observer to sit at the location of the count and manually input the direction of traffic flow into a data collection box called a Turning Movement Counter (TMC). The TMC (Figure 7) shows the possible movements at a four corner intersection with corresponding buttons for the various traffic patterns a vehicle may take. The user simply presses the button that corresponds with the direction of the vehicle and the data is collected. The data can then be uploaded to a computer to be analyzed.

2.6.2 Crash Data

Crash data can first be reviewed when proposing a new intersection design as they correlate to the safety at that location. Car crashes can occur for a number of reasons: a car crash may be a result of flaws in the current intersection design, human error of the driver, or poor sight conditions due to weather. In a crash report, time, vehicle direction, and crash types are just some of the variables reported. The types of accidents being reported can help depict a clearer picture as to why the crashes are occurring. For example, numerous car crashes occurring on the same windy stretch of road may indicate to engineers that the speed limit needs to be lowered or speed bumps should be implemented to slow cars down (Pande, 2016).

The crash data for a given location in Massachusetts can be retrieved from the Department of Transportation and can be turned into a comprehensive crash diagram. A crash diagram is a depiction of crashes from a certain location between a given time period. The crashes are represented by arrows to show the direction and location of the vehicles involved, as well as symbols to show what kind of crash occurred. The goal of the crash diagram is to find a pattern within the crash data (Figure 8) (Pande, 2016).

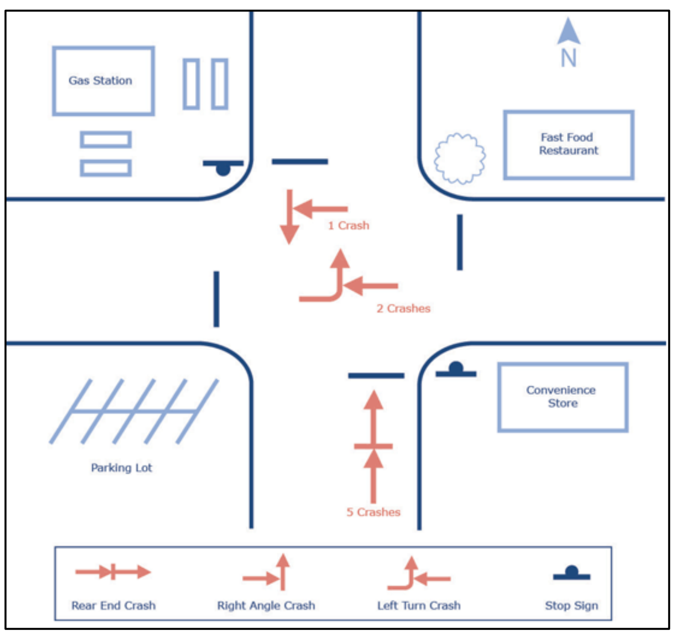

Figure 8: Crash diagram depicting three types of crashing occurring at the intersection (Transportation Safety Planning, 2015)

2.6.3 Crash Rates & Reduction Factors

Crash rates are the crashes per vehicle mile travelled in a given area. It can be calculated with the following equation:

R = (# of Collisions (per year) * 1,000,000)/(ADT * 365 Days)

The crash rate allows engineers to predict the number of crashes in the future. The ADT for this equation will take the product of the peak hour entering volume of the intersection and an assumed K value of 0.090. The K value in this calculation is used as a ratio of study hour traffic to Annual Average Daily Traffic. It approximates the average weekday peak hour traffic (McLeod, n.d).

A crash reduction factor (CRF) is the percentage of crash reductions anticipated after implementing new safety improvements to a location. These factors can be obtained from the Federal Highway Administration (FHWA), as well as private transportation organizations, such as the Transportation Research Board (TRB), and are calculated based on reported crash statistics taken before and after improvements are made. Additionally, these factors are reviewed and modified frequently by the FHWA to ensure that they are accurately depicting the improvements. If a change to an intersection would have a negative impact on the CRF this is also accounted for. For example, reducing the width of a shoulder is likely to increase the likelihood of a crash rather than cause a reduction in the percentages of crashes. Multiplying the crash reduction factor by the collision rate allowed a prediction of the collision rate after improvements are implemented (Pande, 2016). Additionally, Crash Modification Factors (CMF) are used to measure the effectiveness of particular design elements or treatments. The estimated number of crashes without the new treatment is multiplied by the CMF to find the estimated number of crashes with the new treatment. A CMF that is less than 1.0 indicates that there will be a reduction of crashes due to a treatment, while a CMF that is more than 1.0 indicates that there will be an increased number of crashes.

2.6.4 Signal Warrant Analysis

The Manual on Uniform Traffic Control Devices (MUTCD) outlines several different ways that an intersection can warrant a traffic signal. One type of warrant is the volume of traffic received during an eight hour traffic count. If an intersection is receiving high numbers of vehicles during an eight hour period, it may benefit from having a signal installed. Another type of warrant would be the amount of traffic during the peak hour of the day. If the peak hour receives a high volume of vehicles, further investigation can be done to see if the intersection would benefit from a signal. A further type of warrant is the number of crashes at an intersection. If a certain number of crashes occur at an intersection and it is highly probable that these crashes could have been avoided if a signal had been in place, this can warrant a signal due to safety concerns. For the project intersection, data collection and analysis can confirm if any of the warrants outlined by MUTCD apply to the intersection (Pande, 2016).

2.6.5 Level-of-Service

Level-of-Service (LOS) is the quantitative measure of traffic congestion and delay. Taking into account the density of traffic at an intersection as well as the average delay experienced by a driver, the LOS can be calculated. The LOS is represented as a letter grade from A-F. An intersection that receives an "A" letter grade means that a driver experiences little delay while at an intersection. An intersection that receives an "F" letter grade means that a driver experiences maximum delays while travelling through an intersection. That are many ways into improve the LOS of an intersection. For example, the traffic light present is not timed correctly for the volume of traffic it receives in one direction and may simply need to be retimed to accommodate the need (Pande, 2016).

2.6.6 Americans with Disabilities Act Compliance

The Americans With Disabilities Act (ADA) requires that developers provide access to locations for those with disabilities. This applies not only to buildings, but also to intersections, where geometric and control improvements should include improvements to ease of use for those with impaired movement or vision. Not providing appropriate accommodations can drastically limit a person's access to amenities, and ultimately limit where those with disabilities can live. Most importantly with regards to intersection design, many sidewalks and crosswalks are not designed to accommodate those in wheelchairs or other mobility devices. This could encourage those with mobility devices to instead ride in the street, creating a safety hazard (*Curb Ramps and Pedestrian Crossings Under Title II of the ADA*). These are all items that can be addressed when designing improvements to the intersection.

3.0 Methodology

Figure 9: Google Maps Satellite Image of the intersection

The goal of this project was to improve the intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street in Tewksbury, MA based on the needs of the town. The team used the following objectives in order to make recommendations for improvements:

- Collect data on existing intersection conditions
- Analyze data to determine problems in the intersection
- Create and model possible improvement options
- Assess each improvement option through an effectiveness and feasibility analysis
- Select preferred choice according to previous assessments and criteria provided by the town throughout the project
- Present and finish written report

Throughout the duration of the project, the team coordinated closely with the Town of Tewksbury to accomplish these objectives.

3.1 Collect Data on Existing Intersection Conditions

Understanding the current conditions of the intersection first allowed the team to familiarize themselves with the problem at hand.

3.1.1 Compile Existing Data

The existing data was gathered from a variety of sources. This included public information from the MassDOT website in addition to already completed traffic counts for the intersection.

3.1.1.1 Town Concerns

To gain an understanding of context, and the general problems that Tewksbury has with this intersection, past complaints were referenced, if readily available, from the town engineer. Looking at these complaints as a whole allowed specific problem areas to be identified qualitatively.

3.1.1.2 Collect traffic counts from NMCOG

The team coordinated with the Northern Middlesex Council of Governments (NMCOG) to have the agency conduct traffic counts at the intersection. NMCOG conducted road tube counts on all five approaches in the intersection and in turn provided the data to the team. Road tubes counted the vehicle volume, determined the weight class, as well as tracked speed. The tubes were used for 24-hour intervals for a full week to determine the peak hours of volume along each approach to the intersection as well as track the speed of vehicles.

3.1.1.3 Gather Currently Available Crash Data

Crash data was collected from the MassDOT crash database to assist in determining the safety issues associated with the current layout of the intersection. The crash database included data from 2004 to 2015, with approximately forty crashes occurring at this intersection during this time frame. This data was reorganized into a crash diagram detailing crash participants, location within the intersection, and damage type. A crash rate was also calculated using this data.

3.1.2 Collect Necessary Additional Data

Additional data that was necessary to the project included turning movement counts, survey data, and sight distances. If data could not be collected from previously mentioned sources, the data was collected by the team.

3.1.2.1 Intersection Survey

In order to determine the elevation changes for each approach to the intersection, the team surveyed the intersection. The team used WPI's leveling equipment to record the elevation changes.

The leveling approach required two people: one to hold the measuring rod, and one to record the elevation using the leveling lens. The level was placed on the corner of Shawsheen Street and Foster Road. This location was ideal because it provided a clear view of all streets. The general configuration of the total station can be seen in Figure 10.

Figure 10: Surveying Equipment Set Up

Data points were collected along both sides of all five corridors of the intersection. The distance, elevation, and angle were recorded by hand. This data was then entered into the software AutoCAD Civil3D for further analysis.

3.1.2.2 Turning Movements

In order to make basic determinations into geometric or traffic design improvements for any intersection it was beneficial to perform turning movement counts at the intersection. Turning movement counters were used to conduct peak hour counts, using the peak hours determined by NMCOG during the traffic count. These counts were conducted by all four team members, as the team divided into two groups, each group with a count board and pen and paper. The team covered the intersection in two parts; one group located at the intersection of Patten Road and Shawsheen Street, the other group located at the intersection of Foster Road, Beech Street and Shawsheen Street. The left, right, and straight turns analyzed are depicted in Figures 11 and 12 below. For the intersection of Patten Road and Shawsheen Street, the team incorporated the Tewksbury Market Convenience store as part of the intersection. This allowed for the traffic from the Market to be accounted for, as it is affecting the traffic of the intersection.

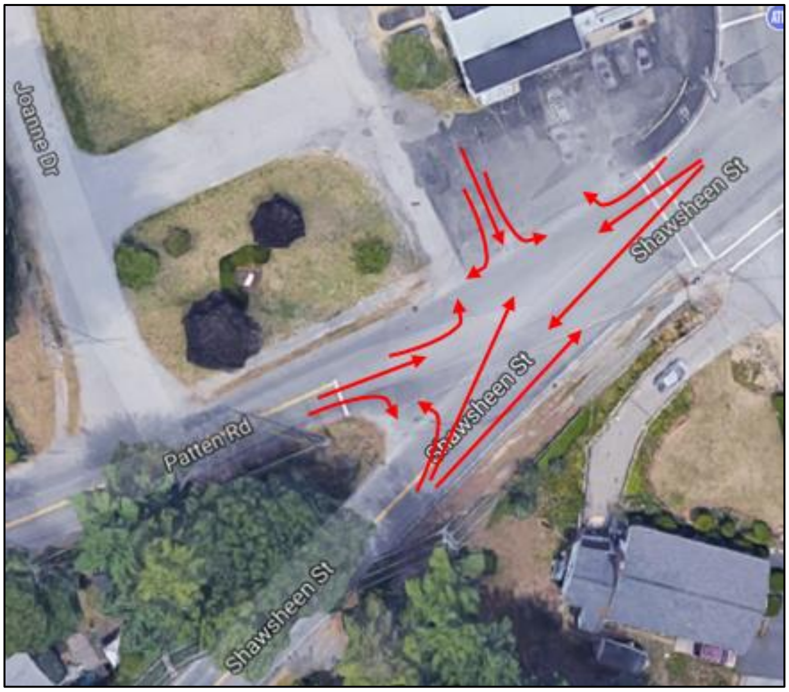

Figure 11: Shawsheen Street/Patten Road Intersection

Figure 12: Foster Road/Beech Street/Shawsheen Street Intersection Flow

Each group was located a safe distance away from the intersection in a car parked parallel to the road. The locations of the cars are shown in Figure 13. The team also accounted for the vehicles turning in and out of the driveway of the local convenience store.

Figure 13: Car Locations

Based on the information provided by NMCOG, the peak morning hour was determined to be 6AM to 8AM and the peak afternoon hour was 3PM to 5PM. The first count was conducted for the morning peak hour on Tuesday, November 7, 2017. The two groups arrived at 5:30AM and noted that the Tewksbury Market convenience store was open and there were a number of cars already parked outside the store. It was previously assumed that the store would not be open that early. The count began promptly at 6AM and ended at 8AM.

The second count was conducted for the afternoon peak hour on Tuesday, November 14, 2017. The two groups arrived at 2:45PM. The count began promptly at 3PM and ended at 5PM.

3.1.2.3 Crash Data

Additional crash data was needed to determine common accident causes. The team worked with Tewksbury to request crash reports from 2015 to 2018 from the Tewksbury Police Department for the intersection, which were not available on MassDOT's Crash Portal database. This data then used to supplement currently available crash data in the created tables.

3.2 Analyze Data to Determine Problems in the Intersection

Following data collection, the team assessed the data by calculating the Level-of-Service to see if the peak hour volumes warranted the addition of a signal and compiled the crash data into diagrams to illustrate the different accidents and the correlation to the design of the intersection.

3.2.1 Crash Analysis

Crash data was compiled and crash diagrams were created to effectively display the location of each individual crash, as well as view the intersection in the context of the crashes as a whole. Crash diagrams gave an opportunity to visually assess the safety of the intersection. This allowed the team to determine problem areas in the intersection that have led to crashes, and the changes that can be implemented to reduce the number and severity of crashes. Qualitatively, by comparing the location of crashes with the types of crashes, specific problems with intersection geometry was identified.

Quantitatively, the compilation and analysis of the crash data allowed the team to identify measures to be taken to improve intersection safety. Efforts were taken to calculate a crash rate using the traffic data provided by NMCOG, and potential improvements in safety can be calculated through the crash reduction factor (CRF). Initial observations indicate that several geometric improvements may be beneficial to safety, and these provided a starting point for assessment, but were by no means the only options assessed. When developing potential improvement scenarios, these CRFs allowed each scenario to be compared by estimated crash rate when improvements are taken as a whole.

3.2.2 Existing Level-of-Service (LOS)

The existing LOS was determined through Highway Capacity Software 2010 (HCS) by modeling the current geometric configuration of the intersection along with the results of the turning movement count performed by the team. The rating generated from the software, a letter from A to F, showed how the intersection is servicing the traffic flow it is receiving.

3.2.3 Signal Warrants

Turning movement count data collected was analyzed to see if the intersection warranted a signal. Turning movement counts from the peak morning and evening traffic were entered into HCS, which determined if a signal was necessary based on warrants from the FHWA Manual of Uniform Traffic Control Devices (MUTCD).

3.2.4 Stopping Sight Distances

Stopping sight distance was calculated by taking into account the time it takes for a driver to perceive and react to a stop and how far a car or truck travels while the brakes are being applied. Stopping distance while braking was calculated with the following equation:

$$D_b = \frac{u^2}{2g(f \ \pm G)}$$

where u is the average travel speed, f is a friction force constant, and G is the grade of the approach, measured during the intersection survey. The team calculated the stopping sight distances for the speed limit and compare it to the sight distances measured in the field. If the sight distances are smaller than the calculated stopping sight distance, then there is not enough time for the drivers to properly react.

3.2.5 Current ADA Compliance

The current intersection was analyzed for its ADA compliance. Intersections need to be accessible to pedestrians of all abilities. Examples of ADA compliance that would be noted are sidewalk width, integrated ramps, and percentage of slope.

3.3 Create and Model Alternatives

Based on the intersection analysis, the team designed several alternatives in order to address issues at the intersection. The first alternative was the "no-build" option, where no major changes are implemented and the intersection continues to be maintained as it is currently. The primary objective of the "no-build" option is to serve as a baseline for the other options to be compared against; typical transportation projects do not select the "no-build" as the preferred alternative.

The team developed several options that offer safety, geometric, and/or capacity improvements to the intersection. The team anticipated that these alternatives would focus more on geometric and safety improvements as opposed to capacity improvements, as an initial site visit established that geometry and sight distances are a greater concern than traffic capacity (see Appendix A). Preliminary design options included, but were not limited to:

- Replacing the intersection with a roundabout

- Realigning Patten Road to intersect Shawsheen Street at 90 degrees, farther west of the main Shawsheen Street/Beech Street/Foster Road 4-way intersection
- Reconfiguring Patten Road to be only one-way leading out of the intersection
- Excavating land so as to level Shawsheen Street on both approaches to the intersection
- Restrict the amount of curb cuts to better define access to the adjacent convenience store
- Altering the traffic control setup to either an all-way stop or a traffic signal

Once the team determined which alternatives to pursue through cost consideration, time of construction, and complexity of the improvements, each alternative was modeled using Automatic Computer-Aided Design 2016 and 2017 (AutoCAD) and Highway Capacity Software 2010 (HCS). To begin, a satellite view of the current intersection was imported into CAD for use as an underlay. With this base in place, the team can lay the various models over existing intersection in CAD. This setup allowed for immediate comparisons of each new design against the existing design for both geometry and land usage.

Each alternative was assessed for its use of space. Ideally, any proposed improvements would be implemented within the existing right-of-way, denoted on the AutoCAD file, so that additional land does not have to be acquired. Land acquisition can be a lengthy process that can significantly delay and/or add cost to a project. In some cases, land acquisition may not be possible depending on the circumstances. Involvement of the Town of Tewksbury was especially important during this step.

3.4 Assess Effectiveness & Feasibility of Alternatives

The team assessed the effectiveness and feasibility of the modelled alternatives through analysis of the new Level-of-Service, cost, environmental impacts and crash reduction factors.

3.4.1 Level-of-Service

Additionally, the team modeled both the existing intersection and each proposed intersection improvement alternative using Highway Capacity Software (HCS). Using traffic data previously collected, the team analyzed and determined the Level-of-Service (LOS) for each alternative. Initially the team determined the LOS at the present before determining the LOS at multiple points in the future, using projected annual growth rates. Finally, each alternative was evaluated for present and future operational serviceability. This step utilized the intersection models created using HCS.

3.4.2 Preliminary Qualitative Environmental Review

With the project advisor and the town of Tewksbury, it was determined that an environmental impact study was not in the scope of this project. However, reducing the amount of pavement in the intersection was a goal of this project for both safety and environmental impact, so design alternatives were qualitatively assessed on the basis of permeable coverage. Once a preferred alternative was selected for construction and the town moves forward with the project, then a full environmental impact review could be conducted.

3.5 Select Preferred Alternative

In order to select the preferred design alternative, each alternative was presented to the town engineer, town planner, a member of the Tewksbury Police Department, and a member of the Tewksbury Fire Department. The feedback provided by these individuals ultimately helped determine what the final recommendation for the intersection would be. Factors that were considered during this feedback period were as follows:

- Perceived improved safety
- Compliance with MassDOT Standards
- Present and future operational serviceability (for both safety and capacity)

After careful consideration of all factors, the alternative that best met all of the criteria was selected as the preferred alternative.

3.6 Cost Analysis

Once the preferred design alternative was finalized, the team prepared a cost estimate. The estimate included all expected costs should the design move forward to construction. In order to construct estimate, the team utilized a resource published by the Commonwealth of Massachusetts, titled "Consultants Estimating Manual" (Consultants Estimating Manual, 2006). Typically, cost estimates are constructed based on cost information from previous projects, and this data was compiled in large publications. Such compilations are typically available at both the state and municipal levels, and the team anticipated using both when preparing cost estimates. The team utilized the cost information provided by the state.

3.7 Presentation of Findings

For the extent of this project, findings and preliminary alternatives were shared by the entire team with the town engineer and interested parties in the town of Tewksbury on January 30, 2018. The attendees included the town planner, a member of the Tewksbury Police Department, and a member of the Tewksbury Fire Department. By doing this, the town had input into the discussion of the preferred alternative, and was able to provide specific criteria to guide this project towards a solution that will best benefit the town's residents. To share the preferred improvement scenario with both WPI and Tewksbury, this team developed a final MQP report with supporting materials. This report included written findings and recommendations in addition to appendices with all intersection data and design models. Finally, the team prepared and presented a poster for WPI's annual Project Presentation Day on April 20th, 2018.

4.0 Results and Analysis

This project's methodology involved collecting data at the intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street, and then utilizing the data to develop several improvement alternatives. This gave rise to many results and findings observed throughout the process.

4.1 Automated Traffic Recorder Counts

The Northern Middlesex Council of Governments (NMCOG) conducted automated traffic recorder (ATR) counts at the intersection on behalf of the project team. After analyzing the data found in Appendix C, the peak periods at the intersection were determined to be 6:00-8:00 AM and 3:00-5:00 PM. These peak periods were utilized in order to complete the turning movement counts.

4.2 Turning Movement Counts

The turning movement counts were completed as described in the methodology. While the complete data are located in Appendix D, the team made several general observations:

In both the morning and afternoon, through traffic on Shawsheen Street was the busiest movement. While more traffic was headed westbound on Shawsheen Street than eastbound in the morning, there was an even amount of vehicles heading both directions in the afternoon. While westbound vehicles heading onto Patten Road from Shawsheen Street was a popular movement, and vice versa eastbound, more vehicles remained on Shawsheen Street to/from the west.

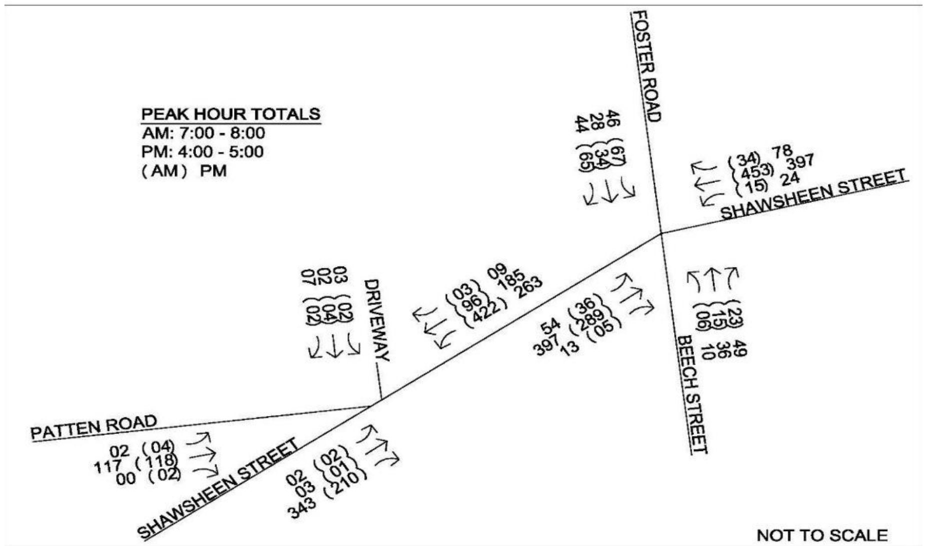

Figure 14: Turning Movement Count Diagram

In both the morning and afternoon, a noticeable number of vehicles turned off both directions of Shawsheen Street onto Foster Road, and vice versa. Beech Street was quiet during the morning count, but became busy during the afternoon count.

School buses were routinely observed passing through the intersection, likely stemming from the nearby elementary school. On one occasion, a westbound bus stopping at Shawsheen Street/Patten Road caused traffic to stop within the Shawsheen Street/Foster Road/Beech Street intersection. A small number of heavy vehicles were observed traveling east/west on Shawsheen Street, and a small number of pedestrians were observed as well.

4.3 Crash Data Analysis

The data collected from MassDOT's Crash Portal website and obtained from the Tewksbury Police Department provided insight on the crash history of the intersections of Foster Road/Beech Street/Shawsheen Street and Shawsheen Street/Patten Road. With the peak hourly volumes and the number of crashes at each intersection, a crash rate was calculated for 2002 to 2017. The equation for this calculation was as follows:

$$\text{Rate} = (A * 1{,}000{,}000) / (V * 365)$$

Where A is the average number of crashes per year and V is the intersection ADT. The intersection ADT was calculated with a standard "K" factor of 0.090. The peak hour volumes for the calculation utilized data from the turning movement count conducted by the team. The afternoon count was higher than the morning count, so the volumes from the afternoon count were used to find the total entering volume of the intersection.

Table 1: Peak Hour Volumes

	Beech St	Foster Rd	Patten Rd	Shawsheen St (EB)	Shawsheen St (WB)	Total Entering Volume
7:00-8:00 AM	44	166	124	213	502	1,049
4:00-5:00 PM	95	118	119	348	499	**1,179**

Table 2: Crash Rate Calculation

K Factor	Intersection ADT (V)	Total # of Crashes	# of Years	Average # of Crashes Per Year (A)	Rate
0.090	1,179/0.090= 13,100	51	16	51/16= 3.19	0.67

The crash rate was calculated to be 0.67. This is slightly higher than the District 4 unsignalized average of 0.56.

4.4 Highway Capacity Software Analysis

The use of Highway Capacity Software (HCS) 2010 allowed for both an analysis of the level of service for the intersections as well as an analysis of signal warrants for the intersections.

4.4.1 Intersection Level of Service

Using HCS 2010, the intersection was analyzed as an unsignalized, two-way stop controlled intersection. After completing the intersection analysis in HCS, the intersection was found to function similarly in both the morning and afternoon peak hours. Additionally, the major road (Shawsheen Street) functioned better than the minor roads (Patten Road, Beech Street, and Foster Road).

Ultimately, a level-of-service (LOS) and associated vehicle delay was computed by HCS for each approach, as seen in the table below:

Table 3: Level of Service & Delay Times

	Shawsheen St	Patten Rd	Foster Rd	Beech St
Morning LOS (7:00-8:00 am)	A	C	F	C
Morning vehicle delay (seconds)	-	21.8	83.5	22.9
Afternoon LOS (4:00-5:00 pm)	A	C	F	E
Afternoon vehicle delay (seconds)	-	20.7	79.2	38.9

These calculations are roughly in line with observations of the intersection during the turning movement counts. Furthermore, the inclusion of pedestrian traffic did not change the intersection calculations, as a minor amount of pedestrians were observed at the intersection.

4.4.2 Signal Warrants Analysis

After completing the HCS analysis of the turning movement count data, the team assessed the need for a traffic control signal at the intersection of Patten Road and Shawsheen Street as well as the intersection of Shawsheen Street, Beech Street and Foster Road. The team used the Mass Highway and the Manual on Uniform Control Devices written by the U.S. Department of Transportation. After assessing the intersection and completing an analysis of the applicable factors in the eight different traffic signal warrants, the team determined only warrant three applied, which pertains to the peak hour. Using the turning movement count data collected at each intersection, the team determined whether or not either intersection warranted a signal. These reports can be found in Appendix E.

Table 4: Signal Warrant Analysis

Warrant	Status
1: Eight-Hour Vehicular Volume	Not Met
2: Four-Hour Vehicular Volume	Not Met
3: Peak Hour	Will be met with 1% traffic growth
4: Pedestrian Volume	Not Met
5: School Crossing	Not Applicable
6: Coordinate Signal System	Not Applicable
7: Crash Experience	Not Met
8: Roadway Network	Not Applicable
9: Intersection Near a Grade Crossing	Not Applicable

The turning movement count data for the intersection of Shawsheen Street and Patten Road was compared to the criteria for warrant three. None of the conditions were met as the stopped time delay experienced was not high enough to exceed 4 vehicle-hours. It does exceed 800 vehicles per hour, and exceeds 100 vehicles per hour on the approach.

At the intersection of Foster Road, Beech Street and Shawsheen Street, the total stopped time delay experienced on Beech Street did not equal or exceed four vehicle-hours. The volume on Beech Street did not equal or exceed 100 vehicles per hour. For this reason, Beech Street as the minor-street approach does not warrant a signal.

With Foster Road as the minor-street approach, the total stopped time delay equaled 3.9 vehicle-hours, which is just below the first condition of exceeding 4 vehicle-hours for a one-lane approach. The volume on the minor-street approach exceeds 100 vehicles per hour and the total entering volume serviced during the hour exceeds 800 vehicles. With 1% traffic growth on all approaches, the total stopped time delay on Foster Road will increase to 4.1 vehicle-hours, which would result in the signal warrant being met.

4.5 Improvement Options

Through observations at the intersection, the team has identified a number of potential geometric improvements to the intersection. Through observations and HCS modeling, geometric improvements in throughput were determined to be unnecessary. Therefore, these improvements aim mainly to address issues of driver confusion, and overall make the intersection less stressful to travel through. These improvements may be implemented individually or in combination, pursuant to the needs of Tewksbury and the available funds.

4.5.1 Market Curb Cut Adjustment

During traffic counts, the team noticed that the majority of near accidents and driver confusion was caused by the entrance and exiting of cars from the center of the intersection to the parking lot of Tewksbury Market. The curb cut for this parking lot extends across the majority of the lot, meaning that an entrance is not defined and cars can pull in and out at almost any location and angle. This can cause near-collisions with cars already in the parking lot, and it was observed several times that cars entering the lot were waiting halfway into the intersection, causing backups for cars going west on Shawsheen Street. To combat this, the team has prepared several potential improvements to better facilitate traffic flow through the market.

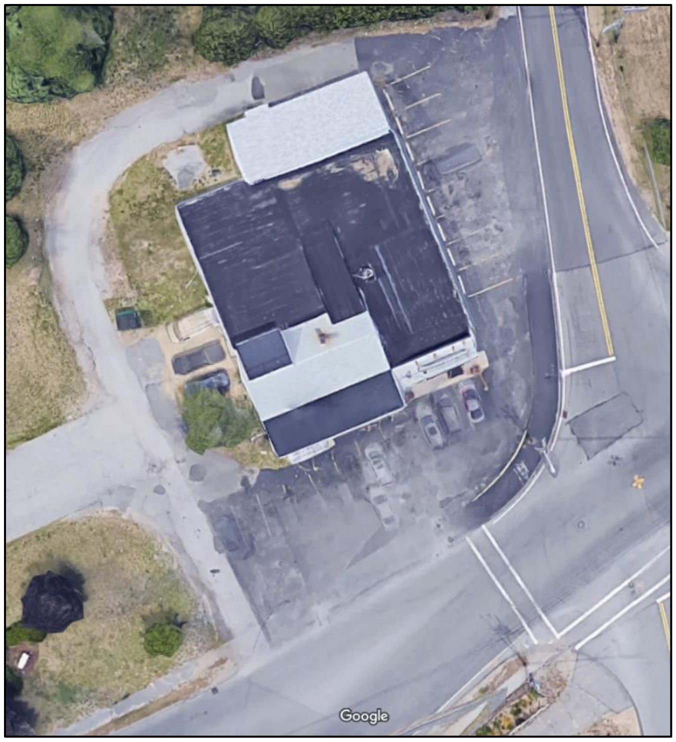

Figure 15: Market Curb Cuts

4.5.2 Market Parking - Option One

Option One leaves the majority of the layout of the parking lot unchanged, and so will likely be easiest to implement for both the town and the owner of the Market. Option One would shrink the curb cuts and have two-way access from both Joanne Drive and Foster Road. Travel from the entrance to the exit could be complete by either the current path through the parking lot in front of the building, or by the development of the path behind the market. The front path would allow more to remain unchanged, but it’s a tight fit for larger vehicles, so space may be a concern. The rear path would alleviate space concerns, but more importantly, traveling vehicles would be separated from actual parking. This would reduce the occurrence of interference between cars traveling through the lot and those pulling into or out of a parking space.

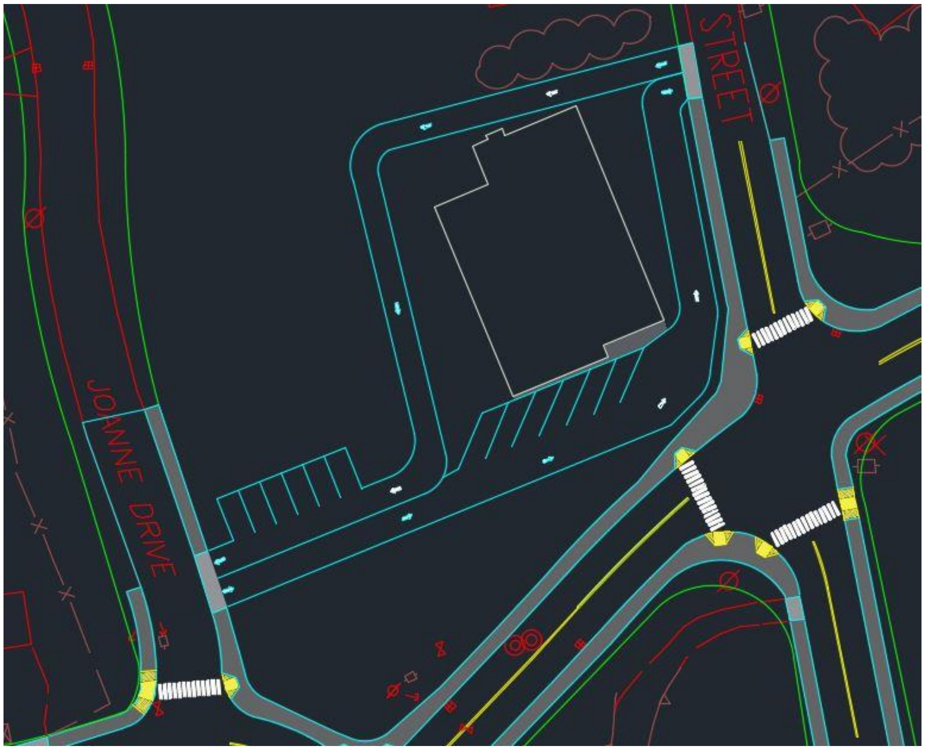

Figure 16: Market Parking - Option One

4.5.2 Market Parking - Option Two

Option Two would change the entrance and exit location for the parking lot to Joanne Drive, which would then exit onto Patten Road before arriving at Shawsheen Street. Although a more complicated route, the exit would be placed far enough away from the intersection to completely eliminate driver confusion related to conflicts between the intersection and the parking lot. In this scenario, the rear traffic path from Option One would make more sense than the front path. Additionally, this option would require an easement be granted to the Tewksbury Market from the town for the traffic traveling onto Joanne Drive behind the memorial.

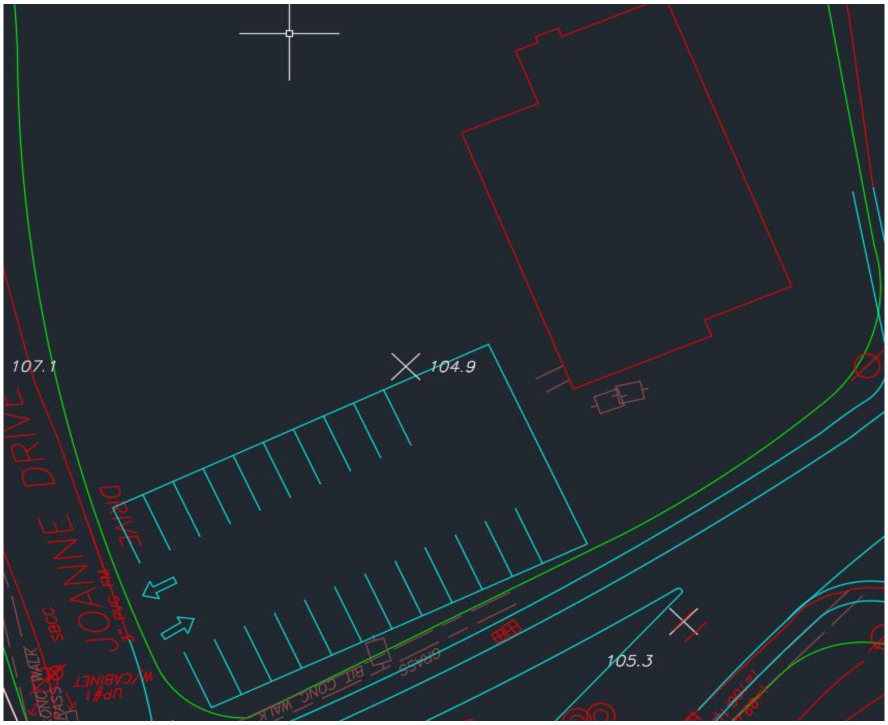

Figure 17: Market Parking - Option Two

4.5.2 Market Parking - Option Three

Option Three would involve a substantial redesign of the parking lot, the memorial, and the adjoining undeveloped land owned by the Tewksbury market. This option would, however, alleviate space concerns in the parking lot, eliminate conflicts with the intersection, and grant the Market more parking space, which may make them more supportive of intersection changes. In this instance, parking on the east and south-east sides of the building would be eliminated. As a replacement, a comparable number of parking spaces would be added on the south-west side of the building, adjacent to the intersection. The parking lot would rest partially on town-owned land currently used for the memorial. This memorial would be moved to an appropriate location and rededicated. Entrance and exit in this scenario would both connect to Joanne Drive.

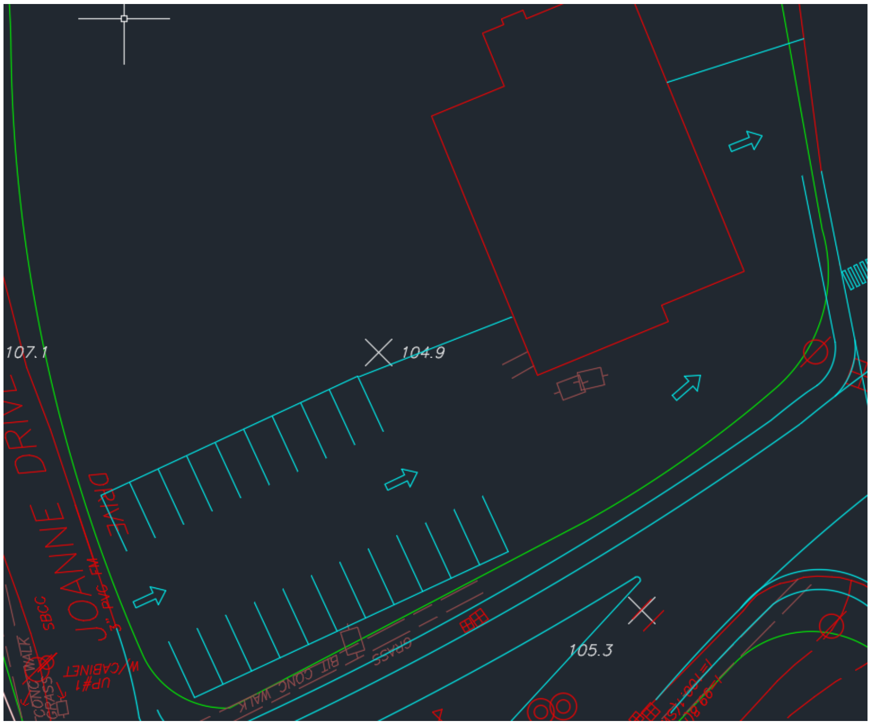

Figure 18: Market Parking - Option Three

4.5.3 Shawsheen Street/Patten Road Intersection Realignment

One major issue with the intersection was identified in the angle between Patten Road and Shawsheen Street at the intersection. Through complaints by the town and its residents, as well as this team's observations, it was identified that drivers heading east on Patten Road were required to pull far into the intersection in order to see oncoming traffic heading east on Shawsheen Street. This was due both to the extreme angle of the intersection, as well as the presence of trees and bushes interfering with line-of-sight. A substantial redesign is necessary to fix these problems. This improvement option would move the intersection of Patten Road and Shawsheen Street about 30 feet to the west, as well as angling Patten Road to intersect Shawsheen Street at more of a right angle. The space currently occupied by the remainder of Patten Road would be replaced with grass, or potentially used as space for Option Three of the parking lot redesign. Additionally, additional width of Shawsheen Street as it enters the intersection would be removed, and Shawsheen Street would remain a consistent width through the intersection. These changes would server to drastically reduce the overall amount of pavement in the intersection. This would not only make the intersection more aesthetically pleasing, but would also make it safer for pedestrians, who would have a shorter distance to cross.

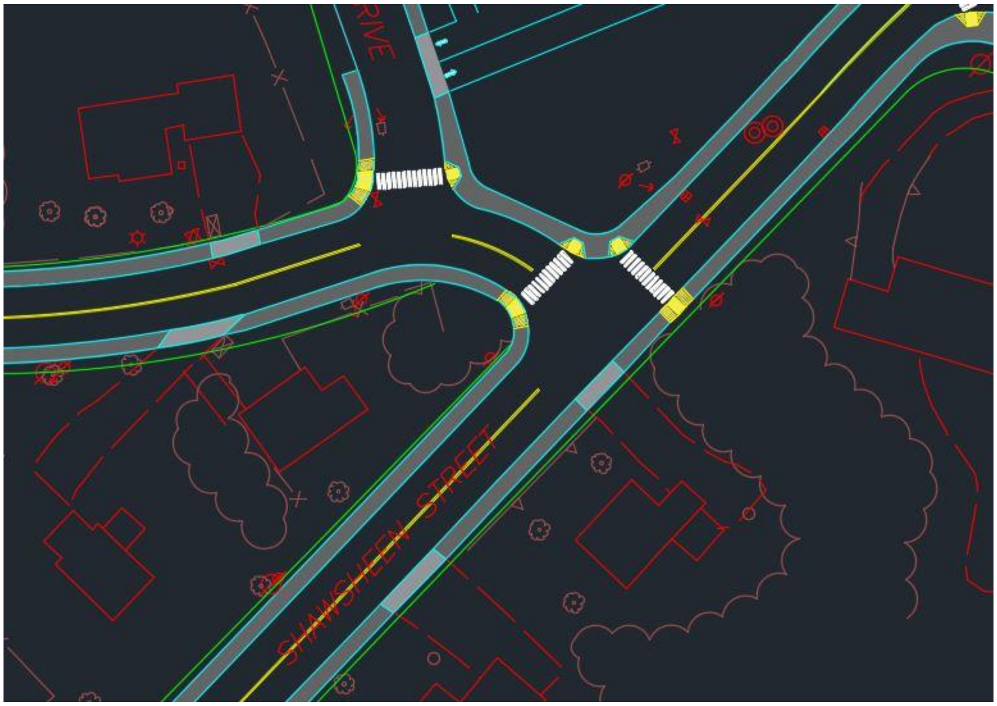

Figure 19: Shawsheen St/ Patten Rd Realignment

4.5.4 Turn Radius Reduction

This improvement option would reduce the radius of the turns on both sides of Foster Road. As it stands, the turns are much wider than recommended by MassDOT standards. Pulling in those curbs would discourage speeding around turns, as well as decreasing pavement in the intersection as a whole. In addition, Foster Road could be slightly realigned to form a right angle with Shawsheen Street, which would allow even tighter radii and safer design speeds.

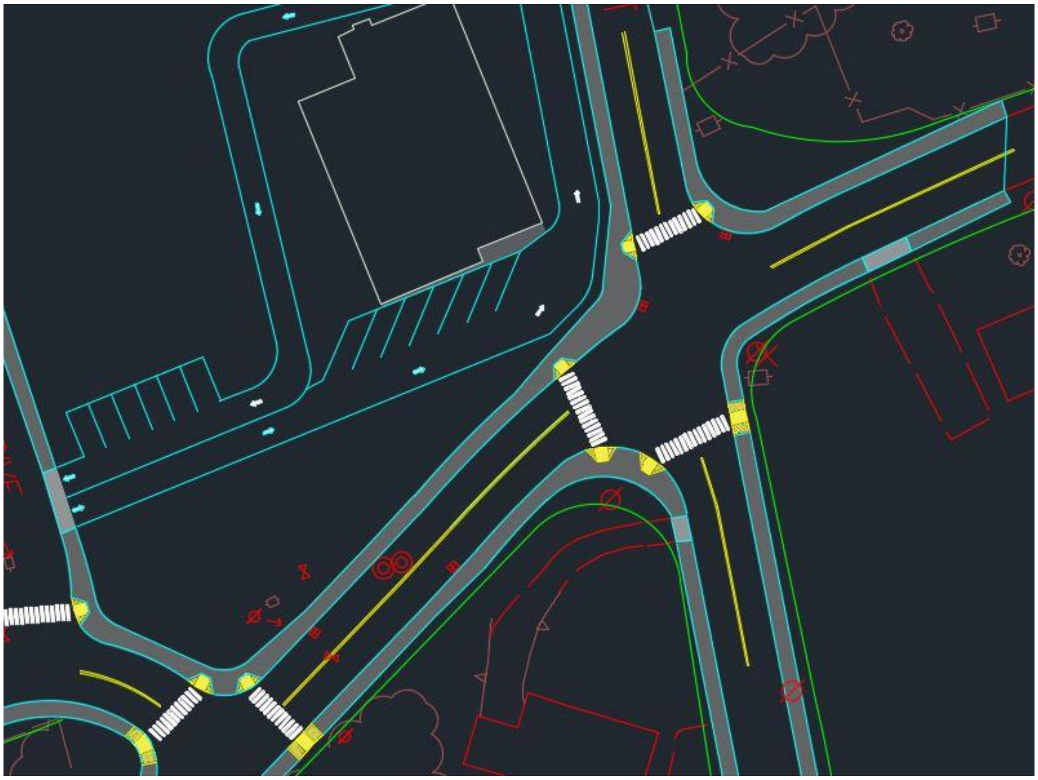

Figure 20: Turn Radius Reduction at Foster Rd & Beech St

4.5.5 ADA Compliant Sidewalks/Crosswalks

As part of meeting MassDOT's standards for Complete Streets, the sidewalks surrounding the intersection would be improved. Each sidewalk would be six feet wide and include 4-inch curbs abutting the roadway. Crosswalks would be designed to comply with ADA standards by utilizing a ramp gradient of 8% and a flare gradient of 9% at each edge of the crosswalk. Each crossing would utilize the "Continental" crosswalk marking pattern.

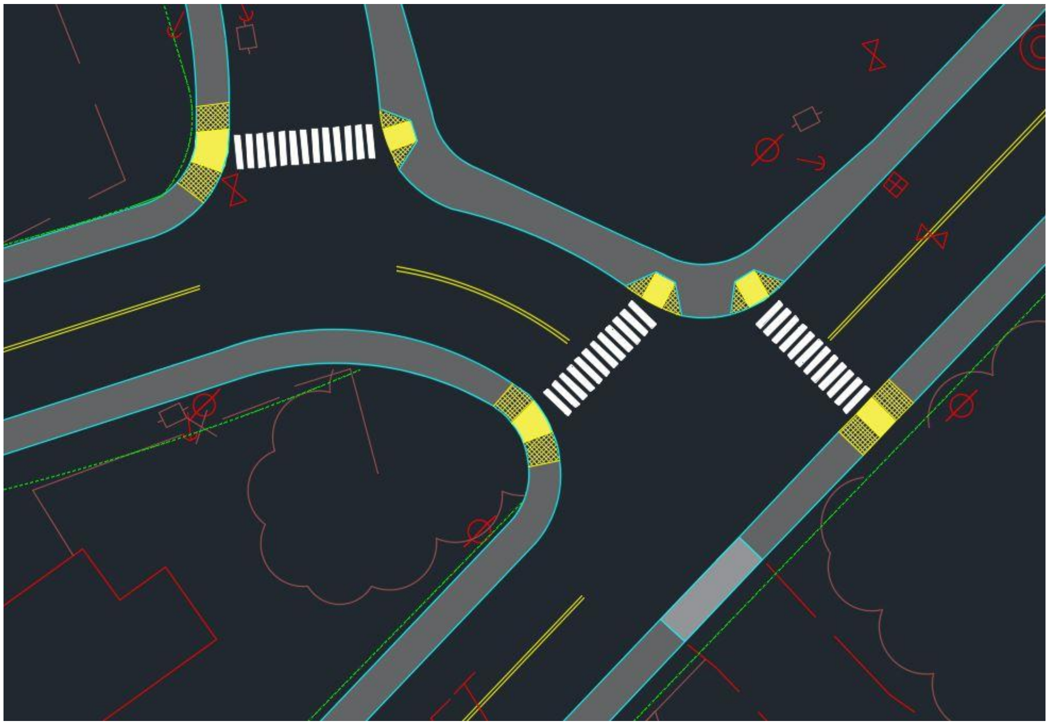

Figure 21: ADA Compliant Crosswalks & Sidewalks

5.0 Conclusion & Recommendations

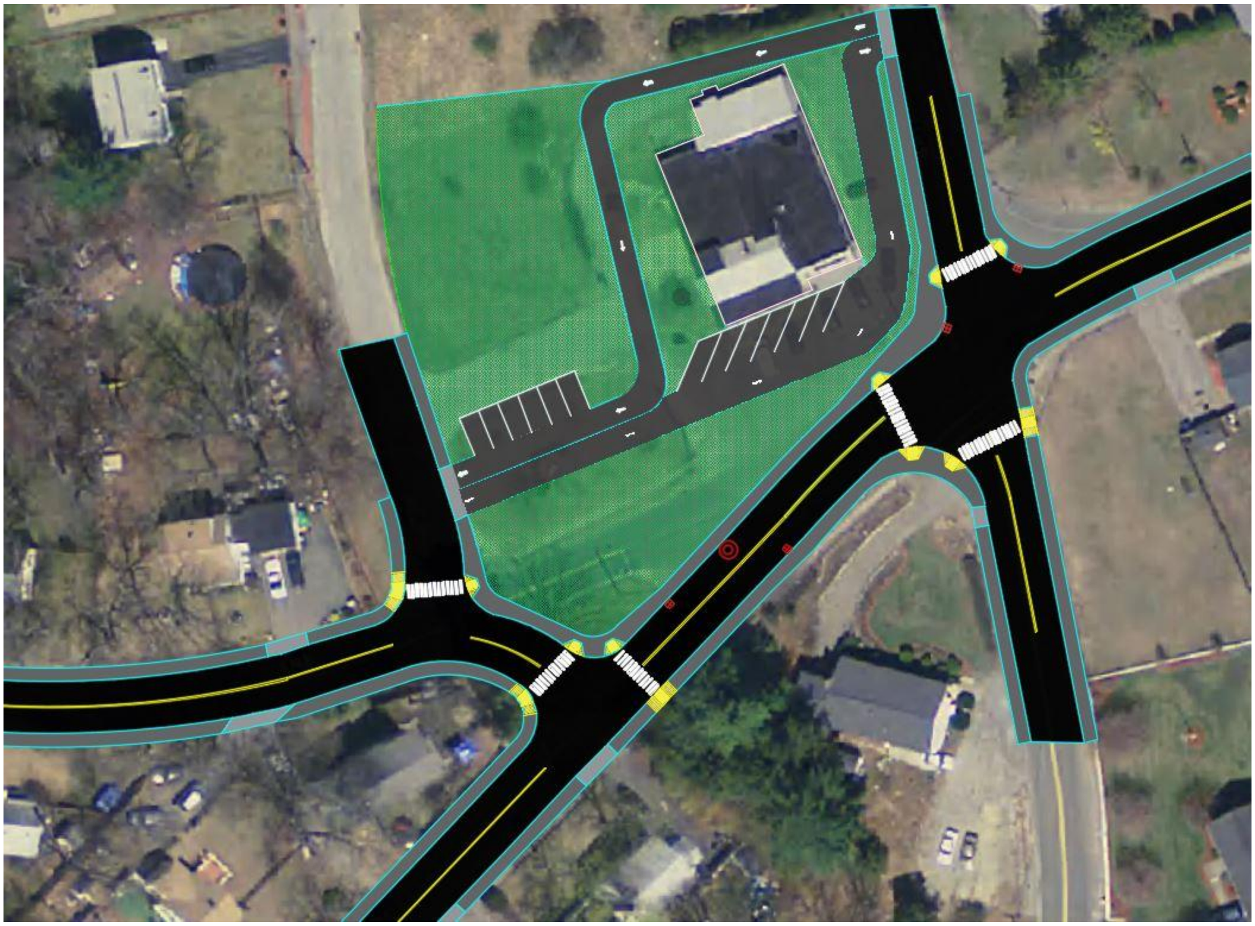

Figure 22: Final Design Alternative

Through both the team's own analysis and the recommendations of town employees, including the DPW, town planner, and the police and fire departments, the choices for improvements were narrowed down to a single redesigned intersection, with multiple possibilities for the market parking lot. For the intersection, both the team and the town concluded that the majority of problems were related to the safety and coherency of the intersection. Changes to the final design of the intersection are intended to improve sight lines, reduce crash rates, and reduce the stress involved in both driving and walking through the intersection.

The final redesign of the intersection was narrowed down to a number of improvements that address these concerns. The improvements are as follows:

- Realigning the intersection of Patten Road and Shawsheen Street, making the intersection a right angle in order to improve visibility for cars leaving Patten Road.

- Narrowing turn radii at the intersection of Shawsheen Street, Foster Road, and Beech Street, reducing the speeds at which cars can make a turn, while making pedestrian crossings shorter and safer.
- Removing or narrowing the parking lot entrance from Shawsheen Street, to prevent conflict and confusion between cars entering and exiting the parking lot, and those traveling through the intersection.
- Realigning Shawsheen Street to maintain a consistent width through the intersection, drastically lowering the width of the pavement in the intersection, and decreasing the distance of pedestrian crossings.
- Making the intersection ADA compliant with the extension of sidewalks, addition of pedestrian ramps, and standardization of crosswalks.

5.1 Crash Modification Factors

The geometric improvements to the intersection provided potential reduction in the current crash rate. Previously calculated, the current crash rate for the intersection was 0.67. The various improvements to the intersection are listed along with their respective CMF. Due to limited research on aspects of CMFs, not every improvement made to the intersection was quantifiable with a CMF.

Table 5: Geometric Improvements and Crash Modification Factors

Geometric Improvement	CMF
Reduced lane width from 12ft to 10ft	0.58
Widening sidewalks	1.12
Add crosswalks	0.60

Note that of the three modifications with available CMFs, only two would attribute to a reduction in crash rate. The widening of sidewalks is considered to increase the number of crashes on the road. With these numbers selected, a final crash rate with the improvements can be calculated.

Table 6: Predicted Crash Rate with CMFs

Total CMF	Current Crash Rate	Predicted Crash Rate with Improvements
0.58*1.12*0.60 = 0.389	0.67	0.389*0.69 = 0.260

With the CMFs the predicted crash rate at the intersection decreases from 0.67 to 0.26. This number is lower than the District 4 average of 0.56.

5.2 Cost Estimate

A cost estimate was determined for the materials needed for the construction of the proposed intersection design. The estimation utilized the mean bid prices provided by MassDOT for projects of similar size in District 4. Quantities for the various materials were pulled from the final AutoCAD file. This estimate did not include the costs associated with the labor required for construction.

Table 7: Cost Estimate for Materials

Item No	Description	Unit of Measure	Unit Price	Total Quantity	Total
201.	CATCH BASIN	EA	$3,250.000	6.000	19,500.00
202.	MANHOLE	EA	$4,000.000	2.000	8,000.00
402.	DENSE GRADED CRUSHED STONE FOR SUB-BASE	CY	$60.000	555.555	33,333.00
420.	HOT MIX ASPHALT BASE COURSE	TON	$100.000	1,160.000	116,000.00
460.	HOT MIX ASPHALT	TON	$85.000	580.000	49,300.00
501.	GRANITE CURB TYPE VA1 - STRAIGHT	FT	$40.000	2,140.000	85,600.00
509.1	GRANITE TRANSITION CURB FOR WHEELCHAIR RAMPS - CURVED	FT	$45.000	108.000	4,860.00
701.	CEMENT CONCRETE SIDEWALK	SY	$50.000	1,555.555	77,777.00
701.1	CEMENT CONCRETE SIDEWALK AT DRIVEWAYS	SY	$60.000	122.222	7,333.00
770.	LAWN SODDING	SY	$9.000	3,222.222	29,000.00
					$430,703.00

5.3 Future Recommendations

As previously stated in the Results section, the portion of the intersection with Shawsheen Street, Beech Street, and Foster Road is currently just shy of meeting the signal warrant for peak hour conditions. By utilizing HCS, it was determined that this warrant will be met with 1% traffic growth from the peak morning hour volume. While signalization is not included in the final design alternative, it remains an option in the future as traffic volume is expected to grow.

The Shawsheen Street/Beech Street/Foster Road intersection was modeled in HCS for a four-way signal utilizing the 1% traffic growth. The model assumes no geometry changes beyond what is already recommended for the intersection. The signal would have two total phases, with approximately 50 seconds of green for Shawsheen Street and 10 seconds of green for Beech Street and Foster Road. This setup produced the following results:

Table 8: Level of Service & Delay Times

	Shawsheen St (EB)	Shawsheen St (WB)	Foster Rd	Beech St
LOS (7:00-8:00 am)	A	A	C	C
Vehicle delay (seconds)	4.5	5.7	29.5	26.1

The most significant improvement is on Foster Road, where the LOS improves from F to C and the vehicle delay decreases from 83.5 seconds to 29.5 seconds. Additionally, the overall intersection LOS was determined to be an A.

With these recommendations in mind, the town of Tewksbury can move forward with making the necessary improvements to the intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street as they see fit.

References

Complete Streets Funding Program Guidance [Massachusetts Department of Transportation]. (2016). Retrieved September 20, 2017, from http://www.massdot.state.ma.us/Portals/8/docs/CompleteStreets/FundingProgramGuidance.pdf

Consultants Estimating Manual [Commonwealth of Massachusetts, Division of Capital Asset Management]. (2006). Retrieved October 1, 2017, from http://www.mass.gov/anf/docs/dcam/dlforms/cem-feb06.pdf

Curb Ramps and Pedestrian Crossings Under Title II of the ADA [United States Department of Justice]. (2007) Retrieved September 20, 2017 from https://www.ada.gov/pcatoolkit/chap6toolkit.htm

Intersection Design [Mass Highway]. (January 2006) Retrieved February 16, 2018, from https://www.massdot.state.ma.us/Portals/8/docs/designGuide/CH_6_a.pdf

Jamar TDC Ultra [Northline Canada]. Retrieved October 7, 2017 from http://www.northlinecanada.com/Counters.aspx

Manual on Uniform Traffic Control Devices [U.S Department of Transportation FHWA]. (2009) Retrieved February 16, 2018, from https://mutcd.fhwa.dot.gov/htm/2009/part4/part4c.htm

Massachusetts Complete Streets Funding Program Participation [Massachusetts Department of Transportation]. (2017). Retrieved September 20, 2017, from https://masscompletestreets.com/Map/

McLeod, Doug. (n.d). Design Aspects of Standard K Factors [Florida Department of Transportation]. Retrieved March 1, 2018, from http://www.fdot.gov/roadway/training/Webinar12/StandardK.pdf

National Society of Professional Engineers. (2017). Retrieved March 1, 2018, from https://www.nspe.org/resources/licensure/what-pe

Northampton Complete Streets Prioritization Plan [Massachusetts Department of Transportation]. (2016). Retrieved September 20, 2017 from https://masscompletestreets.com/PublicDownload.ashx?aWQ9MjgyJnRpZXJJZD0y

Northern Middlesex Regional Transportation Improvement Program: Federal Fiscal Years 2018-2022 [Northern Middlesex Council of Governments]. (2017). Retrieved September 20, 2017, from http://www.nmcog.org/Websites/nmcog/images/TIP/NMMPO%20FFY%202018-2022%2 0TIP%20Endorsed%2052417.pdf

Pande, Anurag. (2016). Traffic Engineering Handbook, Institute of Transportation Engineers. Project Development and Design [Massachusetts Highway Department]. (2006). Retrieved October 1, 2017, from http://www.massdot.state.ma.us/highway/DoingBusinessWithUs/ManualsPublicationsForms/ProjectDevelopmentDesignGuide.aspx State

Transportation Improvement Program [Massachusetts Department of Transportation]. (2016). Retrieved September 20, 2017, from http://www.massdot.state.ma.us/Portals/17/docs/STIP/STIP17-21_Final.pdf 23

Transportation Safety Planning [U.S Department of Transportation, FHWA]. (2015). Retrieved October 7, 2017, from https://safety.fhwa.dot.gov/tsp/fhwasa15089/chap5.cfm#fig512

Appendix A: Project Proposal

Intersection Improvement
Shawsheen St, Patten Rd, Foster Rd, Beech St
Tewksbury, MA

Major Qualifying Project Proposal
October 10th, 2017

Craig Barrett

Vanessa Beutel

James Macfarlane

Patrick Murphy

Advisor

Professor Suzanne LePage

Sponsor

Kevin Hardiman, Town of Tewksbury

Capstone Design

As the culmination of undergraduate studies in Civil Engineering, WPI requires a Major Qualifying Project with a capstone design to fulfill the ABET engineering requirements. The American Society of Civil Engineers suggests seven factors that must be considered by this project in order to meet the Capstone Design requirement. This project addresses the following constraining aspects, including:

- **Economic:** For the town to build any recommended improvements, this project will take into account both the costs of construction and implementation as well as sources of funding. This team will look to identify the most beneficial and efficient improvements for a reasonable cost.
- **Environmental:** Suggested improvements to the intersection of Shawsheen, Beech, Patten, and Foster will be designed with the intention of not adversely affecting the environment. The team will also work to improve the intersection for bicyclists and pedestrians to reduce car usage.
- **Social:** The intent of this project is, ultimately, to improve the health and wellbeing of the community of Tewksbury. The team will determine the most economic and effective solution to benefit the travel of the citizens of Tewksbury.
- **Political:** Throughout the completion of this project, the team will be collaborating with the town engineer and other representatives of the Town of Tewksbury, as necessary, to ensure they are informed of any actions taken. The team's suggested improvements will be presented to the town engineer, to make the final decision and to decide if these changes will benefit the town.
- **Ethical:** The team will not threaten the reputation of WPI nor put the Town of Tewksbury at risk. Before any action is taken or documents are submitted, they will be discussed with the town engineer. All decision-making will be made in compliance with the ASCE Code of Ethics.
- **Health & Safety:** The improvements to the intersection of Shawsheen, Beech, Patten, and Foster will serve to increase safety and create a safer environment by addressing areas with increased crash rates and turning movements with acute or excessively wide angles.
- **Constructability:** In addressing improvements to the intersection of Shawsheen, Beech, Patten, and Foster the team will present the most effective option to the town engineer after assessing the overall cost, size and time needed to complete each alternative design option.
- **Sustainability:** The development of intersection improvements will serve the purpose of improving the intersection for multiple years down the road. Final plans will consider the future traffic demands of the intersection and population growth of the town of Tewksbury to prevent imminent changes following these improvements.

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Acronyms

Acronym	Meaning
AADT	Annual Average Daily Traffic
ADA	Americans with Disabilities Act
ADT	Average Daily Traffic
CAD	Computer-Aided Design
CRF	Crash Reduction Factor
DPW	Department of Public Works
FHWA	Federal Highway Administration
HCS	Highway Capacity Software
LOS	Level-of-Service
MassDOT	Massachusetts Department of Transportation
MPO	Metropolitan Planning Organizations
MQP	Major Qualifying Project
MUTCD	Manual on Uniform Traffic Control Devices
NMCOG	Northern Middlesex Council of Governments
NMMPO	Northern Middlesex Metropolitan Planning Organizations
RPA	Rural Planning Agency
STIP	Massachusetts State Transportation Improvement Program
TMC	Turning Movement Counter

1.0 Introduction

Tewksbury is a town located in Middlesex County within the northeastern corner of Massachusetts. It is considered part of Greater Lowell and is within commuting distance of Boston. Primarily a residential community, a large portion of community members travel elsewhere for their occupations.

In Tewksbury, Shawsheen Street provides a way for residents of surrounding communities to get to Interstate 93. The confluence of Patten Road, Foster Road, and Beech Street with Shawsheen Street is an intersection that the Town of Tewksbury believes would benefit from redevelopment. This Major Qualifying Project (MQP) will provide recommendations on improvements to the five-way intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street in Tewksbury, MA.

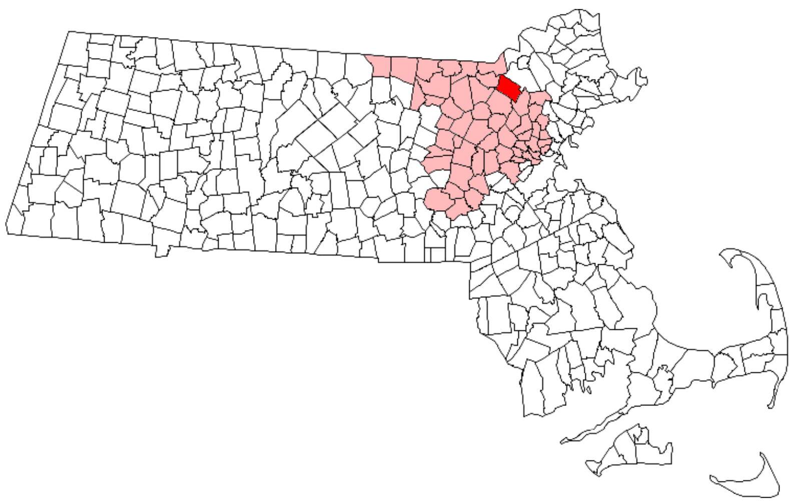


Figure 1: Tewksbury, MA highlighted (red) within Middlesex County (pink)

Currently, this intersection has generated many complaints from members of the community, who consider the intersection to be a nuisance and a danger (see Appendix A). Acute-angle and overly wide-angle turns as well as poor sight lines have caused confusion between drivers, increasing the likeliness of vehicle crashes occurring. The intersection has received no geometric changes in its history.

The team's objectives for this project are as follows:

- Collect data on existing intersection conditions
- Analyze data to determine problems in the intersection
- Create and model possible improvement options
- Assess each improvement option through an effectiveness and feasibility analysis

- Select preferred choice according to previous assessments and criteria provided by the town throughout the project
- Present and finish written report

Through these objectives and the methods contained within this proposal, recommendations will be developed which the town can use to complete improvements to this intersection.

2.0 Background

The background section provides an overview of the Intersection of Shawsheen Street, Beech Street, Patten Road, and Foster Road. It discusses the surrounding area, zoning and existing conditions. It also contains sections regarding the Massachusetts Project Development and Design Guidelines, MassDOT's Complete Streets Program, and Massachusetts State Transportation Improvement Program.

2.1 The Intersection

The intersection of Patten Road, Foster Road, Shawsheen Street and Beech Street has been a fixture in the town of Tewksbury. The 5-way intersection in its present form has not changed significantly since the 1970's. The intersection only receives routine maintenance, such as new stop signs, when necessary. The intersection exhibits both excessively acute and wide angle turns, as well as poor sight lines, leading to many complaints from the community members regarding the layout of the intersection and calls for improvements to be made to the location. The community recognizes that these issues impose potential safety risks and have asked that something be done to increase safety (see Appendix A).

Figure 2: Intersection Location

The primary intersection, shown in Figure 3, consists of Foster Road, Shawsheen Street and Beech Street. A smaller, secondary intersection, shown in Figure 4, is where Patten Road merges with Shawsheen Street. The intersection has stop signs and flashing red stop light on Beech Street, Foster Road, and Patten Road. Shawsheen Street is controlled by a flashing yellow stop light.

Figure 3: The primary intersection of Shawsheen Street, Foster Road, and Beech Street

Figure 4: The secondary intersection between Shawsheen Street & Patten Road (Shawsheen Street runs along the left and Patten Road runs to the right)

2.2 Surrounding Neighborhood

According to the Tewksbury Zoning Bylaws dated October 2015 the highlighted area of the intersection is zoned as “Limited Business.” On the northeastern corner of Foster Road and Shawsheen Street is a convenience store known as Tewksbury Market. It is the only business at the intersection. When designing geometric improvements to the intersection, it will be beneficial to know how the surrounding areas are zoned. This will assist in determining the type of vehicles that utilize the intersection, for example, commuter travelers in residential zones or heavy vehicles in commercial zones.

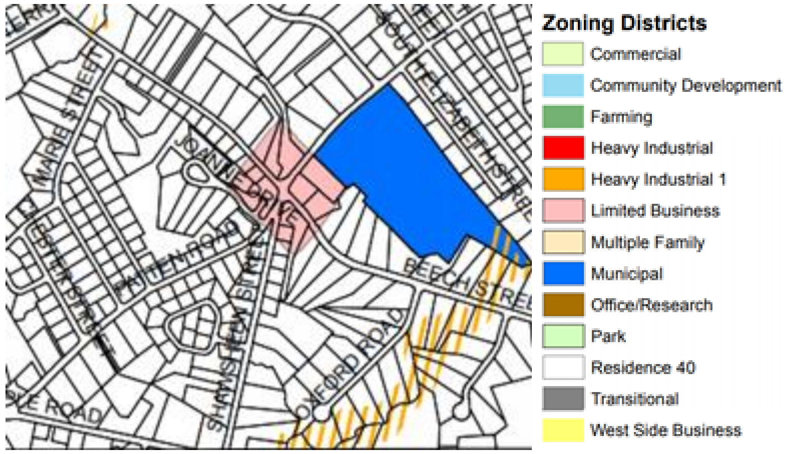


Figure 5: Google Maps Satellite Image of the intersection

The area surrounding the intersection is residential. Beech Street continues south and leads to a dead end. Foster Road travels north from the intersection through a residential area and connects to Chandler Street. Patten Road merges with Shawsheen Street from Whipple Road, forming a triangle, providing an alternate route to connect to Shawsheen Street. Shawsheen Street provides direct access through Tewksbury to Interstate 93, which provides access to cities such as Boston, Massachusetts to the south and Manchester, New Hampshire to the north. Shawsheen Street is also used by residents of Billerica, Massachusetts for access to I-93. Approximately 500 ft from the intersection is the Heath Brook Elementary School, one of four primary schools in the town. The school requires a reduced speed limit of 20 mph when children are present. The Town of Tewksbury is looking to lower the speed limit on Shawsheen Street from 40 miles per to hour to 35 miles per hour, but anticipates making significant modifications to the intersection as well.

2.3 Massachusetts Roadway Design Guidelines

The planning process for transportation improvement projects in Massachusetts are subject to following the Project Development and Design Guidebook if the project receives state or federal funding. Its purpose is to provide a framework for planners when designing improvements for communities. The Guidebook describes project development procedures and design guidelines ranging from pavement design to highway interchange design.

The information provided in Chapter 6 of the Project Development and Design Guidebook directly relates to intersection improvements. Some of this information includes traffic control standards, pedestrian Level-of-Service, and intersection capacities. This chapter will be consulted by the project team to ensure that every aspect of intersection design is considered throughout the duration of the project and that Massachusetts standards are being addressed correctly in the designs.

2.4 MassDOT: Complete Streets

As communities have re-urbanized within the past few decades comes the realization that roads are for more than just cars. More people are walking, biking, or taking public transportation, and often, these forms of transportation feel that they are not given priority in the limited road space. More attention has been drawn towards designs which share space on the road, and this is reflected in Massachusetts state policy through the development of the Complete Streets Program. Through MassDOT, the Complete Streets program intends to instruct and aid municipalities towards developing Complete Streets. Municipalities who choose to be included are given design training for city employees, as well as funding for technical assistance and construction. MassDOT hopes that these incentives, as well as the benefits for the community, will encourage municipalities to incorporate more comprehensive design for their roads.

The program begins with the writing of a commitment letter stating intent to develop a Complete Streets policy. The municipality must send at least one representative to a Complete Streets training workshop. The municipality must then develop a policy to guide future design to follow Complete Streets goals and processes. The policy must guide all municipal construction projects to serve the interest of Complete Streets, and support and encourage multiple modes of transportation. This policy must address certain aspects of the design process, and MassDOT awards points for the completeness of the policy. If the policy scores a minimum of 80 out of 100 points, and is passed by the highest elected official or board, the municipality will be complete with Tier 1 of the funding program (*Complete Streets Funding Program Guidance*). Currently, Tewksbury has submitted their letter of intent, and so is on their way to becoming a Complete Streets Eligible Municipality, and may seek technical assistance up to $50,000 (*Massachusetts Complete Streets Funding Program Participation*).

In Tier 2 of the program, the municipality must develop a prioritization of its Complete Streets projects. If awarded technical assistance, the $50,000 will be used in the development of this prioritization Needs must be established and ranked from a number of municipal assessments, taking into account which areas would be benefitted most by the addition of a Complete Street. This process may involve outside consultants and community involvement.

For instance, Northampton, MA's prioritization plan, which has been approved, ranks fifteen potential projects and provides details about each, as well as desired funding sources (Northampton Complete Streets Prioritization Plan). Once this plan is approved, the municipalities enters Tier 3 of the program, and individual projects can be approved for funding and construction by MassDOT. Each project can receive up to $400,000 towards construction if it is eligible. Funding is prioritized by how well a project meets each of the program's goals.

When designing an intersection, Complete Streets design encourages support for multimodal transportation. This, as with any intersection design, is done through Level-of-Service (LOS), which measures usability of an intersection by average delay time. Unlike traditional design, however, Complete Streets design requires the measurement of LOS for pedestrians, bicycles and motor vehicles separately. Design becomes a balancing act between multiple LOS's, and sacrificing the service of one to improve the capacity of another is generally not encouraged (*Project Development and Design*).

2.5 Northern Middlesex Transportation Improvement Program (TIP)

Tewksbury is part of the Northern Middlesex Council of Governments and the Northern Middlesex MPO (NMMPO). Each year, the NMMPO compiles its regional TIP from each municipal government to determine its highest priority projects. From 2017 to 2021, Northern Middlesex will receive about $42.2 million each year (*State Transportation Improvement Program*).

NMMPO prioritizes projects based on a large number of criteria. Performance measures are set for project safety, efficiency, and bridge and pavement performance, among others. Projects which work towards MassDOT development goals will also be given priority, if they promote positive community development through planning, or protect the environment. Additionally, the TIP takes into account public involvement. When assessing the needs of each project, public opinion is an important factor, and public review and comment on the TIP is encouraged before it is officially submitted to MassDOT (*Northern Middlesex Regional Transportation Improvement Program*). In order to seek TIP funding for this project, the intersection alternatives will be required to meet MassDOT intersection standards.

2.6 Intersection Design Aspects

A large portion of the project will involve understanding the components necessary in intersection design. When approaching intersection design a number of factors need to be considered to ensure safety and functionality.

2.6.1 Crash Data

Crash data can first be reviewed when proposing a new intersection design as they correlate to the safety at that location. Car crashes can occur for a number of reasons: a car crash may be a result of flaws in the current intersection design, human error of the driver, or poor sight conditions due to weather. In a crash report, time, vehicle direction, and crash types are just some of the variables reported. The types of accidents being reported can help depict a clearer picture as to why the crashes are occurring. For example, numerous car crashes occurring on the same windy stretch of road may indicate to engineers that the speed limit needs to be lowered or speed bumps should be implemented to slow cars down (Pande, 2016).

The crash data for a given location can be retrieved from MassDOT and can be turned into a comprehensive crash diagram. A crash diagram is a depiction of crashes from a certain location between a given time period. The crashes are represented by arrows to show the direction and location of the vehicles involved, as well as symbols to show what kind of crash occurred. The goal of the crash diagram is to find a pattern within the crash data (Figure 6) (Pande, 2016).

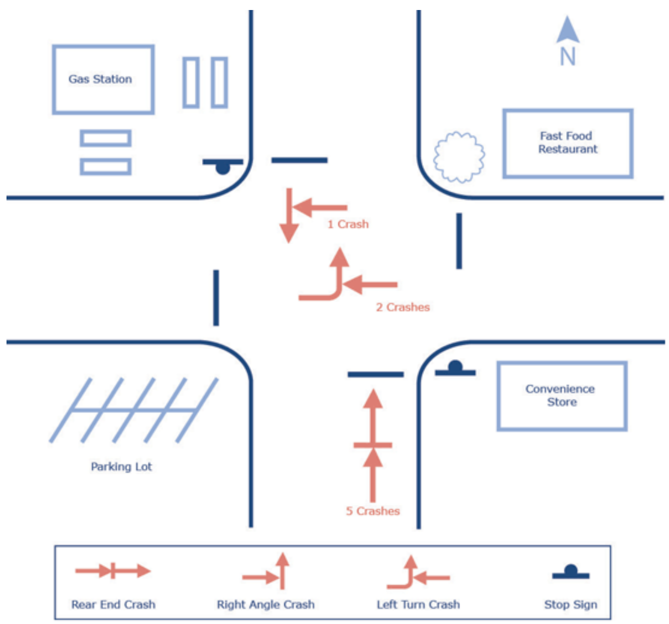


Figure 6: Crash diagram depicting three types of crashing occurring at the intersection (Transportation Safety Planning, 2015)

2.6.2 Turning Movement Counts

Conducting turning movement counts are crucial to determining the volume of traffic at a location. The first part of conducting a count is to determine when a count should take place.

Typically, counts are not done between Friday to Monday because traffic conditions fluctuate greatly due to weekends. Counts should also not be done on or around holidays, as this is not an accurate depiction of traffic volumes. For example, a large influx of traffic may occur on the Wednesday before the Thanksgiving holiday and therefore should not be used to represent the average daily traffic at an intersection.

Automated traffic counters in the form of rubber tubing are often laid out across a road for the duration of one week in order to track the number of drivers that cross into an intersection. This data is collected and can be reviewed to find an optimal time to conduct a manual traffic count.

A manual traffic count requires an observer to sit at the location of the count and manually input the direction of traffic flow into a data collection box called a Turning Movement Counter (TMC). The TMC (Figure 7) shows the possible movements at a four corner intersection with corresponding buttons for the various traffic patterns a vehicle may take. The user simply presses the button that corresponds with the direction of the vehicle and the data is collected. The data can then be uploaded to a computer to be analyzed. From this data, the Average Daily Traffic (ADT) can be calculated by averaging the daily volume over at least two days. Additionally, the Annual Average Daily Traffic can be calculated, taking into account adjustments for variances by month, with the equation:

$$AADT = V_{24ij} * \ DF_i * MF_j$$

Where V_{24ij} is the 24 hour volume for day i and month j, DF_i is the daily adjustment factor for day i, and MF_j is the monthly adjustment factor for month j. Adjusting for the variances by month will incorporate times of the year where there is more or less average daily traffic (Pande, 2016).

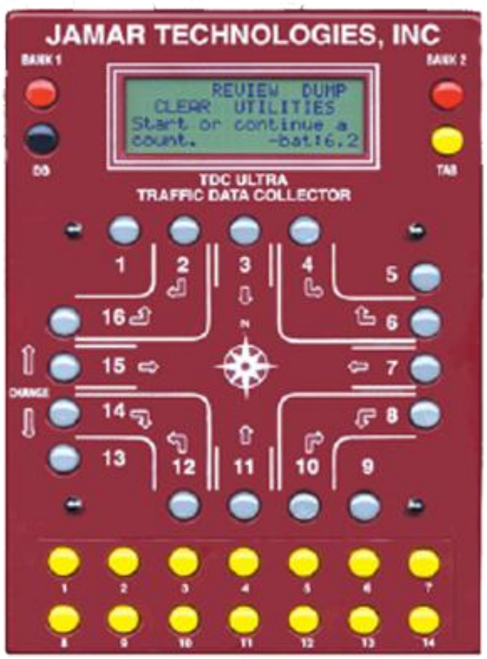


Figure 7: Turning movement counter (*Jamar TDC Ultra, 2017*)

2.6.3 Signal Warrant Analysis

The Manual on Uniform Traffic Control Devices (MUTCD) outlines several different ways that an intersection can warrant a traffic signal. One type of warrant is the volume of traffic received during an eight hour traffic count. If an intersection is receiving high numbers of vehicles during an eight hour period, it may benefit from having a signal installed. Another type of warrant would be the amount of traffic during the peak hour of the day. If the peak hour receives a high volume of vehicles, further investigation can be done to see if the intersection would benefit from a signal. A further type of warrant is the number of crashes at an intersection. If a certain number of crashes occur at an intersection and it is highly probable that these crashes could have been avoided if a signal had been in place, this can warrant a signal due to safety concerns. For the project intersection, data collection and analysis can confirm if any of the warrants outlined by MUTCD apply to the intersection (Pande, 2016).

2.6.4 Americans with Disabilities Act Compliance

The Americans With Disabilities Act (ADA) requires that developers provide access to locations for those with disabilities. This applies not only to buildings, but also to intersections, where geometric and control improvements should include improvements to ease of use for those with impaired movement or vision. Not providing appropriate accommodations can drastically limit a person’s access to amenities, and ultimately limit where those with disabilities can live. Most importantly with regards to intersection design, many sidewalks and crosswalks are not designed with those in wheelchairs or other mobility devices in min. This could encourage those with mobility devices to instead ride in the street, creating a safety hazard (*Curb Ramps and Pedestrian Crossings Under Title II of the ADA*).

Currently the intersection does not accommodate well for those with disabilities. Sidewalks are only available on one side of the road and are extremely narrow, which limits where people in wheelchairs can travel. The intersection lacks warnings for the visually impaired that are reaching the intersection. There are no pedestrian push buttons to signal designated times for people to safely cross the street and there are no indicators for cars to yield for pedestrians, which may make it more difficult for the elderly to cross. These are all things that can be addressed when designing improvements to the intersection.

2.6.5 Level-of-Service

Level-of-Service (LOS) is the quantitative measure of traffic congestion and delay. Taking into account the density of traffic at an intersection as well as the average delay experienced by a driver, the LOS can be calculated. The LOS is represented as a letter grade from A-F. An intersection that receives an “A” letter grade means that a driver experiences little delay while at an intersection. An intersection that receives an “F” letter grade means that a driver experiences maximum delays while travelling through an intersection. That are many ways into improve the LOS of an intersection. Perhaps the traffic light present is not timed correctly for the volume of traffic it receives in one direction and simply need to be retimed to accommodate the need (Pande, 2016).

2.6.6 Crash Rates & Reduction Factors

Crash rates are the crashes per vehicle mile travelled in a given area. It can be calculated with the following equation:

$$R_{sp} = \frac{\#\ of\ Collisions\ (per\ year)\ *\ 1{,}000{,}000}{ADT\ *\ 365\ Days}$$

The crash rate allows engineers to predict the number of crashes in the future.

A crash reduction factor (CRF) is the percentage of crash reductions anticipated after implementing new safety improvements to a location. These factors are provided by the Federal Highway Administration (FHA) and are calculated based on statistics reported to the FHA. Additionally, these factors are reviewed and modified frequently by the FHA to ensure that they are accurately depicting the improvements. If a change to an intersection would have a negative impact on the CRF this is also accounted for. For example, reducing the width of a shoulder is likely to increase the likelihood of a crash rather than cause a reduction in the percentages of crashes. Multiplying the crash reduction factor by the collision rate will allow a prediction of the collision rate after improvements are implemented (Pande, 2016).

3.0 Methodology

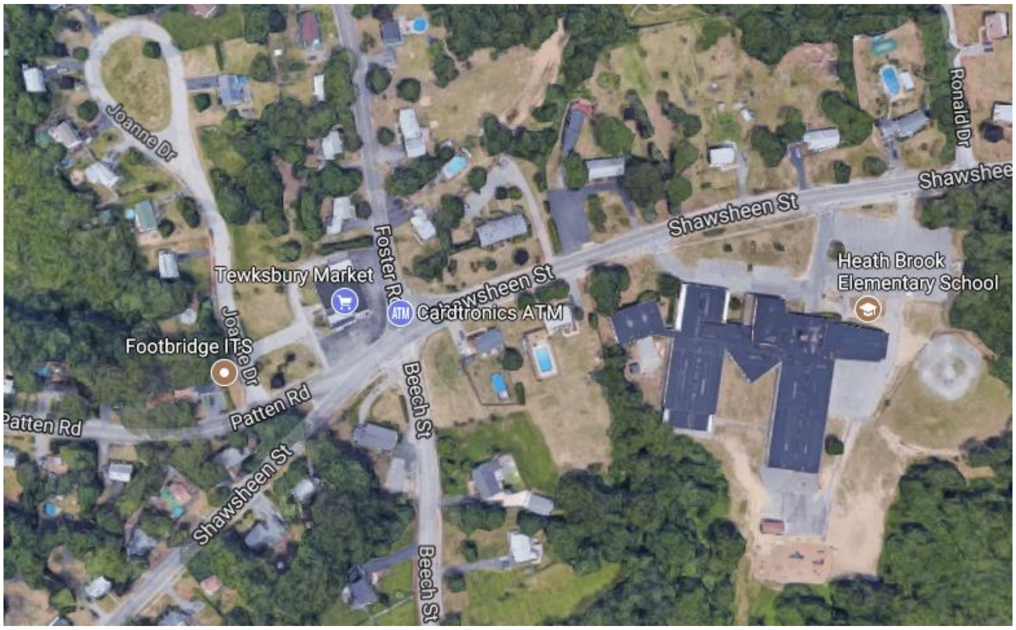


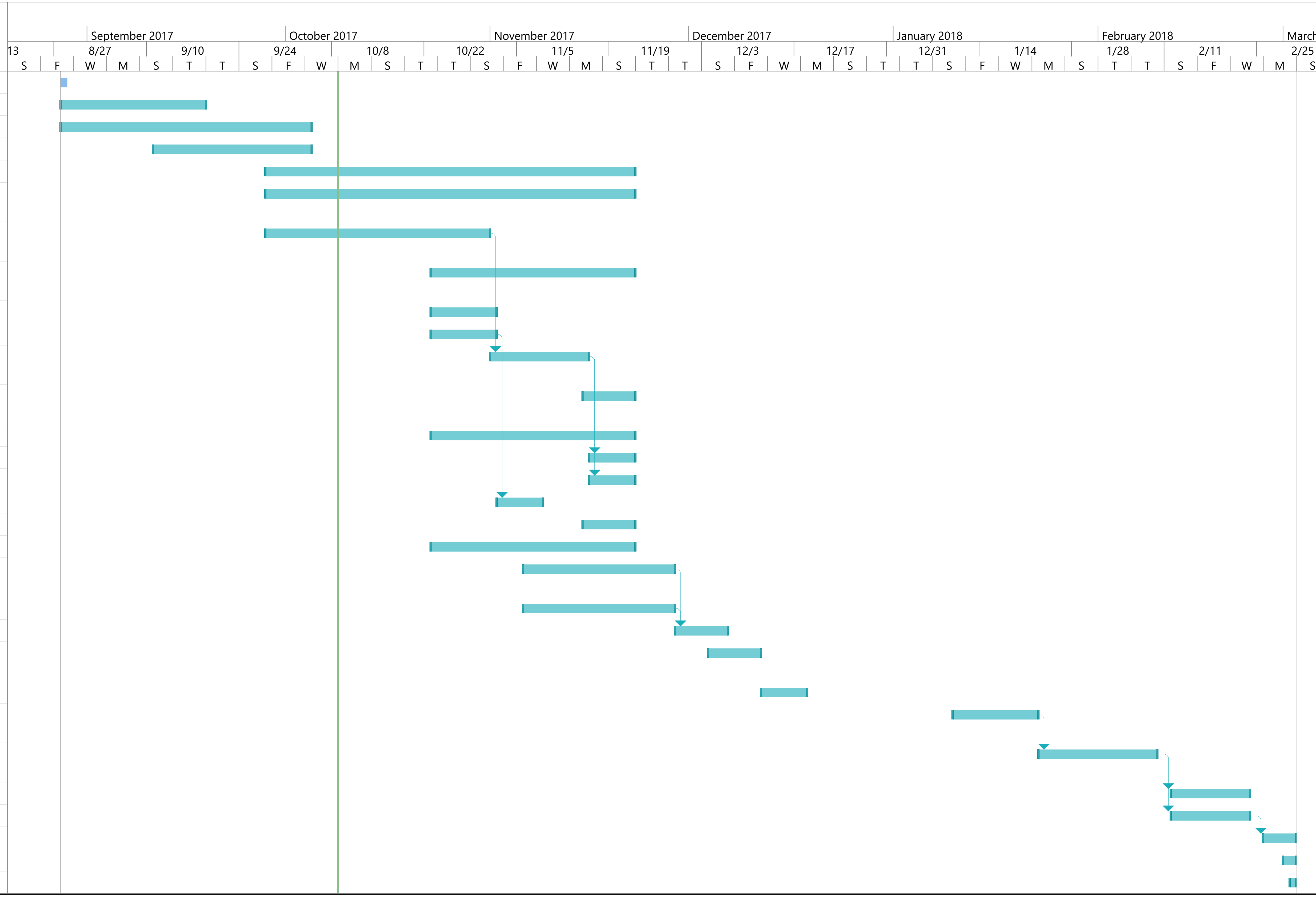
Figure 8: Google Maps Satellite Image of the intersection

The goal of this project is to improve the intersection of Shawsheen Street, Patten Road, Foster Road, and Beech Street in Tewksbury, MA based on the needs of the town. The team will use the following objectives in order to make recommendations for improvements:

- Collect data on existing intersection conditions
- Analyze data to determine problems in the intersection
- Create and model possible improvement options
- Assess each improvement option through an effectiveness and feasibility analysis
- Select preferred choice according to previous assessments and criteria provided by the town throughout the project
- Present and finish written report

These objectives will be accomplished according to the Gantt chart shown below. Throughout the duration of the project, the team will coordinate closely with the Town of Tewksbury to accomplish these objectives.

ID	Task Mode	Task Name	Duration	Start
1		Start	1 day	Mon 8/28/17
2		Project Statement	16 days	Mon 8/28/17
3		Background Research	28 days	Mon 8/28/17
4		Project Proposal	18 days	Mon 9/11/17
5		Compile Existing Data	40 days	Thu 9/28/17
6		Gather Available Crash Data	40 days	Thu 9/28/17
7		Collect Traffic Counts from NMCOG	24 days	Thu 9/28/17
8		Collect Necessary Additional Data	23 days	Mon 10/23/17
9		Interesection Survey	8 days	Mon 10/23/17
10		Sight Distances	8 days	Mon 10/23/17
11		Collect Turning Movement Data	11 days	Wed 11/1/17
12		Collect Crash Data (if necessary)	6 days	Wed 11/15/17
13		Data Analysis	23 days	Mon 10/23/17
14		Signal Warrants	5 days	Thu 11/16/17
15		Existing LOS	5 days	Thu 11/16/17
16		Stopping Sight Distances	5 days	Thu 11/2/17
17		Crash Analysis	6 days	Wed 11/15/17
18		Current ADA Compliance	23 days	Mon 10/23/17
19		Develop Preliminary Design	17 days	Mon 11/6/17
20		Cost Analysis	17 days	Mon 11/6/17
21		Evaluate Design Options	6 days	Wed 11/29/17
22		Revisit Background, Methodology	6 days	Mon 12/4/17
23		Design Presentation	5 days	Tue 12/12/17
24		Finalize Preferred Design	9 days	Wed 1/10/18
25		Recommendations and Conclusion	14 days	Tue 1/23/18
26		Final Revisions	10 days	Mon 2/12/18
27		Executive Summary	10 days	Mon 2/12/18
28		Final Project & Poster	5 days	Mon 2/26/18
29		Final Presentation	2 days	Thu 3/1/18
30		End	1 day	Fri 3/2/18



Project: Tewksbury MQP
Date: Mon 10/9/17

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			

3.1 Collect Data on Existing Intersection Conditions

Understanding the current conditions of the intersection will first allow the team to familiarize themselves with the problem at hand.

3.1.1 Compile Existing Data

The existing data will be gathered from a variety of sources. This includes public information from the MassDOT website in addition to already completed traffic counts for the intersection.

3.1.1.1 Town Concerns

To gain an understanding of context, and the general problems that Tewksbury has with this intersection, past complaints will be referenced, if available, from the town engineer. Looking at these complaints as a whole will allow specific problem areas to be identified qualitatively.

3.1.1.2 Gather Currently Available Crash Data

Crash data will be collected from the MassDOT crash database to assist in determining the safety issues associated with the current layout of the intersection. The crash database currently includes data from 2004 to 2014, with approximately forty crashes occurring at this intersection during this time frame. This data will later be reorganized into a crash diagram detailing crash participants, location within the intersection, and damage type. A crash rate will also be calculated using this data.

3.1.1.3 Collect traffic counts from NMCOG

The team will coordinate with the Northern Middlesex Council of Governments (NMCOG) to conduct traffic counts on this intersection. NMCOG is planning to conduct road tube counts on all five approaches into the intersection, and they will send the data to the team afterwards. First, road tubes can be used to count vehicle volume, determine weight class, as well as track speed. They can be used for 24-hour intervals for a full week to determine the peak hours of volume at the particular intersection as well as track the speed of vehicles at certain time.

3.1.2 Collect Necessary Additional Data

Additional data that is necessary to the project includes turning movement counts, survey data, and sight distances. If data cannot be collected from previously mentioned sources, the data will need to be further investigated or collected by the team.

3.1.2.1 Crash Data (if necessary)

If additional crash data is needed to determine common accident causes, the team will work with Tewksbury to request more recent crash reports from the Tewksbury Police Department for the intersection, which many not be available on MassDOT's database. This data will be used to supplement currently available crash data in the created tables.

3.1.2.2 Turning Movement

In making basic determinations into geometric or traffic design improvements for any intersection it is beneficial to perform turning movement counts. Turning movement counters will then be used to conduct peak hour counts, using the peak hours determined by NMCOG during the traffic count. These counts will be conducted by all four team members, as the team will divide into two groups, each group with a count board and pen and paper. The team will cover the intersection in two parts; one group located at the intersection of Patten Road and Shawsheen Street, the other group located at the intersection of Foster Road, Beech Street and Shawsheen Street. Each group will be located a safe distance away from the intersection likely sitting in a car or on the sidewalk parallel to the road. The team will also account for the vehicles turning in and out of the driveway of the local convenient store. It will account for the number of cars entering and exiting each road and will help detect the flow of traffic at a certain time of day. Data can be used to determine whether the peak hour volume through the intersection could warrant a traffic light. If not, it will still help assess the benefit of other changes.

3.1.2.3 Intersection Survey

In order to determine the elevation changes for each approach to the intersection, the team will conduct surveying work at the intersection. In terms of equipment, WPI owns leveling equipment while the Town of Tewksbury possesses a Total Station; both types of equipment can be used to record the elevation changes. The leveling approach requires two people: one to hold the measuring rod, and one to record the elevation using the leveling lens. However, the Total Station only requires one person to set up and operate: a base unit is mounted on a tripod and placed at a set location, and another unit is carried around in order to collect data at various locations. The elevation data collected will be used to create a contour map, which will then be used to determine how the various elevations impact the intersection's serviceability.

3.1.2.4 Sight Distances

As a part of the intersection survey, sight distances will be measured from each approach to the intersection. Traffic traveling the design speed should be able to recognize and react to the sight of the intersection or any intersection signage and control devices between the time that they see it and the time that they reach the intersection. To accomplish this, this project will measure sight distances using a measuring wheel from the stop bar of the intersection to the farthest point along the road, viewed from a height of three feet, at each intersection entrance.

3.2 Analyze Data to Determine Problems in the Intersection

Following data collection, the team will assess the data by calculating the Level-of-Service, determining to see if the peak hour volumes warrant the addition of a signal and will compile the crash data into diagrams to illustrate the different accidents and the correlation to the design of the intersection.

3.2.1 Signal Warrants

Data collected will be analyzed to see if the intersection warrants a signal. Turning movement counts from the peak morning and evening traffic will most likely be used to determine if a signal is necessary.

3.2.2 Existing Level-of-Service (LOS)

The existing LOS will be determined through Highway Capacity Software (HCS) by modeling the current geometric configuration of the intersection along will the results of the turning movement count performed by the team. The rating generated from the software, a letter from A to F, will show how the intersection is servicing the traffic flow it is receiving.

3.2.3 Stopping Sight Distances

Stopping sight distance is calculated by taking into account the time it takes for a driver to perceive and react to a stop and how far a car or truck travels while the brakes are being applied. Stopping distance while braking will be calculated with the following equation:

$$D_b = \frac{u^2}{2g(f \ \pm G)}$$

where u is the average travel speed, f is a friction force constant, and G is the grade of the approach, measured during the intersection survey. The team will calculate the stopping sight distances for the speed limit and compare it to the sight distances measured in the field. If the sight distances are smaller than the calculated stopping sight distance, then there is not enough time for the drivers to properly react.

3.2.4 Crash Analysis

Crash data will then be compiled and crash diagrams will be created to effectively display the location of each individual crash, as well as view the intersection in the context of the crashes as a whole. Crash diagrams will give an opportunity to visually assess the safety of the intersection. This will allow this team to determine problem areas in the intersection that have led to crashes, and the changes that can be implemented to reduce the number and severity of crashes. Qualitatively, by comparing the location of crashes with the types of crashes, specific problems with intersection geometry can be identified.

Quantitatively, the compilation and analysis of the crash data will allow the team to identify measures to be taken to improve intersection safety. Efforts can be taken to calculate a crash rate using the traffic data provided by NMCOG, and potential improvements in safety can be calculated through the crash reduction factor (CRF). Initial observations indicate that several geometric improvements may be beneficial to safety, and these will provide a starting point for assessment, but will by no means be the only options assessed. When developing potential improvement scenarios, these CRFs will allow each scenario to be compared by estimated crash rate when improvements are taken as a whole.

3.2.5 Current ADA Compliance

The current intersection will be analyzed for its ADA compliance. Intersections need to be accessible to pedestrians of all abilities. Examples of ADA compliance that would be noted are sidewalk width, integrated ramps, and percentage of slope.

3.3 Create and Model Alternatives

Based on the intersection analysis, the team will design several alternatives in order to address issues at the intersection. The first alternative will be the “no-build” option, where no major changes are implemented and the intersection continues to be maintained as it is currently. The primary objective of the “no-build” option is to serve as a baseline for the other options to be compared against; typical transportation projects do not select the “no-build” as the preferred alternative.

The team will develop several options that offer safety, geometric, and/or capacity improvements to the intersection. The team anticipates that these alternatives will focus more on geometric and safety improvements as opposed to capacity improvements, as an initial site visit established that geometry and sight distances are a greater concern than traffic capacity (see Appendix A). Preliminary design options include, but are not limited to:

- Replacing the intersection with a roundabout
- Realigning Patten Road to intersect Shawsheen Street at 90 degrees, farther west of the main Shawsheen Street/Beech Street/Foster Road 4-way intersection
- Reconfiguring Patten Road to be only one-way leading out of the intersection
- Excavating land so as to level Shawsheen Street on both approaches to the intersection
- Restrict the amount of curb cuts to better define access to the adjacent convenience store
- Altering the traffic control setup to either an all-way stop or a traffic signal

Once the team has determined which alternatives to pursue through cost consideration, time of construction, and complexity of the improvements, each alternative will be modeled using Automatic Computer-Aided Design 2016 and 2017 (AutoCAD) and Highway Capacity Software (HCS). To begin, a satellite view of the current intersection will be imported into CAD for use as an underlay. With this base in place, the team can lay the various models over existing intersection in CAD. This setup allows for immediate comparisons of each new design against the existing design for both geometry and land usage.

Each alternative will be assessed for its use of space. Ideally, any proposed improvements would be implemented within the existing right-of-way so that additional land does not have to be acquired. Land acquisition can be a lengthy process that can significantly delay and/or add cost to a project. In some cases, land acquisition may not be possible depending on the circumstances. Involvement of the Town of Tewksbury and local property owners, in particular ones that could be affected by right-of-way changes, will be especially important during this step.

3.4 Assess Effectiveness & Feasibility of Alternatives

The team will assess the effectiveness and feasibility of the modelled alternatives through analysis of the new Level-of-Service, cost, environmental impacts and crash reduction factors.

3.4.1 Level-of-Service

Additionally, the team will model both the existing intersection and each proposed intersection improvement alternative using Highway Capacity Software (HCS). Using traffic data previously collected, the team will analyze and determine the Level-of-Service (LOS) for each alternative. Initially the team will determine the LOS at the present before determining the LOS at multiple points in the future, using projected annual growth rates. Finally, each alternative will be evaluated for present and future operational serviceability. This step will utilize the intersection models created using HCS.

3.4.2 Cost Analysis

Once the design of each alternative is finalized, the team will prepare a cost estimate for each alternative. Each estimate will include all expected costs should the associated design move forward to construction. In order to construct estimates, the team will utilize a resource published by the Commonwealth of Massachusetts, titled “Consultants Estimating Manual” (Consultants Estimating Manual, 2006). Typically, cost estimates are constructed based on cost information from previous projects, and this data is usually compiled in large publications. Such compilations are typically available at both the state and municipal levels, and the team anticipates using both when preparing cost estimates.

After estimating the raw cost of each construction activity, the team will add estimates for markup factors such as contingency, labor, and overhead. These are typically computed as a percentage of the subtotal, or sum of each construction activity; for example, the contingency might be 10% of the subtotal. Once the markup factors have been computed, the final total will be determined for each of the design alternatives.

3.4.3 Preliminary Qualitative Environmental Review

Each alternative will also need to be evaluated for its environmental impact. While in the design phase, a full environmental impact statement would not yet be necessary. Instead, each alternative will have a preliminary analysis conducted. While a full environmental review would involve quantitative analysis, the team will utilize a simple qualitative analysis for each alternative. For example, if a traffic signal was added, there would be longer queue times on each approach, which would lead to higher pollution rates. Each analysis would be compared against each other in order to roughly determine which alternatives are either more or less harmful to the environment. Once a preferred alternative is selected for construction and the town moves forward with the project, then a full environmental impact review would be conducted.

3.5 Select Preferred Alternative

In order to select the preferred design alternative, each alternative must be evaluated and compared against each other.. A typical transportation project will assess each alternative for criteria such as:

- Estimated cost
- Right-of-way/land usage
- Present and future operational serviceability (for both safety and capacity)

After careful consideration of all factors, the alternative that best meets all of the criteria will be selected as the preferred alternative.

After preparing the cost estimate for each alternative as explained above, the estimates will be compared against each other as part of the evaluation. Generally speaking, a lower cost is preferred before considering other factors. However, a more expensive project may end up better meeting the other criteria, as long as the cost is still within reason. Additionally, state and federal funding can potentially be secured if certain project elements are included. Therefore, it is equally important to consider how efficiently potential funding sources are utilized as it is to consider the final monetary figure.

After considering each of these factors for each of the alternatives, the team will draw conclusions on the advantages and disadvantages of each design alternative. The team will also consider how each alternative addresses the criteria and constraints of the project. Ultimately, the team will be able to identify which alternative is the most feasible, and select it as the preferred design alternative.

3.6 Presentation of Findings

For the extent of this project, findings and preliminary alternatives will be shared with the town engineer and interested parties in the town of Tewksbury. By doing this, the town will have input into the discussion of the preferred alternative, and will be able to provide specific criteria to guide this project towards a solution that will best benefit the town’s residents. To share the preferred improvement scenario with Tewksbury, this team will develop a technical report and supporting materials. This report will include written findings and recommendations in addition to appendices with all intersection data and design models. In addition to the final report, the team will present findings to both the project advisor and the Town of Tewksbury. Finally, the team will prepare and present a poster for WPI’s annual Project Presentation Day.

Bibliography

Complete Streets Funding Program Guidance [Massachusetts Department of Transportation]. (2016). Retrieved September 20, 2017, from http://www.massdot.state.ma.us/Portals/8/docs/CompleteStreets/FundingProgramGuidance.pdf

Consultants Estimating Manual [Commonwealth of Massachusetts, Division of Capital Asset Management]. (2006). Retrieved October 1, 2017, from http://www.mass.gov/anf/docs/dcam/dlforms/cem-feb06.pdf

Curb Ramps and Pedestrian Crossings Under Title II of the ADA [United States Department of Justice]. (2007) Retrieved September 20, 2017 from https://www.ada.gov/pcatoolkit/chap6toolkit.htm

Jamar TDC Ultra [Northline Canada]. Retrieved October 7, 2017 from http://www.northlinecanada.com/Counters.aspx

Massachusetts Complete Streets Funding Program Participation [Massachusetts Department of Transportation]. (2017). Retrieved September 20, 2017, from https://masscompletestreets.com/Map/

Northampton Complete Streets Prioritization Plan [Massachusetts Department of Transportation]. (2016). Retrieved September 20, 2017 from https://masscompletestreets.com/PublicDownload.ashx?aWQ9MjgyJnRpZXJJZD0y

Northern Middlesex Regional Transportation Improvement Program: Federal Fiscal Years 2018-2022 [Northern Middlesex Council of Governments]. (2017). Retrieved September 20, 2017, from http://www.nmcog.org/Websites/nmcog/images/TIP/NMMPO%20FFY%202018-2022%20TIP%20Endorsed%2052417.pdf

Pande, Anurag. (2016). Traffic Engineering Handbook, Institute of Transportation Engineers.

Project Development and Design [Massachusetts Highway Department]. (2006). Retrieved October 1, 2017, from http://www.massdot.state.ma.us/highway/DoingBusinessWithUs/ManualsPublicationsForms/ProjectDevelopmentDesignGuide.aspx

State Transportation Improvement Program [Massachusetts Department of Transportation]. (2016). Retrieved September 20, 2017, from http://www.massdot.state.ma.us/Portals/17/docs/STIP/STIP17-21_Final.pdf

Transportation Safety Planning [U.S Department of Transportation, FHWA]. (2015). Retrieved October 7, 2017, from https://safety.fhwa.dot.gov/tsp/fhwasa15089/chap5.cfm#fig512

APPENDIX A - Site Visit 1 Report

Site Visit 1
Tewksbury MQP

Attendees: Craig Barrett, Vanessa Beutel, James Macfarlane, Patrick Murphy, Suzanne LePage (Advisor), Kevin Hardiman (Sponsor)
Date: Sept. 11, 2017

Town Information

1. Are there more recent zoning maps for Tewksbury other than the file posted on the town website? (2015)
    a. How often are the zoning maps updated?
        i. Use the 2015 one, nothing has changed in this intersection
2. Do many children take the bus or private cars?
        i. Yes, almost all of the children
    b. Do children walk to/from the school?
        i. No students walk to school, no crossing guards in the entire town, children either dropped off by cars or bus.
    c. Speed limit
        i. Posted in the 1970's to be 40 mph - this is probably too fast, trying to get it lowered to 35 mph
        ii. Incorrectly posted for years, huge lawsuit for the town
3. What guidelines are generally followed during construction in Tewksbury?
        i. A lot of private developments, zoning encourages development, community likes to see it.
        ii. A lot of construction in general.
        iii. Sidewalks are something the town likes to see.
        iv. Trying to move towards "Complete Streets".

Intersection History

4. Why does Tewksbury believe this intersection should be remodelled?
        i. People complain about it a lot, within the last 3 weeks actually.
        ii. Orientation and site lines are no good and the community knows it.
5. Does the community consider this a "dangerous" intersection?
    a. Are there car crashes at this intersection?
        i. Have to get that information from the police, Kevin can forward that report to us.
        ii. We have traffic counters at WPI.
6. When was the last traffic count conducted?
    a. Where is this information stored?
        i. NMCG - they do the traffic counts.
        ii. But there isn't one for this intersection.
7. When was the last time the intersection was significantly altered/modified?

        i. Town maintain stop signs, otherwise untouched.
    b. When was the flashing light put in place?
        i. Many years.
8. In general, what kind of traffic does the intersection experience? Heavy, moderate, etc.
    a. What time(s) of the day are the busiest at the intersection?
        i. In the morning, traffic from Lowell. Drivers take Whipple to Patton to Shawsheen driving east. People avoid Main Street by taking Chandler to Foster to Shawsheen. Main Street has a lot of traffic, people try to avoid the lights. Foster is a pretty busy road. Beech street is a dead end, limited traffic besides during the morning and night for local residents. Convenience store has not great parking, no curb cuts, people just pull in. River Street and Bridal Road in Billerica, MA. Very similar intersection. The landowner might not be happy about this.
        ii. Sightline issues going from east to west.
        iii. No restrictions for heavy trucks
    b. Is there a lot of turning traffic? Yes, Patten east onto Shawsheen east and Foster south onto Shawsheen east
    c. Is most traffic local or is there a significant amount of thru traffic? People going to Dunkin for their coffee in the morning
    d. Is there noticeable pedestrian traffic at the intersection?
9. What types of vehicles generally pass through the intersection? (Mostly cars, noticeable amount of trucks/heavy vehicles, school buses, etc.)
    a. School busses, potentially trucks
    b. One of the corners of the main 4-way intersection appears to be extra wide, suggesting trucks turning? Not intentionally designed that way

Project Logistics

10. Are there any kind of budget constraints for this remodel?
        i. There are none
    b. Who would fund any potential improvements?
        i. TIP, Complete Streets, town funds
11. What are the technology limitations for the intersection?
    a. Could signals be synced or coordinated with other intersections to improve throughput?
    b. Could sensors be used on the least busy roads?
12. What timeframe would you like construction completed in? (could impact scale of the redesign along with cost)
13. Do you have a preference for or access to traffic modelling software?

Additional Notes:

- They’d love to see a roundabout if it can fit
    - Or make Patten Street one way.

- Or realign Patten to intersect Shawsheen at 90 degrees, farther west from Beech/Foster
    - Example, Main Street and Astle
- No roundabouts in town, currently designing one
- Visioning session with town
    - They really want sidewalks
- MassDOT TIP - funding from state means they have to follow state guidelines
- UMass transportation program (like one day) Baystate Roads Class (look up)
- Complete Streets Community, have to send to MassDOT by end of the year
    - Look into program
    - Offers money to towns for construction
- Look into school bus routes and pickup/drop off timing

Appendix B: Site Visit Reports

Site Visit 1

Tewksbury MQP

Attendees: Craig Barrett, Vanessa Beutel, James Macfarlane, Patrick Murphy, Suzanne LePage (Advisor), Kevin Hardiman (Sponsor)

Date: Sept. 11, 2017

Town Information

1) Are there more recent zoning maps for Tewksbury other than the file posted on the town website? (2015)
2) How often are the zoning maps updated?
   a) Use the 2015 one, nothing has changed in this intersection
3) Do many children take the bus or private cars? Yes, almost all of the children
4) Do children walk to/from the school?
   (a) No students walk to school, no crossing guards in the entire town, children either dropped off by cars or bus.
5) Speed limit
   (a) Posted in the 1970's to be 40 mph - this is probably too fast, trying to get it lowered to 35 mph. Incorrectly posted for years, huge lawsuit for the town
6) What guidelines are generally followed during construction in Tewksbury?
   (a) A lot of private developments, zoning encourages development, community likes to see it.
   (b) A lot of construction in general.
   (c) Sidewalks are something the town likes to see.
   (d) Trying to move towards "Complete Streets".

Intersection History

7) Why does Tewksbury believe this intersection should be remodelled?
   (a) People complain about it a lot, within the last 3 weeks actually.

(b) Orientation and site lines are no good and the community knows it.

8) Does the community consider this a "dangerous" intersection?

. Are there car crashes at this intersection?

(a) Have to get that information from the police, Kevin can forward that report to us.

(b) We have traffic counters at WPI.

9) When was the last traffic count conducted?

(a) Where is this information stored?

(b) NMCG - they do the traffic counts. But there isn't one for this intersection.

(c) When was the last time the intersection was significantly altered/modified? Town maintain stop signs, otherwise untouched.

(d) When was the flashing light put in place? Many years.

10) In general, what kind of traffic does the intersection experience? Heavy, moderate, etc.

(a) What time(s) of the day are the busiest at the intersection? In the morning, traffic from Lowell. Drivers take Whipple to Patton to Shawsheen driving east. People avoid Main Street by taking Chandler to Foster to Shawsheen. Main Street has a lot of traffic, people try to avoid the lights. Foster is a pretty busy road. Beech street is a dead end, limited traffic besides during the morning and night for local residents. Convenience store has not great parking, no curb cuts, people just pull in. River Street and Bridal Road in Billerica, MA. Very similar intersection. The landowner might not be happy about this. Sightline issues going from east to west. No restrictions for heavy trucks

11) Is there a lot of turning traffic? Yes, Patten east onto Shawsheen east and Foster south onto Shawsheen east

(a) Is most traffic local or is there a significant amount of thru traffic? People going to Dunkin for their coffee in the morning

(b) Is there noticeable pedestrian traffic at the intersection?

(c) What types of vehicles generally pass through the intersection? (Mostly cars, noticeable amount of trucks/heavy vehicles, school buses, etc.) School busses, potentially trucks

(d) One of the corners of the main 4-way intersection appears to be extra wide, suggesting trucks turning? Not intentionally designed that way

Project Logistics

12) Are there any kind of budget constraints for this remodel? There are none
13) Who would fund any potential improvements?
    (a) TIP, Complete Streets, town funds
14) What are the technology limitations for the intersection?
15) Could signals be synced or coordinated with other intersections to improve throughput? Could sensors be used on the least busy roads?
16) What timeframe would you like construction completed in? (could impact scale of the redesign along with cost)
17) Do you have a preference for or access to traffic modelling software?

Additional Notes:

- They'd love to see a roundabout if it can fit
- Or make Patten Road one way.
- Or realign Patten Road to intersect Shawsheen Street at 90 degrees, farther west from Beech Street/Foster Road
- Example, Main street, and Astle
- No roundabouts in town, currently designing one
- Visioning session with town
    - They really want sidewalks
- MassDOT TIP - funding from state means they have to follow state guidelines
- UMass transportation program (like one day) Baystate Roads Class (look up)
- Complete Streets Community, have to send to MassDOT by end of the year
    - Look into
    - Offers money to towns for construction
- Look into Bus routes and timings

Appendix C: NMCOG Traffic Counts

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00   AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR LANE 1   Page: 1
Starting: 9/25/2017

Site Reference: Rd Class U5
Site ID: 000000007789
Location: Andover Rd west of Whipple Rd
Direction: EAST

File: AndoverWwhipple.prn
City: Billerica
County: 986-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		6	9	10	14	10			10	39
02:00		3	4	5	5	4			4	17
03:00		4	8	6	6	6			6	24
04:00		6	5	2	4	4			4	17
05:00		14	12	19	15	15			15	60
06:00		52	58	56	57	56			56	223
07:00		127	133	146	120	132			132	526
08:00		198	209	190	197	198			198	794
09:00		157	185	190	142	168			168	674
10:00		116	137	139	127	130			130	519
11:00	84	109	112	96	117	104			104	518
12:00	122	120	109	131		120			120	482
13:00	145	139	140	121		136			136	545
14:00	133	133	158	151		144			144	575
15:00	207	196	209	199		203			203	811
16:00	270	268	295	305		284			284	1138
17:00	371	337	451	479		410			410	1638
18:00	402	437	488	523		462			462	1850
19:00	293	336	329	304		316			316	1262
20:00	118	165	152	164		150			150	599
21:00	80	120	110	115		106			106	425
22:00	60	81	68	81		72			72	290
23:00	43	31	47	44		41			41	165
24:00	19	21	20	29		22			22	89
TOTALS	2347	3176	3448	3505	804	3293			3293	13280
% AVG WKDY	71.3	96.4	104.7	106.4	24.4					
% AVG WEEK	71.3	96.4	104.7	106.4	24.4					
AM Times	12:00	08:00	08:00	08:00	08:00	08:00			08:00	
AM Peaks	122	198	209	190	197	198			198	
PM Times	18:00	18:00	18:00	18:00		18:00			18:00	
PM Peaks	402	437	488	523		462			462	

Site Reference: Rd Class U5
Site ID: 000000007789
Location: Andover Rd west of Whipple Rd
Direction: WEST

File: AndoverWwhipple.prn
City: Billerica
County: 986-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		7	11	10	11	10			10	39
02:00		5	3	6	3	4			4	17
03:00		5	7	10	7	7			7	29
04:00		6	10	5	8	7			7	29
05:00		24	28	14	18	21			21	84
06:00		75	64	96	67	76			76	302
07:00		289	283	451	235	314			314	1258
08:00		467	457	488	371	446			446	1783
09:00		371	470	430	303	394			394	1574
10:00		179	211	188	154	183			183	732
11:00	120	120	132	130	122	125			125	624
12:00	120	95	117	153		121			121	485
13:00	141	120	118	140		130			130	519
14:00	138	135	146	141		140			140	560
15:00	163	154	165	167		162			162	649
16:00	176	221	196	241		208			208	834
17:00	239	260	212	230		235			235	941
18:00	302	309	242	243		274			274	1096
19:00	198	195	211	213		204			204	817
20:00	144	148	144	149		146			146	585
21:00	91	113	111	91		102			102	406
22:00	53	78	76	82		72			72	289
23:00	52	41	40	39		43			43	172
24:00	16	23	22	23		21			21	84
TOTALS	1953	3440	3476	3740	1299	3445			3445	13908
% AVG WKDY	56.7	99.9	100.9	108.6	37.7					
% AVG WEEK	56.7	99.9	100.9	108.6	37.7					
AM Times	11:00	08:00	09:00	08:00	08:00	08:00			08:00	
AM Peaks	120	467	470	488	371	446			446	
PM Times	18:00	18:00	18:00	18:00		18:00			18:00	
PM Peaks	302	309	242	243		274			274	

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00 AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR ALL LANES

Starting: 9/25/2017

Site Reference: Rd Class U5
Site ID: 000000007789
Location: Andover Rd west of Whipple Rd
Direction: ROAD TOTAL

File: AndoverWwhipple.prn
City: Billerica
County: 986-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		13	20	20	25	20			20	78
02:00		8	7	11	8	8			8	34
03:00		9	15	16	13	13			13	53
04:00		12	15	7	12	12			12	46
05:00		38	40	33	33	36			36	144
06:00		127	122	152	124	131			131	525
07:00		416	416	597	355	446			446	1784
08:00		665	666	678	568	644			644	2577
09:00		528	655	620	445	562			562	2248
10:00		295	348	327	281	313			313	1251
11:00	204	229	244	226	239	228			228	1142
12:00	242	215	226	284		242			242	967
13:00	286	259	258	261		266			266	1064
14:00	271	268	304	292		284			284	1135
15:00	370	350	374	366		365			365	1460
16:00	446	489	491	546		493			493	1972
17:00	610	597	663	709		645			645	2579
18:00	704	746	730	766		736			736	2946
19:00	491	531	540	517		520			520	2079
20:00	262	313	296	313		296			296	1184
21:00	171	233	221	206		208			208	831
22:00	113	159	144	163		145			145	579
23:00	95	72	87	83		84			84	337
24:00	35	44	42	52		43			43	173
TOTALS	4300	6616	6924	7245	2103	6740			6740	27188
% AVG WKDY	63.8	98.2	102.7	107.5	31.2					
% AVG WEEK	63.8	98.2	102.7	107.5	31.2					
AM Times	12:00	08:00	08:00	08:00	08:00	08:00			08:00	
AM Peaks	242	665	666	678	568	644			644	
PM Times	18:00	18:00	18:00	18:00		18:00			18:00	
PM Peaks	704	746	730	766		736			736	

Wkday AADT(Factored & Rounded)= 6700
Week AADT(Factored & Rounded)= 6700

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00 AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR LANE 1
Starting: 9/25/2017

Site Reference: Rd Class U5
Site ID: 000000013257
Location: Shawsheen St east of Whipple Rd
Direction: EAST

File: hawsheenEwhipple.prn
City: Billerica
County: 988-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		2	3	5	4	4			4	14
02:00		7	8	6	6	7			7	27
03:00		4	3	0	3	2			2	10
04:00		18	15	18	17	17			17	68
05:00		55	58	80	67	65			65	260
06:00		144	139	279	119	170			170	681
07:00		195	193	183	180	188			188	751
08:00		177	192	189	180	184			184	738
09:00		127	137	135	129	132			132	528
10:00		111	113	106		110			110	330
11:00		132	136	155		141			141	423
12:00	141	132	133	130		134			134	536
13:00	145	126	148	139		140			140	558
14:00	198	202	200	203		201			201	803
15:00	252	254	282	280		267			267	1068
16:00	370	321	418	425		384			384	1534
17:00	361	387	448	444		410			410	1640
18:00	295	312	328	312		312			312	1247
19:00	131	169	157	173		158			158	630
20:00	85	108	112	98		101			101	403
21:00	59	76	64	81		70			70	280
22:00	40	31	38	43		38			38	152
23:00	18	17	20	36		23			23	91
24:00	7	11	7	14		10			10	39
TOTALS	2102	3118	3352	3534	705	3268			3268	12811
% AVG WKDY	64.3	95.4	102.6	108.1	21.6					
% AVG WEEK	64.3	95.4	102.6	108.1	21.6					
AM Times	12:00	07:00	07:00	06:00	07:00	07:00			07:00	
AM Peaks	141	195	193	279	180	188			188	
PM Times	16:00	17:00	17:00	17:00		17:00			17:00	
PM Peaks	370	387	448	444		410			410	

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00 AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR LANE 2
Starting: 9/25/2017

Site Reference: Rd Class U5
Site ID: 000000013257
Location: Shawsheen St east of Whipple Rd
Direction: WEST

File: hawsheenEwhipple.prn
City: Billerica
County: 988-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		4	4	6	4	4			4	18
02:00		3	5	11	6	6			6	25
03:00		5	5	4	6	5			5	20
04:00		22	21	15	17	19			19	75
05:00		68	62	75	62	67			67	267
06:00		284	274	292	219	267			267	1069
07:00		469	465	499	367	450			450	1800
08:00		358	444	408	267	369			369	1477
09:00		173	192	185	146	174			174	696
10:00		121	128	123		124			124	372
11:00		97	114	154		122			122	365
12:00	136	125	141	148		138			138	550
13:00	123	152	120	147		136			136	542
14:00	168	169	174	184		174			174	695
15:00	186	225	194	231		209			209	836
16:00	238	260	219	261		244			244	978
17:00	292	311	262	257		280			280	1122
18:00	176	202	199	201		194			194	778
19:00	148	138	139	139		141			141	564
20:00	100	122	97	99		104			104	418
21:00	58	73	86	85		76			76	302
22:00	48	37	37	42		41			41	164
23:00	17	25	29	25		24			24	96
24:00	10	10	11	9		10			10	40
TOTALS	1700	3453	3422	3600	1094	3378			3378	13269
% AVG WKDY	50.3	102.2	101.3	106.6	32.4					
% AVG WEEK	50.3	102.2	101.3	106.6	32.4					
AM Times	12:00	07:00	07:00	07:00	07:00	07:00			07:00	
AM Peaks	136	469	465	499	367	450			450	
PM Times	17:00	17:00	17:00	16:00		17:00			17:00	
PM Peaks	292	311	262	261		280			280	

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00   AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR ALL LANES
Starting: 9/25/2017

Site Reference: Rd Class U5
Site ID: 000000013257
Location: Shawsheen St east of Whipple Rd
Direction: ROAD TOTAL

File: hawsheenEwhipple.prn
City: Billerica
County: 988-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		6	7	11	8	8			8	32
02:00		10	13	17	12	13			13	52
03:00		9	8	4	9	8			8	30
04:00		40	36	33	34	36			36	143
05:00		123	120	155	129	132			132	527
06:00		428	413	571	338	438			438	1750
07:00		664	658	682	547	638			638	2551
08:00		535	636	597	447	554			554	2215
09:00		300	329	320	275	306			306	1224
10:00		232	241	229		234			234	702
11:00		229	250	309		263			263	788
12:00	277	257	274	278		272			272	1086
13:00	268	278	268	286		275			275	1100
14:00	366	371	374	387		374			374	1498
15:00	438	479	476	511		476			476	1904
16:00	608	581	637	686		628			628	2512
17:00	653	698	710	701		690			690	2762
18:00	471	514	527	513		506			506	2025
19:00	279	307	296	312		298			298	1194
20:00	185	230	209	197		205			205	821
21:00	117	149	150	166		146			146	582
22:00	88	68	75	85		79			79	316
23:00	35	42	49	61		47			47	187
24:00	17	21	18	23		20			20	79
TOTALS	3802	6571	6774	7134	1799	6646			6646	26080
% AVG WKDY	57.2	98.9	101.9	107.3	27.1					
% AVG WEEK	57.2	98.9	101.9	107.3	27.1					
AM Times	12:00	07:00	07:00	07:00	07:00	07:00			07:00	
AM Peaks	277	664	658	682	547	638			638	
PM Times	17:00	17:00	17:00	17:00		17:00			17:00	
PM Peaks	653	698	710	701		690			690	

Wkday AADT(Factored & Rounded)= 6600
Week AADT(Factored & Rounded)= 6600

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00   AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR LANE 1
Starting: 9/25/2017

Site Reference: Rd Class U6
Site ID: 000000007788
Location: Whipple RD North of Shawsheen
Direction: NORTH

File: hippleNshawsheen.prn
City: Billerica
County: 989-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		12	12	9	17	12			12	50
02:00		8	6	9	10	8			8	33
03:00		9	12	8	12	10			10	41
04:00		4	7	6	9	6			6	26
05:00		10	8	13	11	10			10	42
06:00		34	37	19	35	31			31	125
07:00		137	122	87	107	113			113	453
08:00		203	219	184	172	194			194	778
09:00		134	130	127	116	127			127	507
10:00		102	127	98	98	106			106	425
11:00		109	102	104		105			105	315
12:00		86	98	98		94			94	282
13:00	94	110	128	101		108			108	433
14:00	100	128	126	120		118			118	474
15:00	209	204	216	217		212			212	846
16:00	296	282	364	396		334			334	1338
17:00	334	330	359	370		348			348	1393
18:00	321	322	338	328		327			327	1309
19:00	214	284	292	263		263			263	1053
20:00	115	144	138	131		132			132	528
21:00	69	81	92	99		85			85	341
22:00	55	47	66	69		59			59	237
23:00	34	34	35	40		36			36	143
24:00	27	20	33	18		24			24	98
TOTALS	1868	2834	3067	2914	587	2862			2862	11270
% AVG WKDY	65.3	99.0	107.2	101.8	20.5					
% AVG WEEK	65.3	99.0	107.2	101.8	20.5					
AM Times		08:00	08:00	08:00	08:00	08:00			08:00	
AM Peaks		203	219	184	172	194			194	
PM Times	17:00	17:00	16:00	16:00		17:00			17:00	
PM Peaks	334	330	364	396		348			348	

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00 AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR LANE 2
Starting: 9/25/2017

Site Reference: Rd Class U6
Site ID: 000000007788
Location: Whipple RD North of Shawsheen
Direction: SOUTH

File: hippleNshawsheen.prn
City: Billerica
County: 989-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		10	9	15	9	11			11	43
02:00		6	2	2	2	3			3	12
03:00		7	11	8	6	8			8	32
04:00		9	8	12	12	10			10	41
05:00		21	29	28	23	25			25	101
06:00		130	121	125	113	122			122	489
07:00		364	382	317	341	351			351	1404
08:00		349	328	345	302	331			331	1324
09:00		316	272	282	252	280			280	1122
10:00		150	152	152	111	141			141	565
11:00		103	110	120		111			111	333
12:00		95	98	114		102			102	307
13:00	115	102	121	121		115			115	459
14:00	140	129	137	123		132			132	529
15:00	146	161	160	177		161			161	644
16:00	198	218	238	214		217			217	868
17:00	183	183	178	191		184			184	735
18:00	223	226	235	249		233			233	933
19:00	144	160	197	172		168			168	673
20:00	99	96	95	107		99			99	397
21:00	51	84	75	82		73			73	292
22:00	49	52	52	65		54			54	218
23:00	24	40	35	29		32			32	128
24:00	22	28	25	31		26			26	106
TOTALS	1394	3039	3070	3081	1171	2989			2989	11755
% AVG WKDY	46.6	101.7	102.7	103.1	39.2					
% AVG WEEK	46.6	101.7	102.7	103.1	39.2					
AM Times		07:00	07:00	08:00	07:00	07:00			07:00	
AM Peaks		364	382	345	341	351			351	
PM Times	18:00	18:00	16:00	18:00		18:00			18:00	
PM Peaks	223	226	238	249		233			233	

Site Reference: Rd Class U6
Site ID: 000000007788
Location: Whipple RD North of Shawsheen
Direction: ROAD TOTAL

File: hippleNshawsheen.prn
City: Billerica
County: 989-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		22	21	24	26	23			23	93
02:00		14	8	11	12	11			11	45
03:00		16	23	16	18	18			18	73
04:00		13	15	18	21	17			17	67
05:00		31	37	41	34	36			36	143
06:00		164	158	144	148	154			154	614
07:00		501	504	404	448	464			464	1857
08:00		552	547	529	474	526			526	2102
09:00		450	402	409	368	407			407	1629
10:00		252	279	250	209	248			248	990
11:00		212	212	224		216			216	648
12:00		181	196	212		196			196	589
13:00	209	212	249	222		223			223	892
14:00	240	257	263	243		251			251	1003
15:00	355	365	376	394		372			372	1490
16:00	494	500	602	610		552			552	2206
17:00	517	513	537	561		532			532	2128
18:00	544	548	573	577		560			560	2242
19:00	358	444	489	435		432			432	1726
20:00	214	240	233	238		231			231	925
21:00	120	165	167	181		158			158	633
22:00	104	99	118	134		114			114	455
23:00	58	74	70	69		68			68	271
24:00	49	48	58	49		51			51	204
TOTALS	3262	5873	6137	5995	1758	5860			5860	23025
% AVG WKDY	55.7	100.2	104.7	102.3	30.0					
% AVG WEEK	55.7	100.2	104.7	102.3	30.0					
AM Times		08:00	08:00	08:00	08:00	08:00			08:00	
AM Peaks		552	547	529	474	526			526	
PM Times	18:00	18:00	16:00	16:00		18:00			18:00	
PM Peaks	544	548	602	610		560			560	

Wkday AADT(Factored & Rounded)= 5900
Week AADT(Factored & Rounded)= 5900

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00 AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR LANE 1
Starting: 9/25/2017

Site Reference: Rd Class U6
Site ID: 000000007584
Location: Whipple Rd south of Shawsheen
Direction: NORTH

File: hippleSshawsheen.prn
City: Billerica
County: 987-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		8	6	9	10	8			8	33
02:00		10	13	7	14	11			11	44
03:00		4	7	7	9	7			7	27
04:00		18	21	14	18	18			18	71
05:00		61	52	56	52	55			55	221
06:00		145	158	142	144	147			147	589
07:00		240	224	215	215	224			224	894
08:00		193	202	194	192	195			195	781
09:00		144	156	128	134	140			140	562
10:00		131	128	144		134			134	403
11:00	89	117	137	145		122			122	488
12:00	129	145	166	136		144			144	576
13:00	138	146	146	156		146			146	586
14:00	232	252	256	273		253			253	1013
15:00	340	338	381	397		364			364	1456
16:00	370	389	372	339		368			368	1470
17:00	308	333	339	298		320			320	1278
18:00	275	314	296	314		300			300	1199
19:00	157	186	168	181		173			173	692
20:00	86	106	124	115		108			108	431
21:00	65	64	77	84		72			72	290
22:00	40	45	40	52		44			44	177
23:00	32	22	34	24		28			28	112
24:00	12	14	10	22		14			14	58
TOTALS	2273	3425	3513	3452	788	3395			3395	13451
% AVG WKDY	67.0	100.9	103.5	101.7	23.2					
% AVG WEEK	67.0	100.9	103.5	101.7	23.2					
AM Times	12:00	07:00	07:00	07:00	07:00	07:00			07:00	
AM Peaks	129	240	224	215	215	224			224	
PM Times	16:00	16:00	15:00	15:00		16:00			16:00	
PM Peaks	370	389	381	397		368			368	

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00 AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR LANE 2

Starting: 9/25/2017

Site Reference: Rd Class U6
Site ID: 000000007584
Location: Whipple Rd south of Shawsheen
Direction: SOUTH

File: hippleSshawsheen.prn
City: Billerica
County: 987-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		6	4	4	4	4			4	18
02:00		3	10	8	7	7			7	28
03:00		10	5	12	12	10			10	39
04:00		24	29	29	23	26			26	105
05:00		138	126	126	122	128			128	512
06:00		406	406	411	350	393			393	1573
07:00		438	428	470	352	422			422	1688
08:00		382	324	337	254	324			324	1297
09:00		162	176	171	129	160			160	638
10:00		122	124	144		130			130	390
11:00	110	116	119	145		122			122	490
12:00	137	124	161	148		142			142	570
13:00	151	150	136	156		148			148	593
14:00	191	181	186	208		192			192	766
15:00	242	260	252	228		246			246	982
16:00	220	208	206	206		210			210	840
17:00	273	262	264	267		266			266	1066
18:00	173	189	240	215		204			204	817
19:00	119	132	126	138		129			129	515
20:00	80	124	87	122		103			103	413
21:00	69	72	80	80		75			75	301
22:00	32	52	41	43		42			42	168
23:00	28	39	35	34		34			34	136
24:00	13	8	17	13		13			13	51
TOTALS	1838	3608	3582	3715	1253	3530			3530	13996
% AVG WKDY	52.1	102.2	101.5	105.2	35.5					
% AVG WEEK	52.1	102.2	101.5	105.2	35.5					
AM Times	12:00	07:00	07:00	07:00	07:00	07:00			07:00	
AM Peaks	137	438	428	470	352	422			422	
PM Times	17:00	17:00	17:00	17:00		17:00			17:00	
PM Peaks	273	262	264	267		266			266	

Northern Middlesex Council of Governments
FACTORS = SEASONAL: 1.00 AXLE CORRECTION: 1.00
WEEKLY SUMMARY FOR ALL LANES
Starting: 9/25/2017

Site Reference: Rd Class U6
Site ID: 000000007584
Location: Whipple Rd south of Shawsheen
Direction: ROAD TOTAL

File: hippleSshawsheen.prn
City: Billerica
County: 987-2017

TIME	MON 25	TUE 26	WED 27	THU 28	FRI 29	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		14	10	13	14	13			13	51
02:00		13	23	15	21	18			18	72
03:00		14	12	19	21	16			16	66
04:00		42	50	43	41	44			44	176
05:00		199	178	182	174	183			183	733
06:00		551	564	553	494	540			540	2162
07:00		678	652	685	567	646			646	2582
08:00		575	526	531	446	520			520	2078
09:00		306	332	299	263	300			300	1200
10:00		253	252	288		264			264	793
11:00	199	233	256	290		244			244	978
12:00	266	269	327	284		286			286	1146
13:00	289	296	282	312		295			295	1179
14:00	423	433	442	481		445			445	1779
15:00	582	598	633	625		610			610	2438
16:00	590	597	578	545		578			578	2310
17:00	581	595	603	565		586			586	2344
18:00	448	503	536	529		504			504	2016
19:00	276	318	294	319		302			302	1207
20:00	166	230	211	237		211			211	844
21:00	134	136	157	164		148			148	591
22:00	72	97	81	95		86			86	345
23:00	60	61	69	58		62			62	248
24:00	25	22	27	35		27			27	109
TOTALS	4111	7033	7095	7167	2041	6928			6928	27447
% AVG WKDY	59.3	101.5	102.4	103.4	29.5					
% AVG WEEK	59.3	101.5	102.4	103.4	29.5					
AM Times	12:00	07:00	07:00	07:00	07:00	07:00			07:00	
AM Peaks	266	678	652	685	567	646			646	
PM Times	16:00	15:00	15:00	15:00		15:00			15:00	
PM Peaks	590	598	633	625		610			610	

Wkday AADT(Factored & Rounded)= 6900
Week AADT(Factored & Rounded)= 6900

Appendix D: Turning Movement Count Data

		Shawsheen/Beech/Foster				11/7										
BOX D1-1976																
Interval	**SOUTHBOUNDFoster Street**				**WESTBOUNDShawsheen Street**				**NORTHBOUNDBeech Street**				**EASTBOUNDShawsheen Street**			
Start Time	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**
6:00 AM	6	5	10	0	4	41	1	0	2	0	1	0	0	51	3	0
6:15 AM	13	6	8	0	1	68	2	3	7	2	1	0	0	46	1	1
6:30 AM	14	6	13	0	1	84	2	1	5	1	1	0	0	66	2	1
6:45 AM	18	9	12	0	3	88	4	3	5	1	2	0	1	47	9	0
6-7 AM	*51*	*26*	*43*	*0*	*9*	*281*	*9*	*7*	*19*	*4*	*5*	*0*	*1*	*210*	*15*	*2*
7:00 AM	17	6	12	0	6	105	1	0	5	3	3	0	1	70	10	0
7:15 AM	16	10	18	0	6	100	6	0	4	4	0	0	0	61	7	0
7:30 AM	15	11	12	0	13	130	5	0	7	6	1	0	3	87	9	2
7:45 AM	17	7	25	0	9	118	3	0	7	2	2	0	1	71	10	0
7-8 AM	*65*	*34*	*67*	*0*	*34*	*453*	*15*	*0*	*23*	*15*	*6*	*0*	*5*	*289*	*36*	*2*
Bin #	2	3	4	1	6	7	8	5	10	11	12	9	14	15	16	13

		Shawsheen/Patten														
BOX D1-1977																
Interval	**IBOUNDShawsheen Street from Interese**				**WESTBOUNDShawsheen Street**				**NORTHBOUNDPatten Road**				**EASTBOUNDMarket Driveway**			
Start Time	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**
6:00 AM	0	13	34	0	28	1	0	0	0	24	1	0	0	0	1	0
6:15 AM	2	14	67	3	23	0	0	0	0	24	2	1	3	0	2	0
6:30 AM	2	13	87	1	39	2	0	1	2	28	1	0	1	1	0	0
6:45 AM	1	13	92	1	32	0	0	1	0	25	0	0	0	0	1	0
7:00 AM	2	20	103	0	57	0	1	0	1	23	0	0	0	1	0	0
7:15 AM	0	25	91	2	39	1	0	0	0	28	2	0	1	0	0	0
7:30 AM	1	26	116	0	60	0	1	3	1	41	1	1	1	2	0	0
7:45 AM	0	25	112	0	54	0	0	0	0	26	1	1	0	1	2	0
7-8 AM	*3*	*96*	*422*	*2*	*210*	*1*	*2*	*3*	*2*	*118*	*4*	*2*	*2*	*4*	*2*	*0*
Bin #	2	3	4	1	6	7	8	5	10	11	12	9	14	15	16	13

		Shawsheen/Beech/Foster				11/14										
BOX D1-1977																
Interval																
	SOUTHBOUNDFoster Street				**WESTBOUNDShawsheen Street**				**NORTHBOUNDBeech Street**				**EASTBOUNDShawsheen Street**			
Start Time	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**
3:00 PM	7	5	16	0	15	95	6	0	9	4	0	0	2	63	10	0
3:15 PM	5	3	15	0	23	85	12	1	7	6	1	0	1	86	15	2
3:30 PM	5	9	17	0	21	63	3	0	9	4	2	0	3	70	15	0
3:45 PM	7	3	11	0	24	99	7	0	6	2	4	0	6	92	13	2
3-4	*24*	*20*	*59*	*0*	*83*	*342*	*28*	*1*	*31*	*16*	*7*	*0*	*12*	*311*	*53*	*4*
4:00 PM	12	8	13	0	16	98	6	1	10	8	3	0	2	99	15	0
4:15 PM	8	9	15	0	24	81	7	2	12	6	2	0	2	102	14	1
4:30 PM	11	5	5	0	18	112	5	1	14	8	5	0	5	91	14	0
4:45 PM	13	6	13	0	20	106	6	0	13	14	0	0	4	105	11	1
4-5	*44*	*28*	*46*	*0*	*78*	*397*	*24*	*4*	*49*	*36*	*10*	*0*	*13*	*397*	*54*	*2*
Bin #	2	3	4	1	6	7	8	5	10	11	12	9	14	15	16	13

		Shawsheen/Patten														
BOX D1-1976																
Interval																
	BOUNDShawsheen Street from Interese				**WESTBOUNDShawsheen Street**				**NORTHBOUNDPatten Road**				**EASTBOUNDMarket Driveway**			
Start Time	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**	**Right**	**Straight**	**Left**	**HV**
3:00 PM	3	50	45	2	52	3	1	0	1	21	0	0	2	1	1	0
3:15 PM	1	38	56	1	76	2	0	2	0	25	0	2	2	0	2	0
3:30 PM	1	31	38	0	59	1	1	0	0	29	2	0	2	1	2	0
3:45 PM	2	40	67	0	71	1	0	1	0	37	0	1	1	1	2	0
4:00 PM	2	43	70	1	90	0	1	0	0	25	0	0	2	0	0	0
4:15 PM	1	37	53	2	88	1	0	0	0	29	1	1	1	1	2	0
4:30 PM	5	55	73	1	82	1	0	0	0	27	1	0	2	0	0	0
4:45 PM	1	50	67	1	83	1	1	1	0	36	0	0	2	1	1	0
4-5 PM	*9*	*185*	*263*	*5*	*343*	*3*	*2*	*1*	*0*	*117*	*2*	*1*	*7*	*2*	*3*	*0*
Bin #	2	3	4	1	6	7	8	5	10	11	12	9	14	15	16	13

Appendix E: HCS Reports

HCS+: Unsignalized Intersections Release 5.6

TWO-WAY STOP CONTROL SUMMARY

Analyst:
Agency/Co.:
Date Performed: 11/7/2017
Analysis Time Period: 7-8 AM
Intersection: Shawsheen-Patten
Jurisdiction:
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Patten
Intersection Orientation: EW   Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street: Approach	Eastbound			Westbound		
Movement	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	2	210	0	0	426	98
Peak-Hour Factor, PHF	0.50	0.88	1.00	1.00	0.92	0.94
Hourly Flow Rate, HFR	4	238	0	0	463	104
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided		/			
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration	LTR			LTR		
Upstream Signal?		No			No	

Minor Street: Approach	Northbound			Southbound		
Movement	7	8	9	10	11	12
	L	T	R	L	T	R
Volume				118	0	2
Peak Hour Factor, PHF				0.72	1.00	0.50
Hourly Flow Rate, HFR				163	0	4
Percent Heavy Vehicles				0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			/		No	/
Lanes				0	1	0
Configuration					LTR	

Delay, Queue Length, and Level of Service

Approach	EB	WB	Northbound			Southbound		
Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR					LTR	
v (vph)	4	0					167	
C(m) (vph)	1015	1341					378	
v/c	0.00	0.00					0.44	
95% queue length	0.01	0.00					2.19	
Control Delay	8.6	7.7					21.8	
LOS	A	A					C	
Approach Delay							21.8	
Approach LOS							C	

HCS+: Unsignalized Intersections Release 5.6

Phone: Fax:
E-Mail:

TWO-WAY STOP CONTROL(TWSC) ANALYSIS

Analyst:
Agency/Co.:
Date Performed: 11/7/2017
Analysis Time Period: 7-8 AM
Intersection: Shawsheen-Patten
Jurisdiction:
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Patten
Intersection Orientation: EW Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street Movements	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	2	210	0	0	426	98
Peak-Hour Factor, PHF	0.50	0.88	1.00	1.00	0.92	0.94
Peak-15 Minute Volume	1	60	0	0	116	26
Hourly Flow Rate, HFR	4	238	0	0	463	104
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided			/		
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	
Upstream Signal?		No			No	

Minor Street Movements	7	8	9	10	11	12
	L	T	R	L	T	R
Volume				118	0	2
Peak Hour Factor, PHF				0.72	1.00	0.50
Peak-15 Minute Volume				41	0	1
Hourly Flow Rate, HFR				163	0	4
Percent Heavy Vehicles				0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage				/		No /
RT Channelized?						
Lanes				0	1	0
Configuration					LTR	

Pedestrian Volumes and Adjustments

Movements	13	14	15	16
Flow (ped/hr)	0	0	0	0

Lane Width (ft)	12.0	12.0	12.0	12.0
Walking Speed (ft/sec)	4.0	4.0	4.0	4.0
Percent Blockage	0	0	0	0

Upstream Signal Data

		Prog. Flow vph	Sat Flow vph	Arrival Type	Green Time sec	Cycle Length sec	Prog. Speed mph	Distance to Signal feet
S2	Left-Turn							
	Through							
S5	Left-Turn							
	Through							

Worksheet 3-Data for Computing Effect of Delay to Major Street Vehicles

	Movement 2	Movement 5
Shared ln volume, major th vehicles:	238	463
Shared ln volume, major rt vehicles:	0	104
Sat flow rate, major th vehicles:	1700	1700
Sat flow rate, major rt vehicles:	1700	1700
Number of major street through lanes:	1	1

Worksheet 4-Critical Gap and Follow-up Time Calculation

Critical Gap Calculation

Movement		1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(c,base)		4.1	4.1				7.1	6.5	6.2
t(c,hv)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(hv)		0	0				0	0	0
t(c,g)				0.20	0.20	0.10	0.20	0.20	0.10
Percent Grade				0.00	0.00	0.00	0.00	0.00	0.00
t(3,lt)		0.00	0.00				0.70	0.00	0.00
t(c,T):	1-stage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2-stage	0.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00
t(c)	1-stage	4.1	4.1				6.4	6.5	6.2
	2-stage								

Follow-Up Time Calculations

Movement	1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(f,base)	2.20	2.20				3.50	4.00	3.30
t(f,HV)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
P(HV)	0	0				0	0	0
t(f)	2.2	2.2				3.5	4.0	3.3

Worksheet 5-Effect of Upstream Signals

Computation 1-Queue Clearance Time at Upstream Signal

	Movement 2		Movement 5	
	V(t)	V(l,prot)	V(t)	V(l,prot)
V prog				

Total Saturation Flow Rate, s (vph)
Arrival Type
Effective Green, g (sec)
Cycle Length, C (sec)
Rp (from Exhibit 16-11)
Proportion vehicles arriving on green P
g(q1)
g(q2)
g(q)

Computation 2-Proportion of TWSC Intersection Time blocked	Movement 2 V(t)	Movement 2 V(l,prot)	Movement 5 V(t)	Movement 5 V(l,prot)
alpha				
beta				
Travel time, t(a) (sec)				
Smoothing Factor, F				
Proportion of conflicting flow, f				
Max platooned flow, V(c,max)				
Min platooned flow, V(c,min)				
Duration of blocked period, t(p)				
Proportion time blocked, p	0.000		0.000	

Computation 3-Platoon Event Periods	Result
p(2)	0.000
p(5)	0.000
p(dom)	
p(subo)	
Constrained or unconstrained?	

Proportion unblocked for minor movements, p(x)	(1) Single-stage Process	(2) Two-Stage Process Stage I	(3) Two-Stage Process Stage II
p(1)			
p(4)			
p(7)			
p(8)			
p(9)			
p(10)			
p(11)			
p(12)			

Computation 4 and 5
Single-Stage Process

Movement	1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
V c,x	567	238				761	761	515
s								
Px								
V c,u,x								
C r,x								
C plat,x								

Two-Stage Process

	7	8	10	11

	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2
V(c,x)								
s						1500		1500
P(x)								
V(c,u,x)								
C(r,x)								
C(plat,x)								

Worksheet 6-Impedance and Capacity Equations

Step 1: RT from Minor St.	9	12
Conflicting Flows		515
Potential Capacity		564
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity		564
Probability of Queue free St.	1.00	0.99

Step 2: LT from Major St.	4	1
Conflicting Flows	238	567
Potential Capacity	1341	1015
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity	1341	1015
Probability of Queue free St.	1.00	1.00
Maj L-Shared Prob Q free St.	1.00	1.00

Step 3: TH from Minor St.	8	11
Conflicting Flows		761
Potential Capacity		337
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	1.00	1.00
Movement Capacity		335
Probability of Queue free St.	1.00	1.00

Step 4: LT from Minor St.	7	10
Conflicting Flows		761
Potential Capacity		376
Pedestrian Impedance Factor	1.00	1.00
Maj. L, Min T Impedance factor	1.00	
Maj. L, Min T Adj. Imp Factor.	1.00	
Cap. Adj. factor due to Impeding mvmnt	0.99	1.00
Movement Capacity		375

Worksheet 7-Computation of the Effect of Two-stage Gap Acceptance

Step 3: TH from Minor St.	8	11
Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		
Probability of Queue free St.		

Part 2 - Second Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 3 - Single Stage		
Conflicting Flows		761
Potential Capacity		337
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	1.00	1.00
Movement Capacity		335

Result for 2 stage process:		
a		
y		
C t		335
Probability of Queue free St.	1.00	1.00

Step 4: LT from Minor St.	7	10
Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 2 - Second Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 3 - Single Stage		
Conflicting Flows		761
Potential Capacity		376
Pedestrian Impedance Factor	1.00	1.00
Maj. L, Min T Impedance factor	1.00	
Maj. L, Min T Adj. Imp Factor.	1.00	
Cap. Adj. factor due to Impeding mvmnt	0.99	1.00
Movement Capacity		375

Results for Two-stage process:		
a		
y		
C t		375

Worksheet 8-Shared Lane Calculations

Movement	7 L	8 T	9 R	10 L	11 T	12 R
Volume (vph)				163	0	4
Movement Capacity (vph)				375	335	564
Shared Lane Capacity (vph)					378	

Worksheet 9-Computation of Effect of Flared Minor Street Approaches

Movement	7	8	9	10	11	12
	L	T	R	L	T	R
C sep				375	335	564
Volume				163	0	4
Delay						
Q sep						
Q sep +1						
round (Qsep +1)						
n max						
C sh					378	
SUM C sep						
n						
C act						

Worksheet 10-Delay, Queue Length, and Level of Service

Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR					LTR	
v (vph)	4	0					167	
C(m) (vph)	1015	1341					378	
v/c	0.00	0.00					0.44	
95% queue length	0.01	0.00					2.19	
Control Delay	8.6	7.7					21.8	
LOS	A	A					C	
Approach Delay							21.8	
Approach LOS							C	

Worksheet 11-Shared Major LT Impedance and Delay

	Movement 2	Movement 5
p(oj)	1.00	1.00
v(il), Volume for stream 2 or 5	238	463
v(i2), Volume for stream 3 or 6	0	104
s(il), Saturation flow rate for stream 2 or 5	1700	1700
s(i2), Saturation flow rate for stream 3 or 6	1700	1700
P*(oj)	1.00	1.00
d(M,LT), Delay for stream 1 or 4	8.6	7.7
N, Number of major street through lanes	1	1
d(rank,1) Delay for stream 2 or 5	0.0	0.0

HCS+: Unsignalized Intersections Release 5.6

TWO-WAY STOP CONTROL SUMMARY

Analyst:
Agency/Co.:
Date Performed: 11/14/2017
Analysis Time Period: 4-5 PM
Intersection: Shawsheen-Patten
Jurisdiction:
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Patten
Intersection Orientation: EW   Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street: Approach	Eastbound			Westbound		
Movement	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	2	343	0	0	265	192
Peak-Hour Factor, PHF	0.50	0.95	1.00	1.00	0.91	0.87
Hourly Flow Rate, HFR	4	361	0	0	291	220
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided			/		
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	
Upstream Signal?		No			No	

Minor Street: Approach	Northbound			Southbound		
Movement	7	8	9	10	11	12
	L	T	R	L	T	R
Volume				117	0	0
Peak Hour Factor, PHF				0.81	1.00	1.00
Hourly Flow Rate, HFR				144	0	0
Percent Heavy Vehicles				0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			/			No /
Lanes				0	1	0
Configuration					LTR	

Delay, Queue Length, and Level of Service

Approach	EB	WB	Northbound			Southbound		
Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR					LTR	
v (vph)	4	0					144	
C(m) (vph)	1065	1209					371	
v/c	0.00	0.00					0.39	
95% queue length	0.01	0.00					1.79	
Control Delay	8.4	8.0					20.7	
LOS	A	A					C	
Approach Delay							20.7	
Approach LOS							C	

HCS+: Unsignalized Intersections Release 5.6

Phone: Fax:
E-Mail:

TWO-WAY STOP CONTROL(TWSC) ANALYSIS

Analyst:
Agency/Co.:
Date Performed: 11/14/2017
Analysis Time Period: 4-5 PM
Intersection: Shawsheen-Patten
Jurisdiction:
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Patten
Intersection Orientation: EW Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street Movements	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	2	343	0	0	265	192
Peak-Hour Factor, PHF	0.50	0.95	1.00	1.00	0.91	0.87
Peak-15 Minute Volume	1	90	0	0	73	55
Hourly Flow Rate, HFR	4	361	0	0	291	220
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided			/		
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	
Upstream Signal?		No			No	

Minor Street Movements	7	8	9	10	11	12
	L	T	R	L	T	R
Volume				117	0	0
Peak Hour Factor, PHF				0.81	1.00	1.00
Peak-15 Minute Volume				36	0	0
Hourly Flow Rate, HFR				144	0	0
Percent Heavy Vehicles				0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			/			No /
RT Channelized?						
Lanes				0	1	0
Configuration					LTR	

Pedestrian Volumes and Adjustments

Movements	13	14	15	16
Flow (ped/hr)	0	0	0	0

Lane Width (ft)	12.0	12.0	12.0	12.0
Walking Speed (ft/sec)	4.0	4.0	4.0	4.0
Percent Blockage	0	0	0	0

Upstream Signal Data

		Prog. Flow vph	Sat Flow vph	Arrival Type	Green Time sec	Cycle Length sec	Prog. Speed mph	Distance to Signal feet
S2	Left-Turn							
	Through							
S5	Left-Turn							
	Through							

Worksheet 3-Data for Computing Effect of Delay to Major Street Vehicles

	Movement 2	Movement 5
Shared ln volume, major th vehicles:	361	291
Shared ln volume, major rt vehicles:	0	220
Sat flow rate, major th vehicles:	1700	1700
Sat flow rate, major rt vehicles:	1700	1700
Number of major street through lanes:	1	1

Worksheet 4-Critical Gap and Follow-up Time Calculation

Critical Gap Calculation

Movement		1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(c,base)		4.1	4.1				7.1	6.5	6.2
t(c,hv)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(hv)		0	0				0	0	0
t(c,g)				0.20	0.20	0.10	0.20	0.20	0.10
Percent Grade				0.00	0.00	0.00	0.00	0.00	0.00
t(3,lt)		0.00	0.00				0.70	0.00	0.00
t(c,T):	1-stage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2-stage	0.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00
t(c)	1-stage	4.1	4.1				6.4	6.5	6.2
	2-stage								

Follow-Up Time Calculations

Movement	1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(f,base)	2.20	2.20				3.50	4.00	3.30
t(f,HV)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
P(HV)	0	0				0	0	0
t(f)	2.2	2.2				3.5	4.0	3.3

Worksheet 5-Effect of Upstream Signals

Computation 1-Queue Clearance Time at Upstream Signal

	Movement 2 V(t)	Movement 2 V(l,prot)	Movement 5 V(t)	Movement 5 V(l,prot)
V prog				

Total Saturation Flow Rate, s (vph)				
Arrival Type				
Effective Green, g (sec)				
Cycle Length, C (sec)				
Rp (from Exhibit 16-11)				
Proportion vehicles arriving on green P				
g(q1)				
g(q2)				
g(q)				

Computation 2-Proportion of TWSC Intersection Time blocked

	Movement 2		Movement 5	
	V(t)	V(l,prot)	V(t)	V(l,prot)
alpha				
beta				
Travel time, t(a) (sec)				
Smoothing Factor, F				
Proportion of conflicting flow, f				
Max platooned flow, V(c,max)				
Min platooned flow, V(c,min)				
Duration of blocked period, t(p)				
Proportion time blocked, p	0.000		0.000	

Computation 3-Platoon Event Periods	Result
p(2)	0.000
p(5)	0.000
p(dom)	
p(subo)	
Constrained or unconstrained?	

Proportion unblocked for minor movements, p(x)	(1) Single-stage Process	(2) Two-Stage Process Stage I	(3) Two-Stage Process Stage II
p(1)			
p(4)			
p(7)			
p(8)			
p(9)			
p(10)			
p(11)			
p(12)			

Computation 4 and 5
Single-Stage Process

Movement	1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
V c,x	511	361				770	770	401
s								
Px								
V c,u,x								
C r,x								
C plat,x								

Two-Stage Process

	7	8	10	11

	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2
V(c,x)								
s						1500		1500
P(x)								
V(c,u,x)								
C(r,x)								
C(plat,x)								

Worksheet 6-Impedance and Capacity Equations

Step 1: RT from Minor St.	9	12
Conflicting Flows		401
Potential Capacity		653
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity		653
Probability of Queue free St.	1.00	1.00

Step 2: LT from Major St.	4	1
Conflicting Flows	361	511
Potential Capacity	1209	1065
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity	1209	1065
Probability of Queue free St.	1.00	1.00
Maj L-Shared Prob Q free St.	1.00	1.00

Step 3: TH from Minor St.	8	11
Conflicting Flows		770
Potential Capacity		333
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	1.00	1.00
Movement Capacity		331
Probability of Queue free St.	1.00	1.00

Step 4: LT from Minor St.	7	10
Conflicting Flows		770
Potential Capacity		372
Pedestrian Impedance Factor	1.00	1.00
Maj. L, Min T Impedance factor	1.00	
Maj. L, Min T Adj. Imp Factor.	1.00	
Cap. Adj. factor due to Impeding mvmnt	1.00	1.00
Movement Capacity		371

Worksheet 7-Computation of the Effect of Two-stage Gap Acceptance

Step 3: TH from Minor St.	8	11
Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		
Probability of Queue free St.		

```
_____________________________________________________________________________
Part 2 - Second Stage
Conflicting Flows
Potential Capacity
Pedestrian Impedance Factor
Cap. Adj. factor due to Impeding mvmnt
Movement Capacity
_____________________________________________________________________________
Part 3 - Single Stage
Conflicting Flows                                               770
Potential Capacity                                              333
Pedestrian Impedance Factor                     1.00            1.00
Cap. Adj. factor due to Impeding mvmnt          1.00            1.00
Movement Capacity                                               331
_____________________________________________________________________________
Result for 2 stage process:
a
y
C t                                                             331
Probability of Queue free St.                   1.00            1.00
_____________________________________________________________________________
Step 4: LT from Minor St.                          7               10
_____________________________________________________________________________
Part 1 - First Stage
Conflicting Flows
Potential Capacity
Pedestrian Impedance Factor
Cap. Adj. factor due to Impeding mvmnt
Movement Capacity
_____________________________________________________________________________
Part 2 - Second Stage
Conflicting Flows
Potential Capacity
Pedestrian Impedance Factor
Cap. Adj. factor due to Impeding mvmnt
Movement Capacity
_____________________________________________________________________________
Part 3 - Single Stage
Conflicting Flows                                               770
Potential Capacity                                              372
Pedestrian Impedance Factor                     1.00            1.00
Maj. L, Min T Impedance factor                  1.00
Maj. L, Min T Adj. Imp Factor.                  1.00
Cap. Adj. factor due to Impeding mvmnt          1.00            1.00
Movement Capacity                                               371
_____________________________________________________________________________
Results for Two-stage process:
a
y
C t                                                             371
_____________________________________________________________________________

Worksheet 8-Shared Lane Calculations
_____________________________________________________________________________
Movement                              7      8      9     10     11     12
                                      L      T      R      L      T      R
_____________________________________________________________________________
Volume (vph)                                              144    0      0
Movement Capacity (vph)                                   371    331    653
Shared Lane Capacity (vph)                                       371
_____________________________________________________________________________
```

Worksheet 9-Computation of Effect of Flared Minor Street Approaches

Movement	7 L	8 T	9 R	10 L	11 T	12 R
C sep				371	331	653
Volume				144	0	0
Delay						
Q sep						
Q sep +1						
round (Qsep +1)						
n max						
C sh					371	
SUM C sep						
n						
C act						

Worksheet 10-Delay, Queue Length, and Level of Service

Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR					LTR	
v (vph)	4	0					144	
C(m) (vph)	1065	1209					371	
v/c	0.00	0.00					0.39	
95% queue length	0.01	0.00					1.79	
Control Delay	8.4	8.0					20.7	
LOS	A	A					C	
Approach Delay							20.7	
Approach LOS							C	

Worksheet 11-Shared Major LT Impedance and Delay

	Movement 2	Movement 5
p(oj)	1.00	1.00
v(il), Volume for stream 2 or 5	361	291
v(i2), Volume for stream 3 or 6	0	220
s(il), Saturation flow rate for stream 2 or 5	1700	1700
s(i2), Saturation flow rate for stream 3 or 6	1700	1700
P*(oj)	1.00	1.00
d(M,LT), Delay for stream 1 or 4	8.4	8.0
N, Number of major street through lanes	1	1
d(rank,1) Delay for stream 2 or 5	0.0	0.0

HCS 2010: MUTCD Signal Warrants Release 6.50

Analyst:
Agency:
Date: 12/4/2017
Project ID:
EW Street: Shawsheen

Intersection: Shawsheen-Patten
Jurisdiction:
Units: U.S. Customary
Analysis Year:
NS Street: Patten

General Information

Major St. Speed (mph): 40
Nearest Signal (ft): 0
Crashes per Yr: 3

Population: Not less than 10000
Coordinated Signal System: N

School Crossing

Students in Highest Hour: 0
Adequate Gaps in Period: 0
Minutes in Period: 0

Roadway Network

Two Major Routes: 0
Weekend Count: 0
5-yr Growth Factor: 0

Geometry and Traffic

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes	0	1	0	0	1	0	0	0	0	0	1	0
LaneUsage		LTR			LTR						LTR	

Results

Warrant 1: Eight-Hour Vehicular Volume	[ ]
1 A. Minimum Vehicular Volumes	[ ]
1 B. Interruption of Continuous Traffic	[ ]
1 80% Vehicular --and-- Interruption Volumes	[ ]
Warrant 2: Four-Hour Vehicular Volume	
2 A. Four-Hour Vehicular Volumes	[ ]
Warrant 3: Peak Hour	[ ]
3 A. Peak-Hour Conditions	[ ]
3 B. Peak-Hour Vehicular Volume Hours Met	[ ]
Warrant 4: Pedestrian Volume	[ ]
4 A. Pedestrian Volumes	[ ]
4 B. Gaps Same Period	[ ]
Warrant 5: School Crossing	[ ]
5 A. Student Volumes	[ ]
5 B. Gaps Same Period	[ ]
Warrant 6: Coordinated Signal System	
6 Degree of Platooning	[ ]
Warrant 7: Crash Experience	[ ]
7 A. Adequate trials of alternatives	[ ]

7 B. Reported crashes [ ]
7 80% Volumes for Warrants 1A, 1B --or-- 4 [ ]

Warrant 8: Roadway Network [ ]
8 A. Weekday Volume [ ]
8 B. Weekend Volume [ ]

Summary

Hours	Major Volume	Minor Volume	Total Volume	Delay (Veh-hr)	1A 100%	1A 80%	1B 100%	1B 80%	2 100%	3A 100%	3B 100%
06-07	437	165	602	0.0	No	Yes	No	No	No	No	No
07-08	736	120	856	2.8	No	Yes	No	Yes	No	No	No
08-09	553	226	779	0.0	Yes	Yes	No	No	No	No	No
09-10	306	154	460	0.0	No	No	No	No	No	No	No
10-11	234	144	378	0.0	No	No	No	No	No	No	No
11-12	263	148	411	0.0	No	No	No	No	No	No	No
12-13	272	165	437	0.0	No	No	No	No	No	No	No
13-14	276	145	421	0.0	No	No	No	No	No	No	No
14-15	375	203	578	0.0	No	No	No	No	No	No	No
15-16	476	260	736	0.0	No	Yes	No	No	No	No	No
16-17	802	117	919	0.7	No	No	Yes	Yes	No	No	No
17-18	690	290	980	0.0	Yes	Yes	No	Yes	Yes	No	No
Total	5420	2137	7557		2	5	1	3	1	0	0

Traffic Volumes (vph)

Eastbound L	Eastbound T	Eastbound R	Westbound L	Westbound T	Westbound R	Northbound L	Northbound T	Northbound R	Southbound L	Southbound T	Southbound R
0	170	0	0	267	0	0	0	0	0	165	0
2	210	0	0	426	98	0	0	0	118	0	2
0	184	0	0	369	0	0	0	0	0	226	0
0	132	0	0	174	0	0	0	0	0	154	0
0	110	0	0	124	0	0	0	0	0	144	0
0	141	0	0	122	0	0	0	0	0	148	0
0	134	0	0	138	0	0	0	0	0	165	0
0	140	0	0	136	0	0	0	0	0	145	0
0	201	0	0	174	0	0	0	0	0	203	0
0	267	0	0	209	0	0	0	0	0	260	0
2	343	0	0	265	192	0	0	0	117	0	0
0	410	0	0	280	0	0	0	0	0	290	0

Pedestrian Volumes and Gaps (Per Hour)

Volume	Gap	Volume	Gap	Volume	Gap	Volume	Gap
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Delay	sec/veh	veh-hrs	sec/veh	veh-hrs	sec/veh	veh-hrs	sec/veh	veh-hrs
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8.7	0.5	8.0	1.2	0.0	0.0*	83.5	2.8
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.6	0.8	7.7	1.0	0.0	0.0	21.8	0.7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

HCS+: Unsignalized Intersections Release 5.6

TWO-WAY STOP CONTROL SUMMARY

Analyst:
Agency/Co.:
Date Performed: 11/07/2017
Analysis Time Period: 7-8 AM
Intersection: Shawsheen/Beech/Foster
Jurisdiction:
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Beech/Foster
Intersection Orientation: EW   Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street: Approach	Eastbound			Westbound		
Movement	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	36	289	5	15	453	34
Peak-Hour Factor, PHF	0.90	0.83	0.42	0.63	0.87	0.65
Hourly Flow Rate, HFR	40	348	11	23	520	52
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided		/			
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	
Upstream Signal?		No			No	

Minor Street: Approach	Northbound			Southbound		
Movement	7	8	9	10	11	12
	L	T	R	L	T	R
Volume	6	15	23	67	34	65
Peak Hour Factor, PHF	0.50	0.63	0.82	0.67	0.77	0.95
Hourly Flow Rate, HFR	12	23	28	99	44	68
Percent Heavy Vehicles	0	0	0	0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			No /			No /
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	

Delay, Queue Length, and Level of Service

Approach	EB	WB	Northbound			Southbound		
Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR		LTR			LTR	
v (vph)	40	23		63			211	
C(m) (vph)	1009	1209		264			231	
v/c	0.04	0.02		0.24			0.91	
95% queue length	0.12	0.06		0.91			7.73	
Control Delay	8.7	8.0		22.9			83.5	
LOS	A	A		C			F	
Approach Delay				22.9			83.5	
Approach LOS				C			F	

HCS+: Unsignalized Intersections Release 5.6

Phone: Fax:
E-Mail:

TWO-WAY STOP CONTROL(TWSC) ANALYSIS

Analyst:
Agency/Co.:
Date Performed: 11/07/2017
Analysis Time Period: 7-8 AM
Intersection: Shawsheen/Beech/Foster
Jurisdiction:
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Beech/Foster
Intersection Orientation: EW Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street Movements	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	36	289	5	15	453	34
Peak-Hour Factor, PHF	0.90	0.83	0.42	0.63	0.87	0.65
Peak-15 Minute Volume	10	87	3	6	130	13
Hourly Flow Rate, HFR	40	348	11	23	520	52
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided			/		
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	
Upstream Signal?		No			No	

Minor Street Movements	7	8	9	10	11	12
	L	T	R	L	T	R
Volume	6	15	23	67	34	65
Peak Hour Factor, PHF	0.50	0.63	0.82	0.67	0.77	0.95
Peak-15 Minute Volume	3	6	7	25	11	17
Hourly Flow Rate, HFR	12	23	28	99	44	68
Percent Heavy Vehicles	0	0	0	0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			No /			No /
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	

Pedestrian Volumes and Adjustments

Movements	13	14	15	16
Flow (ped/hr)	1	1	1	1

Lane Width (ft)	12.0	12.0	12.0	12.0
Walking Speed (ft/sec)	4.0	4.0	4.0	4.0
Percent Blockage	0	0	0	0

Upstream Signal Data

		Prog. Flow vph	Sat Flow vph	Arrival Type	Green Time sec	Cycle Length sec	Prog. Speed mph	Distance to Signal feet
S2	Left-Turn							
	Through							
S5	Left-Turn							
	Through							

Worksheet 3-Data for Computing Effect of Delay to Major Street Vehicles

	Movement 2	Movement 5
Shared ln volume, major th vehicles:	348	520
Shared ln volume, major rt vehicles:	11	52
Sat flow rate, major th vehicles:	1700	1700
Sat flow rate, major rt vehicles:	1700	1700
Number of major street through lanes:	1	1

Worksheet 4-Critical Gap and Follow-up Time Calculation

Critical Gap Calculation

Movement		1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(c,base)		4.1	4.1	7.1	6.5	6.2	7.1	6.5	6.2
t(c,hv)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(hv)		0	0	0	0	0	0	0	0
t(c,g)				0.20	0.20	0.10	0.20	0.20	0.10
Percent Grade				0.00	0.00	0.00	0.00	0.00	0.00
t(3,lt)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
t(c,T):	1-stage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2-stage	0.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00
t(c)	1-stage	4.1	4.1	7.1	6.5	6.2	7.1	6.5	6.2
	2-stage								

Follow-Up Time Calculations

Movement	1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(f,base)	2.20	2.20	3.50	4.00	3.30	3.50	4.00	3.30
t(f,HV)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
P(HV)	0	0	0	0	0	0	0	0
t(f)	2.2	2.2	3.5	4.0	3.3	3.5	4.0	3.3

Worksheet 5-Effect of Upstream Signals

Computation 1-Queue Clearance Time at Upstream Signal

	Movement 2 V(t)	Movement 2 V(l,prot)	Movement 5 V(t)	Movement 5 V(l,prot)
V prog				

Total Saturation Flow Rate, s (vph)				
Arrival Type				
Effective Green, g (sec)				
Cycle Length, C (sec)				
Rp (from Exhibit 16-11)				
Proportion vehicles arriving on green P				
g(q1)				
g(q2)				
g(q)				

Computation 2-Proportion of TWSC Intersection Time blocked

	Movement 2		Movement 5	
	V(t)	V(l,prot)	V(t)	V(l,prot)
alpha				
beta				
Travel time, t(a) (sec)				
Smoothing Factor, F				
Proportion of conflicting flow, f				
Max platooned flow, V(c,max)				
Min platooned flow, V(c,min)				
Duration of blocked period, t(p)				
Proportion time blocked, p	0.000		0.000	

Computation 3-Platoon Event Periods	Result
p(2)	0.000
p(5)	0.000
p(dom)	
p(subo)	
Constrained or unconstrained?	

Proportion unblocked for minor movements, p(x)	(1) Single-stage Process	(2) Two-Stage Process Stage I	(3) Two-Stage Process Stage II
p(1)			
p(4)			
p(7)			
p(8)			
p(9)			
p(10)			
p(11)			
p(12)			

Computation 4 and 5
Single-Stage Process

Movement	1	4	7	8	9	10	11	12
	L	L	L	T	R	L	T	R
V c,x	573	360	1083	1053	356	1053	1033	548
s								
Px								
V c,u,x								
C r,x								
C plat,x								

Two-Stage Process

	7	8	10	11

	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2
V(c,x)								
s		1500		1500		1500		1500
P(x)								
V(c,u,x)								
C(r,x)								
C(plat,x)								

Worksheet 6-Impedance and Capacity Equations

Step 1: RT from Minor St.	9	12
Conflicting Flows	356	548
Potential Capacity	693	540
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity	692	539
Probability of Queue free St.	0.96	0.87

Step 2: LT from Major St.	4	1
Conflicting Flows	360	573
Potential Capacity	1210	1010
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity	1209	1009
Probability of Queue free St.	0.98	0.96
Maj L-Shared Prob Q free St.	0.97	0.95

Step 3: TH from Minor St.	8	11
Conflicting Flows	1053	1033
Potential Capacity	228	234
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	0.92	0.92
Movement Capacity	210	216
Probability of Queue free St.	0.89	0.80

Step 4: LT from Minor St.	7	10
Conflicting Flows	1083	1053
Potential Capacity	197	206
Pedestrian Impedance Factor	1.00	1.00
Maj. L, Min T Impedance factor	0.73	0.82
Maj. L, Min T Adj. Imp Factor.	0.79	0.86
Cap. Adj. factor due to Impeding mvmnt	0.69	0.83
Movement Capacity	136	170

Worksheet 7-Computation of the Effect of Two-stage Gap Acceptance

Step 3: TH from Minor St.	8	11
Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		
Probability of Queue free St.		

Part 2 - Second Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 3 - Single Stage		
Conflicting Flows	1053	1033
Potential Capacity	228	234
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	0.92	0.92
Movement Capacity	210	216

Result for 2 stage process:		
a		
y		
C t	210	216
Probability of Queue free St.	0.89	0.80

Step 4: LT from Minor St.	7	10

Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 2 - Second Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 3 - Single Stage		
Conflicting Flows	1083	1053
Potential Capacity	197	206
Pedestrian Impedance Factor	1.00	1.00
Maj. L, Min T Impedance factor	0.73	0.82
Maj. L, Min T Adj. Imp Factor.	0.79	0.86
Cap. Adj. factor due to Impeding mvmnt	0.69	0.83
Movement Capacity	136	170

Results for Two-stage process:		
a		
y		
C t	136	170

Worksheet 8-Shared Lane Calculations

Movement	7 L	8 T	9 R	10 L	11 T	12 R
Volume (vph)	12	23	28	99	44	68
Movement Capacity (vph)	136	210	692	170	216	539
Shared Lane Capacity (vph)		264			231	

Worksheet 9-Computation of Effect of Flared Minor Street Approaches

Movement	7 L	8 T	9 R	10 L	11 T	12 R
C sep	136	210	692	170	216	539
Volume	12	23	28	99	44	68
Delay						
Q sep						
Q sep +1						
round (Qsep +1)						
n max						
C sh		264			231	
SUM C sep						
n						
C act						

Worksheet 10-Delay, Queue Length, and Level of Service

Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR		LTR			LTR	
v (vph)	40	23		63			211	
C(m) (vph)	1009	1209		264			231	
v/c	0.04	0.02		0.24			0.91	
95% queue length	0.12	0.06		0.91			7.73	
Control Delay	8.7	8.0		22.9			83.5	
LOS	A	A		C			F	
Approach Delay				22.9			83.5	
Approach LOS				C			F	

Worksheet 11-Shared Major LT Impedance and Delay

	Movement 2	Movement 5
p(oj)	0.96	0.98
v(il), Volume for stream 2 or 5	348	520
v(i2), Volume for stream 3 or 6	11	52
s(il), Saturation flow rate for stream 2 or 5	1700	1700
s(i2), Saturation flow rate for stream 3 or 6	1700	1700
P*(oj)	0.95	0.97
d(M,LT), Delay for stream 1 or 4	8.7	8.0
N, Number of major street through lanes	1	1
d(rank,1) Delay for stream 2 or 5	0.4	0.2

HCS+: Unsignalized Intersections Release 5.6

TWO-WAY STOP CONTROL SUMMARY

Analyst:
Agency/Co.:
Date Performed: 11/14/2017
Analysis Time Period: 4-5 PM
Intersection: Shawsheen/Beech/Foster
Jurisdiction:
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Beech/Foster
Intersection Orientation: EW   Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street: Approach	Eastbound			Westbound		
Movement	1 L	2 T	3 R	4 L	5 T	6 R
Volume	54	397	13	24	397	78
Peak-Hour Factor, PHF	0.90	0.95	0.65	0.86	0.89	0.81
Hourly Flow Rate, HFR	60	417	20	27	446	96
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided			/		
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration	LTR			LTR		
Upstream Signal?		No			No	

Minor Street: Approach	Northbound			Southbound		
Movement	7 L	8 T	9 R	10 L	11 T	12 R
Volume	10	36	49	46	28	44
Peak Hour Factor, PHF	0.50	0.64	0.88	0.77	0.78	0.85
Hourly Flow Rate, HFR	20	56	55	59	35	51
Percent Heavy Vehicles	0	0	0	0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			No /			No /
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	

Delay, Queue Length, and Level of Service

Approach	EB	WB	Northbound			Southbound		
Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR		LTR			LTR	
v (vph)	60	27		131			145	
C(m) (vph)	1033	1126		232			178	
v/c	0.06	0.02		0.56			0.81	
95% queue length	0.18	0.07		3.12			5.59	
Control Delay	8.7	8.3		38.9			79.2	
LOS	A	A		E			F	
Approach Delay				38.9			79.2	
Approach LOS				E			F	

HCS+: Unsignalized Intersections Release 5.6

Phone: Fax:
E-Mail:

TWO-WAY STOP CONTROL(TWSC) ANALYSIS

Analyst:
Agency/Co.:
Date Performed: 11/14/2017
Analysis Time Period: 4-5 PM
Intersection: Shawsheen/Beech/Foster
Jurisdiction:
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Beech/Foster
Intersection Orientation: EW Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street Movements	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	54	397	13	24	397	78
Peak-Hour Factor, PHF	0.90	0.95	0.65	0.86	0.89	0.81
Peak-15 Minute Volume	15	104	5	7	112	24
Hourly Flow Rate, HFR	60	417	20	27	446	96
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided			/		
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration	LTR			LTR		
Upstream Signal?		No			No	

Minor Street Movements	7	8	9	10	11	12
	L	T	R	L	T	R
Volume	10	36	49	46	28	44
Peak Hour Factor, PHF	0.50	0.64	0.88	0.77	0.78	0.85
Peak-15 Minute Volume	5	14	14	15	9	13
Hourly Flow Rate, HFR	20	56	55	59	35	51
Percent Heavy Vehicles	0	0	0	0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			No /			No /
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	

Pedestrian Volumes and Adjustments

Movements	13	14	15	16
Flow (ped/hr)	3	4	4	2

Lane Width (ft)	12.0	12.0	12.0	12.0
Walking Speed (ft/sec)	4.0	4.0	4.0	4.0
Percent Blockage	0	0	0	0

Upstream Signal Data

	Prog. Flow vph	Sat Flow vph	Arrival Type	Green Time sec	Cycle Length sec	Prog. Speed mph	Distance to Signal feet
S2 Left-Turn							
Through							
S5 Left-Turn							
Through							

Worksheet 3-Data for Computing Effect of Delay to Major Street Vehicles

	Movement 2	Movement 5
Shared ln volume, major th vehicles:	417	446
Shared ln volume, major rt vehicles:	20	96
Sat flow rate, major th vehicles:	1700	1700
Sat flow rate, major rt vehicles:	1700	1700
Number of major street through lanes:	1	1

Worksheet 4-Critical Gap and Follow-up Time Calculation

Critical Gap Calculation

Movement	1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(c,base)	4.1	4.1	7.1	6.5	6.2	7.1	6.5	6.2
t(c,hv)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(hv)	0	0	0	0	0	0	0	0
t(c,g)			0.20	0.20	0.10	0.20	0.20	0.10
Percent Grade			0.00	0.00	0.00	0.00	0.00	0.00
t(3,lt)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
t(c,T): 1-stage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-stage	0.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00
t(c) 1-stage	4.1	4.1	7.1	6.5	6.2	7.1	6.5	6.2
2-stage								

Follow-Up Time Calculations

Movement	1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(f,base)	2.20	2.20	3.50	4.00	3.30	3.50	4.00	3.30
t(f,HV)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
P(HV)	0	0	0	0	0	0	0	0
t(f)	2.2	2.2	3.5	4.0	3.3	3.5	4.0	3.3

Worksheet 5-Effect of Upstream Signals

Computation 1-Queue Clearance Time at Upstream Signal

	Movement 2 V(t)	Movement 2 V(l,prot)	Movement 5 V(t)	Movement 5 V(l,prot)
V prog				

Total Saturation Flow Rate, s (vph)
Arrival Type
Effective Green, g (sec)
Cycle Length, C (sec)
Rp (from Exhibit 16-11)
Proportion vehicles arriving on green P
g(q1)
g(q2)
g(q)

Computation 2-Proportion of TWSC Intersection Time blocked

	Movement 2		Movement 5	
	V(t)	V(l,prot)	V(t)	V(l,prot)
alpha				
beta				
Travel time, t(a) (sec)				
Smoothing Factor, F				
Proportion of conflicting flow, f				
Max platooned flow, V(c,max)				
Min platooned flow, V(c,min)				
Duration of blocked period, t(p)				
Proportion time blocked, p	0.000		0.000	

Computation 3-Platoon Event Periods	Result
p(2)	0.000
p(5)	0.000
p(dom)	
p(subo)	
Constrained or unconstrained?	

Proportion unblocked for minor movements, p(x)	(1) Single-stage Process	(2) Two-Stage Process Stage I	(3) Two-Stage Process Stage II
p(1)			
p(4)			
p(7)			
p(8)			
p(9)			
p(10)			
p(11)			
p(12)			

Computation 4 and 5
Single-Stage Process

Movement	1	4	7	8	9	10	11	12
	L	L	L	T	R	L	T	R
V c,x	544	441	1145	1149	435	1156	1111	499
s								
Px								
V c,u,x								
C r,x								
C plat,x								

Two-Stage Process

	7	8	10	11

	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2
V(c,x)								
s		1500		1500		1500		1500
P(x)								
V(c,u,x)								
C(r,x)								
C(plat,x)								

Worksheet 6-Impedance and Capacity Equations

Step 1: RT from Minor St.	9	12
Conflicting Flows	435	499
Potential Capacity	625	576
Pedestrian Impedance Factor	0.99	1.00
Movement Capacity	621	574
Probability of Queue free St.	0.91	0.91

Step 2: LT from Major St.	4	1
Conflicting Flows	441	544
Potential Capacity	1130	1035
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity	1126	1033
Probability of Queue free St.	0.98	0.94
Maj L-Shared Prob Q free St.	0.96	0.92

Step 3: TH from Minor St.	8	11
Conflicting Flows	1149	1111
Potential Capacity	200	211
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	0.88	0.88
Movement Capacity	177	187
Probability of Queue free St.	0.68	0.81

Step 4: LT from Minor St.	7	10
Conflicting Flows	1145	1156
Potential Capacity	178	175
Pedestrian Impedance Factor	0.99	1.00
Maj. L, Min T Impedance factor	0.72	0.60
Maj. L, Min T Adj. Imp Factor.	0.78	0.69
Cap. Adj. factor due to Impeding mvmnt	0.71	0.63
Movement Capacity	126	110

Worksheet 7-Computation of the Effect of Two-stage Gap Acceptance

Step 3: TH from Minor St.	8	11
Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		
Probability of Queue free St.		

Part 2 - Second Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 3 - Single Stage		
Conflicting Flows	1149	1111
Potential Capacity	200	211
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	0.88	0.88
Movement Capacity	177	187

Result for 2 stage process:		
a		
y		
C t	177	187
Probability of Queue free St.	0.68	0.81

Step 4: LT from Minor St.	7	10

Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 2 - Second Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		

Part 3 - Single Stage		
Conflicting Flows	1145	1156
Potential Capacity	178	175
Pedestrian Impedance Factor	0.99	1.00
Maj. L, Min T Impedance factor	0.72	0.60
Maj. L, Min T Adj. Imp Factor.	0.78	0.69
Cap. Adj. factor due to Impeding mvmnt	0.71	0.63
Movement Capacity	126	110

Results for Two-stage process:		
a		
y		
C t	126	110

Worksheet 8-Shared Lane Calculations

Movement	7 L	8 T	9 R	10 L	11 T	12 R
Volume (vph)	20	56	55	59	35	51
Movement Capacity (vph)	126	177	621	110	187	574
Shared Lane Capacity (vph)		232			178	

Worksheet 9-Computation of Effect of Flared Minor Street Approaches

Movement	7	8	9	10	11	12
	L	T	R	L	T	R
C sep	126	177	621	110	187	574
Volume	20	56	55	59	35	51
Delay						
Q sep						
Q sep +1						
round (Qsep +1)						
n max						
C sh		232			178	
SUM C sep						
n						
C act						

Worksheet 10-Delay, Queue Length, and Level of Service

Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR		LTR			LTR	
v (vph)	60	27		131			145	
C(m) (vph)	1033	1126		232			178	
v/c	0.06	0.02		0.56			0.81	
95% queue length	0.18	0.07		3.12			5.59	
Control Delay	8.7	8.3		38.9			79.2	
LOS	A	A		E			F	
Approach Delay				38.9			79.2	
Approach LOS				E			F	

Worksheet 11-Shared Major LT Impedance and Delay

	Movement 2	Movement 5
p(oj)	0.94	0.98
v(il), Volume for stream 2 or 5	417	446
v(i2), Volume for stream 3 or 6	20	96
s(il), Saturation flow rate for stream 2 or 5	1700	1700
s(i2), Saturation flow rate for stream 3 or 6	1700	1700
P*(oj)	0.92	0.96
d(M,LT), Delay for stream 1 or 4	8.7	8.3
N, Number of major street through lanes	1	1
d(rank,1) Delay for stream 2 or 5	0.7	0.3

HCS 2010: MUTCD Signal Warrants Release 6.50

Analyst:
Agency:
Date: 12/4/2017
Project ID:
EW Street: Shawsheen

Intersection: Shawsheen-Foster-Beech
Jurisdiction:
Units: U.S. Customary
Analysis Year:
NS Street: Foster/Beech

General Information

Major St. Speed (mph): 40
Nearest Signal (ft): 0
Crashes per Yr: 3

Population: Not less than 10000
Coordinated Signal System: N

School Crossing

Students in Highest Hour: 0
Adequate Gaps in Period: 0
Minutes in Period: 0

Roadway Network

Two Major Routes: 0
Weekend Count: 0
5-yr Growth Factor: 0

Geometry and Traffic

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes	0	1	0	0	1	0	0	1	0	0	1	0
LaneUsage		LTR			LTR			LTR			LTR	

Results

Warrant 1: Eight-Hour Vehicular Volume [ ]
1 A. Minimum Vehicular Volumes [ ]
1 B. Interruption of Continuous Traffic [ ]
1 80% Vehicular --and-- Interruption Volumes [ ]

Warrant 2: Four-Hour Vehicular Volume
2 A. Four-Hour Vehicular Volumes [ ]

Warrant 3: Peak Hour [ ]
3 A. Peak-Hour Conditions [ ]
3 B. Peak-Hour Vehicular Volume Hours Met [ ]

Warrant 4: Pedestrian Volume [ ]
4 A. Pedestrian Volumes [ ]
4 B. Gaps Same Period [ ]

Warrant 5: School Crossing [ ]
5 A. Student Volumes [ ]
5 B. Gaps Same Period [ ]

Warrant 6: Coordinated Signal System
6 Degree of Platooning [ ]

Warrant 7: Crash Experience [ ]
7 A. Adequate trials of alternatives [ ]

7 B. Reported crashes [ ]
7 80% Volumes for Warrants 1A, 1B --or-- 4 [ ]

Warrant 8: Roadway Network [ ]
8 A. Weekday Volume [ ]
8 B. Weekend Volume [ ]

Summary

Hours	Major Volume	Minor Volume	Total Volume	Delay (Veh-hr)	1A 100%	1A 80%	1B 100%	1B 80%	2 100%	3A 100%	3B 100%
06-07	525	120	673	0.0	No	Yes	No	No	No	No	No
07-08	832	166	1042	3.9	Yes	Yes	Yes	Yes	Yes	No	No
08-09	634	123	815	0.0	No	Yes	No	Yes	No	No	No
09-10	382	71	503	0.0	No	No	No	No	No	No	No
10-11	299	62	388	0.0	No	No	No	No	No	No	No
11-12	367	57	446	0.0	No	No	No	No	No	No	No
12-13	383	58	478	0.0	No	No	No	No	No	No	No
13-14	409	69	513	0.0	No	No	No	No	No	No	No
14-15	530	92	652	0.0	No	No	No	No	No	No	No
15-16	829	103	986	0.0	No	No	Yes	Yes	No	No	No
16-17	963	118	1176	2.6	No	No	Yes	Yes	Yes	No	No
17-18	927	113	1129	0.0	No	No	Yes	Yes	No	No	No
Total	7080	1152	8801		1	3	4	5	2	0	0

Traffic Volumes (vph)

Eastbound L	Eastbound T	Eastbound R	Westbound L	Westbound T	Westbound R	Northbound L	Northbound T	Northbound R	Southbound L	Southbound T	Southbound R
15	210	1	9	281	9	5	4	19	43	26	51
36	289	5	15	453	34	6	15	23	67	34	65
0	184	0	0	450	0	0	58	0	0	123	0
0	132	0	0	250	0	0	50	0	0	71	0
0	110	0	0	189	0	0	27	0	0	62	0
0	141	0	0	226	0	0	22	0	0	57	0
0	134	0	0	249	0	0	37	0	0	58	0
0	140	0	0	269	0	0	35	0	0	69	0
0	201	0	0	329	0	0	30	0	0	92	0
53	311	12	28	342	83	7	16	31	59	20	24
54	397	13	24	397	78	10	36	49	46	28	44
0	410	0	0	517	0	0	89	0	0	113	0

Pedestrian Volumes and Gaps (Per Hour)

Volume	Gap	Volume	Gap	Volume	Gap	Volume	Gap
0	0	0	0	0	0	0	0
1	0	1	0	1	0	1	0
1	0	1	0	1	0	1	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
1	0	0	0	2	0	0	0
2	0	1	0	0	0	2	0
0	0	0	0	0	0	0	0

Delay	sec/veh	veh-hrs	sec/veh	veh-hrs	sec/veh	veh-hrs	sec/veh	veh-hrs
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8.7	0.8	8.0	1.1	22.9	0.3	83.5	3.9
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.7	1.1	8.3	1.2	38.9	1.0	79.2	2.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

HCS+: Unsignalized Intersections Release 5.6

TWO-WAY STOP CONTROL SUMMARY

Analyst:
Agency/Co.:
Date Performed: 11/07/2017
Analysis Time Period: 7-8 AM
Intersection: Shawsheen/Beech/Foster
Jurisdiction: 1% increase in traffic
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Beech/Foster
Intersection Orientation: EW   Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street: Approach	Eastbound			Westbound		
Movement	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	36	292	5	15	458	34
Peak-Hour Factor, PHF	0.90	0.83	0.42	0.63	0.87	0.65
Hourly Flow Rate, HFR	40	351	11	23	526	52
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided		/			
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	
Upstream Signal?		No			No	

Minor Street: Approach	Northbound			Southbound		
Movement	7	8	9	10	11	12
	L	T	R	L	T	R
Volume	6	15	23	68	34	66
Peak Hour Factor, PHF	0.50	0.63	0.82	0.67	0.77	0.95
Hourly Flow Rate, HFR	12	23	28	101	44	69
Percent Heavy Vehicles	0	0	0	0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			No /			No /
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	

Delay, Queue Length, and Level of Service

Approach	EB	WB	Northbound			Southbound		
Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR		LTR			LTR	
v (vph)	40	23		63			214	
C(m) (vph)	1004	1206		260			228	
v/c	0.04	0.02		0.24			0.94	
95% queue length	0.12	0.06		0.92			8.13	
Control Delay	8.7	8.0		23.2			89.8	
LOS	A	A		C			F	
Approach Delay				23.2			89.8	
Approach LOS				C			F	

HCS+: Unsignalized Intersections Release 5.6

Phone: Fax:
E-Mail:

TWO-WAY STOP CONTROL(TWSC) ANALYSIS

Analyst:
Agency/Co.:
Date Performed: 11/07/2017
Analysis Time Period: 7-8 AM
Intersection: Shawsheen/Beech/Foster
Jurisdiction: 1% increase in traffic
Units: U. S. Customary
Analysis Year:
Project ID:
East/West Street: Shawsheen
North/South Street: Beech/Foster
Intersection Orientation: EW Study period (hrs): 0.25

Vehicle Volumes and Adjustments

Major Street Movements	1	2	3	4	5	6
	L	T	R	L	T	R
Volume	36	292	5	15	458	34
Peak-Hour Factor, PHF	0.90	0.83	0.42	0.63	0.87	0.65
Peak-15 Minute Volume	10	88	3	6	132	13
Hourly Flow Rate, HFR	40	351	11	23	526	52
Percent Heavy Vehicles	0	--	--	0	--	--
Median Type/Storage	Undivided			/		
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration	LTR			LTR		
Upstream Signal?		No			No	

Minor Street Movements	7	8	9	10	11	12
	L	T	R	L	T	R
Volume	6	15	23	68	34	66
Peak Hour Factor, PHF	0.50	0.63	0.82	0.67	0.77	0.95
Peak-15 Minute Volume	3	6	7	25	11	17
Hourly Flow Rate, HFR	12	23	28	101	44	69
Percent Heavy Vehicles	0	0	0	0	0	0
Percent Grade (%)		0			0	
Flared Approach: Exists?/Storage			No	/		No /
RT Channelized?						
Lanes	0	1	0	0	1	0
Configuration		LTR			LTR	

Pedestrian Volumes and Adjustments

Movements	13	14	15	16
Flow (ped/hr)	1	1	1	1

Lane Width (ft)	12.0	12.0	12.0	12.0
Walking Speed (ft/sec)	4.0	4.0	4.0	4.0
Percent Blockage	0	0	0	0

Upstream Signal Data

	Prog. Flow vph	Sat Flow vph	Arrival Type	Green Time sec	Cycle Length sec	Prog. Speed mph	Distance to Signal feet
S2 Left-Turn							
Through							
S5 Left-Turn							
Through							

Worksheet 3-Data for Computing Effect of Delay to Major Street Vehicles

	Movement 2	Movement 5
Shared ln volume, major th vehicles:	351	526
Shared ln volume, major rt vehicles:	11	52
Sat flow rate, major th vehicles:	1700	1700
Sat flow rate, major rt vehicles:	1700	1700
Number of major street through lanes:	1	1

Worksheet 4-Critical Gap and Follow-up Time Calculation

Critical Gap Calculation

Movement		1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(c,base)		4.1	4.1	7.1	6.5	6.2	7.1	6.5	6.2
t(c,hv)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(hv)		0	0	0	0	0	0	0	0
t(c,g)				0.20	0.20	0.10	0.20	0.20	0.10
Percent Grade				0.00	0.00	0.00	0.00	0.00	0.00
t(3,lt)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
t(c,T):	1-stage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2-stage	0.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00
t(c)	1-stage	4.1	4.1	7.1	6.5	6.2	7.1	6.5	6.2
	2-stage								

Follow-Up Time Calculations

Movement	1 L	4 L	7 L	8 T	9 R	10 L	11 T	12 R
t(f,base)	2.20	2.20	3.50	4.00	3.30	3.50	4.00	3.30
t(f,HV)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
P(HV)	0	0	0	0	0	0	0	0
t(f)	2.2	2.2	3.5	4.0	3.3	3.5	4.0	3.3

Worksheet 5-Effect of Upstream Signals

Computation 1-Queue Clearance Time at Upstream Signal

	Movement 2 V(t)	Movement 2 V(l,prot)	Movement 5 V(t)	Movement 5 V(l,prot)
V prog				

Total Saturation Flow Rate, s (vph)
Arrival Type
Effective Green, g (sec)
Cycle Length, C (sec)
Rp (from Exhibit 16-11)
Proportion vehicles arriving on green P
g(q1)
g(q2)
g(q)

Computation 2-Proportion of TWSC Intersection Time blocked

	Movement 2		Movement 5	
	V(t)	V(l,prot)	V(t)	V(l,prot)
alpha				
beta				
Travel time, t(a) (sec)				
Smoothing Factor, F				
Proportion of conflicting flow, f				
Max platooned flow, V(c,max)				
Min platooned flow, V(c,min)				
Duration of blocked period, t(p)				
Proportion time blocked, p		0.000		0.000

Computation 3-Platoon Event Periods	Result
p(2)	0.000
p(5)	0.000
p(dom)	
p(subo)	
Constrained or unconstrained?	

Proportion unblocked for minor movements, p(x)	(1) Single-stage Process	(2) Two-Stage Process Stage I	(3) Two-Stage Process Stage II
p(1)			
p(4)			
p(7)			
p(8)			
p(9)			
p(10)			
p(11)			
p(12)			

Computation 4 and 5
Single-Stage Process

Movement	1	4	7	8	9	10	11	12
	L	L	L	T	R	L	T	R
V c,x	579	363	1094	1063	358	1062	1042	554
s								
Px								
V c,u,x								
C r,x								
C plat,x								

Two-Stage Process

	7	8	10	11

	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2	Stage1	Stage2
V(c,x)								
s		1500		1500		1500		1500
P(x)								
V(c,u,x)								
C(r,x)								
C(plat,x)								

Worksheet 6-Impedance and Capacity Equations

Step 1: RT from Minor St.	9	12
Conflicting Flows	358	554
Potential Capacity	691	536
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity	690	535
Probability of Queue free St.	0.96	0.87

Step 2: LT from Major St.	4	1
Conflicting Flows	363	579
Potential Capacity	1207	1005
Pedestrian Impedance Factor	1.00	1.00
Movement Capacity	1206	1004
Probability of Queue free St.	0.98	0.96
Maj L-Shared Prob Q free St.	0.97	0.95

Step 3: TH from Minor St.	8	11
Conflicting Flows	1063	1042
Potential Capacity	225	232
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	0.92	0.92
Movement Capacity	207	214
Probability of Queue free St.	0.89	0.79

Step 4: LT from Minor St.	7	10
Conflicting Flows	1094	1062
Potential Capacity	193	203
Pedestrian Impedance Factor	1.00	1.00
Maj. L, Min T Impedance factor	0.73	0.82
Maj. L, Min T Adj. Imp Factor.	0.79	0.86
Cap. Adj. factor due to Impeding mvmnt	0.69	0.82
Movement Capacity	133	167

Worksheet 7-Computation of the Effect of Two-stage Gap Acceptance

Step 3: TH from Minor St.	8	11
Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		
Probability of Queue free St.		

Part 2 - Second Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		
Part 3 - Single Stage		
Conflicting Flows	1063	1042
Potential Capacity	225	232
Pedestrian Impedance Factor	1.00	1.00
Cap. Adj. factor due to Impeding mvmnt	0.92	0.92
Movement Capacity	207	214
Result for 2 stage process:		
a		
y		
C t	207	214
Probability of Queue free St.	0.89	0.79

Step 4: LT from Minor St.	7	10
Part 1 - First Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		
Part 2 - Second Stage		
Conflicting Flows		
Potential Capacity		
Pedestrian Impedance Factor		
Cap. Adj. factor due to Impeding mvmnt		
Movement Capacity		
Part 3 - Single Stage		
Conflicting Flows	1094	1062
Potential Capacity	193	203
Pedestrian Impedance Factor	1.00	1.00
Maj. L, Min T Impedance factor	0.73	0.82
Maj. L, Min T Adj. Imp Factor.	0.79	0.86
Cap. Adj. factor due to Impeding mvmnt	0.69	0.82
Movement Capacity	133	167
Results for Two-stage process:		
a		
y		
C t	133	167

Worksheet 8-Shared Lane Calculations

Movement	7 L	8 T	9 R	10 L	11 T	12 R
Volume (vph)	12	23	28	101	44	69
Movement Capacity (vph)	133	207	690	167	214	535
Shared Lane Capacity (vph)		260			228	

Worksheet 9-Computation of Effect of Flared Minor Street Approaches

Movement	7 L	8 T	9 R	10 L	11 T	12 R
C sep	133	207	690	167	214	535
Volume	12	23	28	101	44	69
Delay						
Q sep						
Q sep +1						
round (Qsep +1)						
n max						
C sh		260			228	
SUM C sep						
n						
C act						

Worksheet 10-Delay, Queue Length, and Level of Service

Movement	1	4	7	8	9	10	11	12
Lane Config	LTR	LTR		LTR			LTR	
v (vph)	40	23		63			214	
C(m) (vph)	1004	1206		260			228	
v/c	0.04	0.02		0.24			0.94	
95% queue length	0.12	0.06		0.92			8.13	
Control Delay	8.7	8.0		23.2			89.8	
LOS	A	A		C			F	
Approach Delay				23.2			89.8	
Approach LOS				C			F	

Worksheet 11-Shared Major LT Impedance and Delay

	Movement 2	Movement 5
p(oj)	0.96	0.98
v(il), Volume for stream 2 or 5	351	526
v(i2), Volume for stream 3 or 6	11	52
s(il), Saturation flow rate for stream 2 or 5	1700	1700
s(i2), Saturation flow rate for stream 3 or 6	1700	1700
P*(oj)	0.95	0.97
d(M,LT), Delay for stream 1 or 4	8.7	8.0
N, Number of major street through lanes	1	1
d(rank,1) Delay for stream 2 or 5	0.4	0.2

HCS 2010: MUTCD Signal Warrants Release 6.50

Analyst:
Agency:
Date: 12/4/2017
Project ID: 1% increase in traffic
EW Street: Shawsheen

Intersection: Shawsheen-Foster-Beech
Jurisdiction:
Units: U.S. Customary
Analysis Year:
NS Street: Foster/Beech

General Information

Major St. Speed (mph): 40
Nearest Signal (ft): 0
Crashes per Yr: 3

Population: Not less than 10000
Coordinated Signal System: N

School Crossing

Students in Highest Hour: 0
Adequate Gaps in Period: 0
Minutes in Period: 0

Roadway Network

Two Major Routes: 0
Weekend Count: 0
5-yr Growth Factor: 0

Geometry and Traffic

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes	0	1	0	0	1	0	0	1	0	0	1	0
LaneUsage	LTR			LTR			LTR			LTR		

Results

Warrant 1: Eight-Hour Vehicular Volume	[ ]
1 A. Minimum Vehicular Volumes	[ ]
1 B. Interruption of Continuous Traffic	[ ]
1 80% Vehicular --and-- Interruption Volumes	[ ]
Warrant 2: Four-Hour Vehicular Volume	
2 A. Four-Hour Vehicular Volumes	[ ]
Warrant 3: Peak Hour	[X]
3 A. Peak-Hour Conditions	[X]
3 B. Peak-Hour Vehicular Volume Hours Met	[ ]
Warrant 4: Pedestrian Volume	[ ]
4 A. Pedestrian Volumes	[ ]
4 B. Gaps Same Period	[ ]
Warrant 5: School Crossing	[ ]
5 A. Student Volumes	[ ]
5 B. Gaps Same Period	[ ]
Warrant 6: Coordinated Signal System	
6 Degree of Platooning	[ ]
Warrant 7: Crash Experience	[ ]
7 A. Adequate trials of alternatives	[ ]

7 B. Reported crashes [ ]
7 80% Volumes for Warrants 1A, 1B --or-- 4 [ ]

Warrant 8: Roadway Network [ ]
8 A. Weekday Volume [ ]
8 B. Weekend Volume [ ]

Summary

Hours	Major Volume	Minor Volume	Total Volume	Delay (Veh-hr)	1A 100%	1A 80%	1B 100%	1B 80%	2 100%	3A 100%	3B 100%
06-07	525	120	673	0.0	No	Yes	No	No	No	No	No
07-08	832	166	1042	4.1	Yes	Yes	Yes	Yes	Yes	Yes	No
08-09	634	123	815	0.0	No	Yes	No	Yes	No	No	No
09-10	382	71	503	0.0	No	No	No	No	No	No	No
10-11	299	62	388	0.0	No	No	No	No	No	No	No
11-12	367	57	446	0.0	No	No	No	No	No	No	No
12-13	383	58	478	0.0	No	No	No	No	No	No	No
13-14	409	69	513	0.0	No	No	No	No	No	No	No
14-15	530	92	652	0.0	No	No	No	No	No	No	No
15-16	829	103	986	0.0	No	No	Yes	Yes	No	No	No
16-17	963	118	1176	2.6	No	No	Yes	Yes	Yes	No	No
17-18	927	113	1129	0.0	No	No	Yes	Yes	No	No	No
Total	7080	1152	8801		1	3	4	5	2	1	0

Traffic Volumes (vph)

Eastbound L	Eastbound T	Eastbound R	Westbound L	Westbound T	Westbound R	Northbound L	Northbound T	Northbound R	Southbound L	Southbound T	Southbound R
15	210	1	9	281	9	5	4	19	43	26	51
36	289	5	15	453	34	6	15	23	67	34	65
0	184	0	0	450	0	0	58	0	0	123	0
0	132	0	0	250	0	0	50	0	0	71	0
0	110	0	0	189	0	0	27	0	0	62	0
0	141	0	0	226	0	0	22	0	0	57	0
0	134	0	0	249	0	0	37	0	0	58	0
0	140	0	0	269	0	0	35	0	0	69	0
0	201	0	0	329	0	0	30	0	0	92	0
53	311	12	28	342	83	7	16	31	59	20	24
54	397	13	24	397	78	10	36	49	46	28	44
0	410	0	0	517	0	0	89	0	0	113	0

Pedestrian Volumes and Gaps (Per Hour)

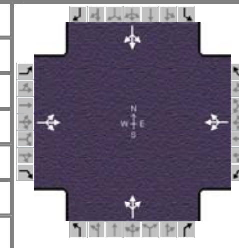
Volume	Gap	Volume	Gap	Volume	Gap	Volume	Gap
0	0	0	0	0	0	0	0
1	0	1	0	1	0	1	0
1	0	1	0	1	0	1	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
1	0	0	0	2	0	0	0
2	0	1	0	0	0	2	0
0	0	0	0	0	0	0	0

Delay	sec/veh	veh-hrs	sec/veh	veh-hrs	sec/veh	veh-hrs	sec/veh	veh-hrs
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8.7	0.8	8.0	1.1	22.9	0.3	89.8	4.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.7	1.1	8.3	1.2	38.9	1.0	79.2	2.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

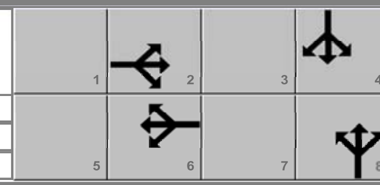
HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	1/19/2018	Area Type	Other
Jurisdiction		Time Period		PHF	0.92
Intersection		Analysis Year	2018	Analysis Period	1> 7:00
File Name	Signal_ShawsheenBeechFoster_AM.xus				
Project Description					



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	36	292	5	15	458	34	6	15	23	68	34	66

Signal Information										
Cycle, s	70.0	Reference Phase	2							
Offset, s	0	Reference Point	Begin	Green	49.4	10.6	0.0	0.0	0.0	0.0
Uncoordinated	No	Simult. Gap E/W	On	Yellow	4.0	4.0	0.0	0.0	0.0	0.0
Force Mode	Fixed	Simult. Gap N/S	On	Red	1.0	1.0	0.0	0.0	0.0	0.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase		2		6		8		4
Case Number		8.0		8.0		8.0		8.0
Phase Duration, s		54.4		54.4		15.6		15.6
Change Period, (*Y+R$_c$*), s		5.0		5.0		5.0		5.0
Max Allow Headway (*MAH*), s		0.0		0.0		3.2		3.2
Queue Clearance Time (*g$_s$*), s						3.9		10.3
Green Extension Time (*g$_e$*), s		0.0		0.0		0.4		0.4
Phase Call Probability						0.99		0.99
Max Out Probability						0.00		0.00

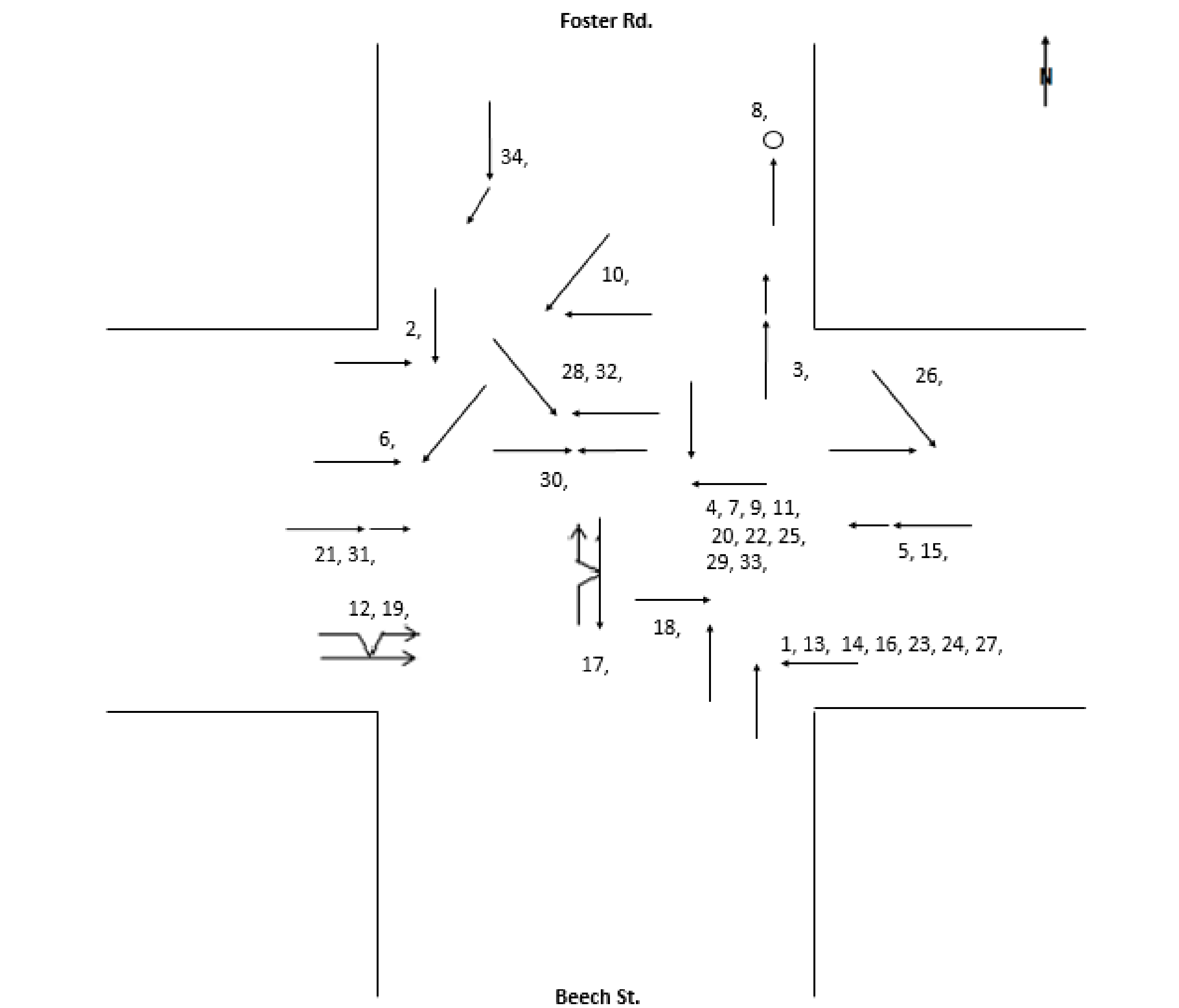
Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	5	2	12	1	6	16	3	8	18	7	4	14
Adjusted Flow Rate (*v*), veh/h		362			551			48			183	
Adjusted Saturation Flow Rate (*s*), veh/h/ln		1590			1669			1566			1485	
Queue Service Time (*g$_s$*), s		0.0			0.0			0.0			6.4	
Cycle Queue Clearance Time (*g$_c$*), s		5.6			10.0			1.9			8.3	
Green Ratio (*g/C*)		0.71			0.71			0.15			0.15	
Capacity (*c*), veh/h		1180			1232			295			296	
Volume-to-Capacity Ratio (*X*)		0.307			0.447			0.162			0.617	
Available Capacity (*c$_a$*), veh/h		1180			1232			603			597	
Back of Queue (*Q*), veh/ln (50th percentile)		1.4			2.5			0.7			2.8	
Queue Storage Ratio (*RQ*) (50th percentile)		0.00			0.00			0.00			0.00	
Uniform Delay (*d$_1$*), s/veh		3.8			4.5			26.0			28.7	
Incremental Delay (*d$_2$*), s/veh		0.7			1.2			0.1			0.8	
Initial Queue Delay (*d$_3$*), s/veh		0.0			0.0			0.0			0.0	
Control Delay (*d*), s/veh		4.5			5.7			26.1			29.5	
Level of Service (LOS)		A			A			C			C	
Approach Delay, s/veh / LOS	4.5		A	5.7		A	26.1		C	29.5		C
Intersection Delay, s/veh / LOS	10.0						A					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.0	B	2.0	B	2.1	B	2.1	B
Bicycle LOS Score / LOS	1.1	A	1.4	A	0.6	A	0.8	A

 HCS 2010™ Streets Version 6.50 Generated: 2/28/2018 2:02:13 PM

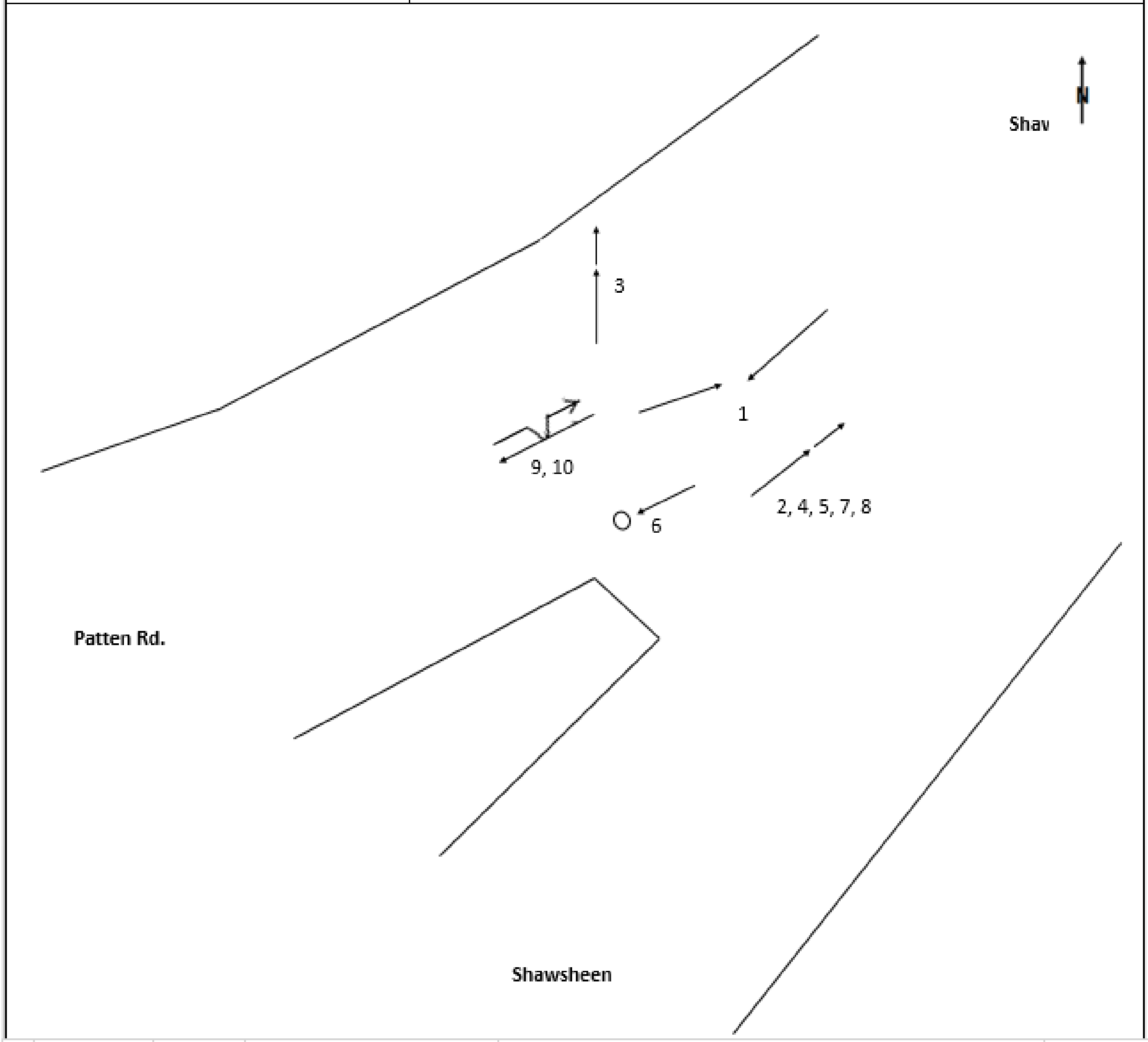
Appendix F: Crash Diagrams

Vehicle Crash Diagram	Town: Tewksbury
	Location: Shawsheen/Foster/Beech



#	Date	Time	Crash Type	Vehicule Direction	Weather
1	13-May-2002	7:00 AM	Angle	V1:Northbound/V2:Westbound	Rain
2	29-Jun-2002	3:30 AM	Angle	V1:Eastbound/V2:Southbound	Clear
3	01-Mar-2003	5:00 PM	Rear-end	V1:Northbound / V2:Northbound	Clear
4	23-Nov-2003	2:25 PM	Angle	V1:Southbound / V2:Westbound	Clear
5	30-Apr-2004	6:05 PM	Rear-end	V1:Westbound / V2:Westbound	Clear/Clear
6	22-May-2004	3:15 AM	Angle	V1:Eastbound / V2:Westbound	Cloudy
7	09-Jun-2004	9:25 PM	Angle	V1:Southbound / V2:Westbound	Rain/Rain
8	08-Jul-2004	3:15 PM	Single vehicle crash	V1:Northbound	Rain/Cloudy
9	23-Feb-2005	7:45 AM	Angle	V1:Not reported / V2:Not reported	Clear
10	18-Apr-2005	4:05 AM	Angle	V1:Westbound / V2:Westbound	Clear
11	12-May-2005	12:00 PM	Angle	V1:Southbound / V2:Not reported	Clear
12	24-Jun-2005	1:10 PM	Sideswipe, same direction	V1:Eastbound / V2:Not reported	Clear
13	21-Nov-2005	4:50 PM	Not reported	V1:Westbound / V2:Northbound	Clear
14	12-Mar-2006	11:20 AM	Not reported	V1:Not reported / V2:Not reported	Cloudy
15	14-Sep-2006	3:24 PM	Rear-end	V1:Westbound / V2:Westbound	Cloudy/Rain
16	22-Oct-2006	2:18 AM	Angle	V1:Westbound / V2:Northbound	Clear
17	15-Dec-2006	4:15 PM	Sideswipe, opposite direction	V1:Northbound / V2:Westbound	Cloudy
18	28-Mar-2007	12:07 PM	Angle	V1: Backing / V2:Travelling straight ahead	Dry
19	05-May-2007	1:26 AM	Sideswipe, same direction	V1: Travelling straight ahead / V2:Overtaking/passing	Dry
20	15-Nov-2007	1:00 AM	Not reported	V1: Travelling straight ahead / V2:Slowing or stopped in traffic	Wet
21	08-Jan-2008	8:55 AM	Rear-end	V1: Travelling straight ahead / V2:Slowing or stopped in traffic	Dry
22	31-Jan-2008	3:45 AM	Angle	V1: Travelling straight ahead / V2:Turning left	Dry
23	04-Apr-2008	5:19 PM	Angle	V1: Not reported / V2:Travelling straight ahead	Wet
24	03-May-2008	4:59 PM	Angle	V1: Travelling straight ahead / V2:Travelling straight ahead	Wet
25	09-May-2008	6:00 PM	Angle	V1: Slowing or stopped in traffic / V2:Other	Wet
26	18-Jan-2011	3:41 PM	Angle	V1: Slowing or stopped in traffic / V2:Travelling straight ahead	Slush
27	23-Sep-2011	4:25 PM	Angle	V1: Travelling straight ahead / V2:Travelling straight ahead	Wet
28	04-Oct-2011	4:28 PM	Angle	V1: Travelling straight ahead / V2:Turning left	Wet
29	15-Feb-2014	5:10 PM	Angle	V1: Slowing or stopped in traffic / V2:Turning right	Snow
30	10-Sep-2014	6:56 AM	Head-on	V1: Travelling straight ahead / V2:Travelling straight ahead	Dry
31	22-Dec-2014	8:51 AM	Rear-end	V1: Travelling straight ahead / V2:Slowing or stopped in traffic	Wet
32	22-Jul-2015	5:09 PM	Angle	V1: Turning left / V2:Travelling straight ahead	Dry
33	21-Oct-2015	3:10 PM	Angle	V1: Travelling straight ahead / V2:Travelling straight ahead	Dry
34	23-Dec-2015	4:38 PM	Unknown	V1: Slowing or stopped in traffic / V2:Backing	Wet

Vehicle Crash Diagram	Town: Tewksbury
	Location: Shawsheen/Patten



#	Date	Time	Crash Type	Vehicule Direction	Weather
1	09-Feb-2002	3:32 PM	Angle	V1:Westbound/V2:Eastbound	Clear
2	04-Feb-2006	12:20 PM	Rear-end	V1:Eastbound / V2:Eastbound	Clear
3	14-Feb-2006	3:10 AM	Rear-end	V1:Northbound / V2:Northbound	Clear
4	30-Dec-2006	1:55 AM	Rear-end	V1:Eastbound / V2:Eastbound	Snow
5	26-Jun-2009	2:14 PM	Rear-end	V1: Slowing or stopped in traffic / V2:Travelling straight ahead	Wet
6	20-Feb-2012	12:00 AM	Single vehicle crash	V1: Travelling straight ahead	Dry
7	21-Dec-2013	12:09 PM	Rear-end	V1: Slowing or stopped in traffic / V2:Slowing or stopped in traffic	Wet
8	04-Jan-2014	12:42 PM	Rear-end	V1: Slowing or stopped in traffic / V2:Slowing or stopped in traffic	Snow
9	22-Oct-2014	2:20 PM	Sideswipe, opposite direction	V1: Turning left / V2:Travelling straight ahead	Wet
10	08-Mar-2015	6:48 PM	Sideswipe, opposite direction	V1: Entering traffic lane / V2:Travelling straight ahead	Dry

Appendix G: Police Crash Reports

Date	Time	Crash Type	Location
3/31/2016	5:39 PM	Angle	Shawsheen/Patten
5/11/2016	12:43 AM	Object	Shawsheen Street
4/20/2017	3:53 PM	Angle	Shawsheen/Foster
5/21/2017	7:18 PM	Angle	Tewksbury Marker
6/16/2017	5:24 PM	Angle	Shawsheen/Beech
6/30/2017	4:26 PM	Object	Shawsheen Street
11/1/2017	7:19 AM	Angle	Shawsheen/Foster

Appendix H: Crash Rate Calculations

INTERSECTION CRASH RATE WORKSHEET

PEAK HOUR VOLUMES

APPROACH :	**1**	**2**	**3**	**4**	**5**	**Total Peak Hourly Approach Volume**
DIRECTION :	Patten	Beech	Shawsheen	Shawsheen	Foster	
PEAK HOURLY VOLUMES (AM/PM) :	119	95	348	499	118	**1,179**

" K " FACTOR :	**0.090**	INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME :	**13,100**

TOTAL # OF CRASHES :	51	# OF YEARS :	16	AVERAGE # OF CRASHES PER YEAR (**A**) :	**3.19**

CRASH RATE CALCULATION : **0.67**

RATE = $\dfrac{(A * 1{,}000{,}000)}{(V * 365)}$