Pedestrian Safety and Walkability in the Shrewsbury Town Center

A Major Qualifying Project submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Bachelor of Science Degree in Civil Engineering

By:
Kristen E. Antunes
Jessica P. D'Agostino

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Advisors:
Leonard Albano
Suzanne LePage

WPI

Stantec

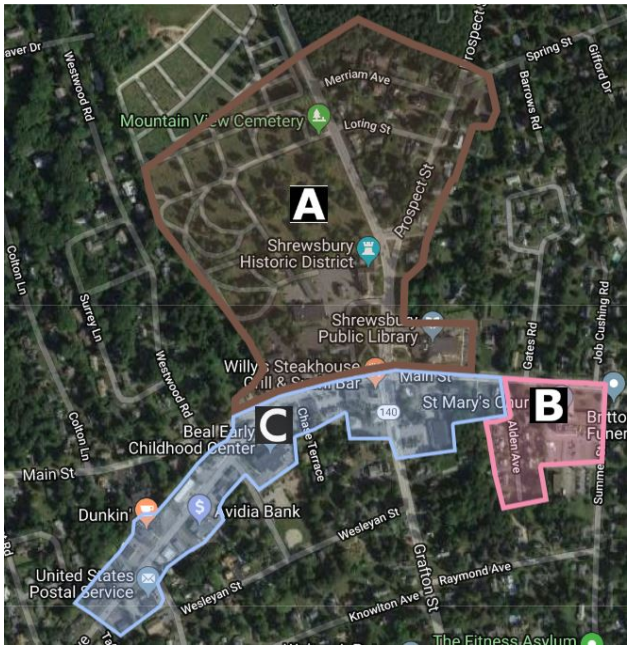
Abstract

This project, on behalf of Stantec, aimed to improve the walkability and pedestrian safety in the Town Center of Shrewsbury, Massachusetts. Analysis was conducted on the core intersection's existing conditions, as well as pedestrian patterns in various areas to identify key problems. Potential improvement options were identified, presented to Town representatives, and the most viable solutions were selected. Signage and pavement marking improvements were proposed, as well as multimodal transportation improvements to address long-term goals.

Executive Summary

Shrewsbury is located in Worcester County, which is centrally situated within the heart of Massachusetts. The goal of this Major Qualifying Project was to enhance walkability and safety in the Town Center in Shrewsbury. The team examined existing conditions of the Town Center, reviewed case studies, developed potential solutions, and recommended a final plan based on stakeholder feedback to meet this goal.

The team first defined the Town Center to develop a scope for the study and divided the Center into distinct character areas. The uses of each area were determined, and the needs and challenges were defined. This allowed for the potential solutions and recommendations to fit the needs of the Town Center.



The Three Character Areas Located in the Town Center

The study of existing conditions included collecting Turning Movement Counts, a Level of Service (LOS) analysis, Crash Data analysis, Heavy Vehicle Data, and Pedestrian Observations. From the data collected and the best practices represented in case studies, a list of countermeasures was created and categorized to understand their area of impact. The needs and challenges of each area was revisited to eliminate infeasible countermeasures and to ensure each area's unique desires were met. Two conceptual design plans were created and presented to the Town of Shrewsbury representatives to determine the priorities of the Town.

The final recommendations for this project were based on the individual area while also considering overarching goals of improving walkability and pedestrian safety in the Town Center. The Final Plan contains the following countermeasures and improvements:

Area A: Signal Timing Modifications and addition of a Radar Feedback Speed Sign
Area B: Addition of Rectangular Rapid Flashing Beacons and two Ladder Crosswalks
Area C: Continuation of sidewalk at two plazas, additional crosswalk and updated signage, and updated striping for on-street parking

Acknowledgments

This project was made possible with the resources provided by Worcester Polytechnic Institute (WPI) and Stantec. The team would like to thank both WPI and Stantec as a whole. The team would also like to thank individual personnel who helped with the completion of this project. From WPI, our advisors Leonard Albano and Suzanne LePage. We would like to thank Stantec personnel: Frederick Moseley, Rachel Santarsiero, Jennifer Ducey, Walt Woo, and Erica Lotz. From the Central Massachusetts Regional Planning Commission (CMRPC), we would like to thank Richard Rydant and Robert Raymond. We would also like to thank the Town of Shrewsbury, specifically Kristen Las, Christopher McGoldrick, Bernard Cahill, and Andrew Truman for their continued support throughout the project.

Authorship

This Major Qualifying Project (MQP) was completed by Civil Engineering Undergraduate Students from Worcester Polytechnic Institute (WPI). Both members of the team were responsible for reading the paper as a whole and editing, as well as writing sections for the paper.

Team member Kristen Antunes wrote the Abstract, Professional Licensure Statement, Introduction, and a significant portion of the Background. For the Methodology Kristen Antunes wrote the following sections: Identifying Key problems in the Town Center, Resident and Business Owner Comments, Document Existing Traffic Conditions, Calculate Existing Efficiency Conditions, Discussion of Heavy Vehicles, Pedestrian Analysis, Heavy Vehicle Case Study, Countermeasure, Eliminating Countermeasures. For the Results Kristen Antunes wrote the following sections: Character Areas, Area A: Historic and Municipal, Area C: Local and Chain Business, Resident and Business Owner Comments, Existing Conditions Analysis, Traffic Volumes, Intersection Efficiency, Heavy Vehicle Analysis, Pedestrian Study, Case Study 2: Heavy Vehicles, Countermeasures, Develop Conceptual Designs, Stakeholder Feedback, Selection of Final Plan, Summary of Final Plan, and Cost Estimate. Kristen Antunes also wrote the Recommendations sections for this MQP report.

Team member Jessica D'Agostino wrote the Capstone Design Statement. In the Background, she wrote the Summary of 2017 Corridor Study Route 140. For the Methodology, Jessica D'Agostino wrote the following sections: Character Areas, Crash Data Analysis, Speed Case Study, Pedestrian Safety Case Study, Evaluating Potential Solutions, Developing Conceptual Design, and Cost Estimate. For the Results Section, Jessica D'Agostino wrote the following sections: Defining the Town Center, Area B: Residential, Crash Data Results Summary, Case Study 1: High Speeds and Traffic Volumes, and Case Study 3: Pedestrian Safety.

Capstone Design Statement

This Major Qualifying Project (MQP) focuses on assessing the walkability and pedestrian safety in the Town Center of Shrewsbury, Massachusetts. The Town of Shrewsbury is focused on making the Town Center a destination for residents and visitors. The team aimed to create conceptual designs and recommendations for pedestrian safety and walkability. The team analyzed the existing conditions of the Town Center to determine key problems within the area. The team worked closely with representatives from both Stantec and the Town of Shrewsbury to meet the needs of the Town Center. This project has several design constraints including economic, environmental, social and political, ethical, and health and safety. By considering the constraints, this project will satisfy the Worcester Polytechnic Institute (WPI) criteria for capstone design, as defined by the Accreditation Board for Engineering and Technology (ABET). The following examines the five constraints related to this project and how the team addressed these constraints:

Economic

Funding for civil engineering and planning projects is an important factor. Many of the projects currently being implemented in the Town of Shrewsbury are funded through grants from the federal government, and therefore have standard regulations that come from sources like the Federal Highway Admiration (FHWA). A cost analysis is often associated with projects to ensure that each proposed project fits within a budget. The team fulfilled this constraint by conducting a cost estimate of the Final Plan proposed and recommending the Town to apply for the Complete Streets Funding Program.

Environmental

With many of the projects funded through federal grants, most, if not all projects have an environmental component to ensure no or limited damage to the environment occurs during the build. An environmental analysis of the area is completed during the design phase, to ensure that the proposed project would not interrupt naturally occurring processes, like rain runoff. Another aspect to consider is whether the proposed project plan would cause long-term, detrimental effects and how to prevent these issues from arising. The team fulfilled this constraint with the Final Plan proposed. Modifying the signalization will reduce all vehicles idling at the core intersection, reducing emissions. Continuation of the sidewalks in Area C will improve drainage of rain runoff.

Social and Political

The team worked to proposed solutions that meet the needs of citizens. The team worked closely with the Town of Shrewsbury and our sponsor, Stantec, to gain an understanding of what the Town needs. Looking through the *Town of Shrewsbury Master Plan 2016* and the *Town Center Visioning Report 2019,* the team better understood the opinions and concerns of citizens of Shrewsbury.

Ethical

This project abided by the American Society of Civil Engineers (ASCE) Code of Ethics for all civil engineers. It is paramount that engineers follow the Code of Ethics to ensure that they are maintaining the safety and welfare of the public, honesty, competence, professionalism, and professional development. The team fulfilled this constraint by working closely with Stantec and the WPI advisors to ensure that ethical rules were followed throughout the duration of this project.

Health and Safety

The project aims to address pedestrian safety by focusing on traffic calming measures and walkability in the Town Center. The team worked with both the Town of Shrewsbury and Stantec to ensure that all aspects of safety are being considered in the final project. The team fulfilled this constraint by having weekly meetings with personnel in Stantec and the WPI advisors. The Final Plan proposed by the team follows Americans with Disabilities Act (ADA) standards and the Manual on Uniform Traffic Control Device (MUTCD) standards, thus the health and safety was considered.

Professional Licensure Statement

The Professional Engineering license helps to safeguard the practice and ensures that the needs of community members impacted by a project will be met. The National Council of Examiners for Engineering and Surveying (NCEES) provides the Professional Engineering (PE) License to ensure that all engineers are held to a high standard and the public is protected. To obtain the PE license, there are certain steps to be completed.

The first step in obtaining a PE license is the bachelor's degree. The bachelor's degree must be obtained from a university that is EAC/ABET-accredited. Next, candidates are required to pass the Fundamentals of Engineering (FE) exam, which tests basic engineering knowledge acquired at the university level. Once this first exam is passed, the candidate will become an Engineering in Training (EIT). After this step, four years of experience is needed in the industry before attempting the Principles and Practice of Engineering (PE) exam. Throughout these four years of experience, an engineer will tackle real world issues and challenges. Each State board administers their own PE exam and administers the license. After passing the PE exam, the engineer obtains their PE License (National Council of Examiners for Engineering and Surveying, n.d.).

The PE license allows for an engineer to prepare and sign the final plans and creates many new opportunities in the field. This license is often a goal of engineers, as it allows for professional development and the addition of new skills and challenges. This project allowed our team to work with experienced, licensed engineers and has provided us with the skills necessary to begin this next phase of our careers.

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1. Introduction

Shrewsbury is located in Worcester County, which is centrally situated within the heart of Massachusetts. The intersection of Route 140 and Main Street is geographically considered the Town Center and extends outward, as seen in Figure 1. The Town Center of Shrewsbury contains the town's Historic District, local and chain businesses, and municipal buildings.

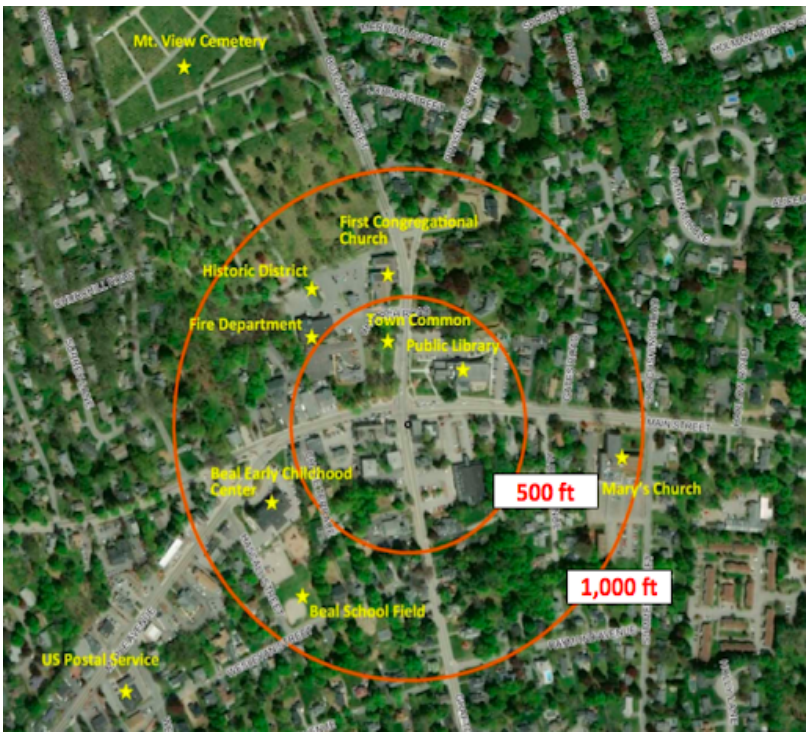

Figure 1: Shrewsbury Town Center (Horsley Witten Group, Inc. 2019)

There have been concerns from residents of Shrewsbury and visitors to the Town Center about pedestrian safety and walkability due to automobile congestion and heavy vehicle traffic. Due to the large curb cuts for local businesses and high traffic speeds and volumes, pedestrians do not feel comfortable when traveling through the Town Center. Additionally, heavy vehicles frequently pass through the intersection of Route 140 and Main Street, creating greater congestion and traffic volume.

There is a desire from the Town to make improvements to pedestrian and bicycle infrastructure and to make the Town Center a walkable destination. This is exemplified in the *Shrewsbury Master Plan 2016* (Horsley Witten Group, Inc. et al, 2016) and Town *Center Visioning Report 2019* (Horsley Witten Group, Inc., 2019). These reports highlight Town goals to promote an environment of parking and walking to destinations. The Town hopes to promote the current historic features of the Town Center, while also striving for continuous improvement for residents and visitors.

There are currently a number of potential development projects in the Greater Worcester Area that impact the Town Center, as well as projects within the Shrewsbury Town Center itself. Many new commercial shipping facilities are being built in the area to meet online shopping demands. A new facility recently opened in the neighboring town of Boylston, creating an influx of heavy vehicles, and more facilities are being proposed. Within the Town Center, the Beal Early Childhood Center Building Redevelopment project is underway. The site is to be redeveloped, which could enhance the feel and functionality of the area. With these new development changes comes an increase in traffic and a greater need to support the ease of all types of transportation in the Town Center.

With these problems and potential changes to the Town Center in mind, this project aims to increase pedestrian safety and walkability in the Shrewsbury Town Center. To achieve this, the following objectives will be met:

- Identify key problems in the Shrewsbury Town Center
- Analyze case studies to inform results and potential solutions
- Develop potential solutions and conceptual designs
- Select final solutions by evaluating conceptual designs

2. Background

The following sections provide an overview of the problems associated with the Town Center, including bicycle and pedestrian safety, as well as future development goals and projects in Shrewsbury. Additionally, it describes the case studies used to inform the project methods.

2.1 Pedestrian and Bicycle Mobility in Downtown Shrewsbury

Through the *Town of Shrewsbury Master Plan 2016* (Horsley Witten Group Inc., et al, 2016) and the *Town Center Vision Report 2019* (Horsley Witten Group, Inc., 2019), resident comments can be found relating to the Town Center. Residents of Shrewsbury and business owners have addressed their concerns over pedestrian safety, walkability, and traffic flow in the Town Center.

The *Town of Shrewsbury Master Plan 2016* focuses on the overall improvement of Shrewsbury for short and long-term plans. The *Master Plan* contains goals for a more walkable Town Center in Shrewsbury. It notes the challenges associated with pedestrian travel in the Town Center area, notably at the intersection between Route 140 and Main Street. To increase pedestrian safety, the *Master Plan* describes the Town's desire to not widen the roads further and to address issues with signal timing and coordination. Another goal in the *Master Plan* is to decrease the number of curb cuts to reduce pedestrian and vehicle conflicts.

The *Town Center Vision Report* collected public data through various means, one of which was an electronic survey sent out in October 2018. This survey had 340 responses with a majority expressing concerns over the traffic flow and pedestrian safety. The report cites high volumes during peak hour and "the speeds at which motorist travel are often dangerous" (Horsley Witten Group, Inc., 2019). In addition to the concerns about the Town Center, the report highlights the desire for improvements to be made and emphasizes the many opportunities to change the perception of the Town Center.

2.2 Shrewsbury Development and Industry Goals

The Town of Shrewsbury has goals for continual development of the Town Center, which are outlined in the *Town Center Visioning Report* and the *Master Plan*. In future development, the Town would like buildings to promote the historic character. The new buildings should engage the street, and design of the façade and the streetscape should be considered in the development process (Horsley Witten Group, Inc., 2019).

There are currently development projects that could shape the Town Center. For example, the Beal Early Childhood Center is in the process of being redeveloped. This building is located in the Town Center and is currently a school for young children. Resident surveys and comments have informed a development policy that will be communicated to the property developers of

this site. The addition to the Town Center should "include uses that will increase foot traffic and draw visitors from other parts of Shrewsbury and beyond" (Horsley Witten Group, Inc., 2019). The new development should also provide parking opportunities that can be used for the Town Center as a whole. These future development projects are intended to increase pedestrian traffic and could potentially modify the ways in which the current Town Center functions. As the Town Center continues to modernize, it is paramount to support and promote walkability.

2.3 Economic Development in the Greater Worcester Area

A new culture of online shopping has created an increase in shipping facilities. This can be seen within the Greater Worcester Area, as new shipping facilities are opening across Central Massachusetts.

The Town Center of Shrewsbury is surrounded by a few of these facilities, including those owned by Amazon, UPS, and FedEx. As seen in Figure 2, shipping facilities are located in the neighboring towns, creating higher percentages of heavy vehicles on local roads.

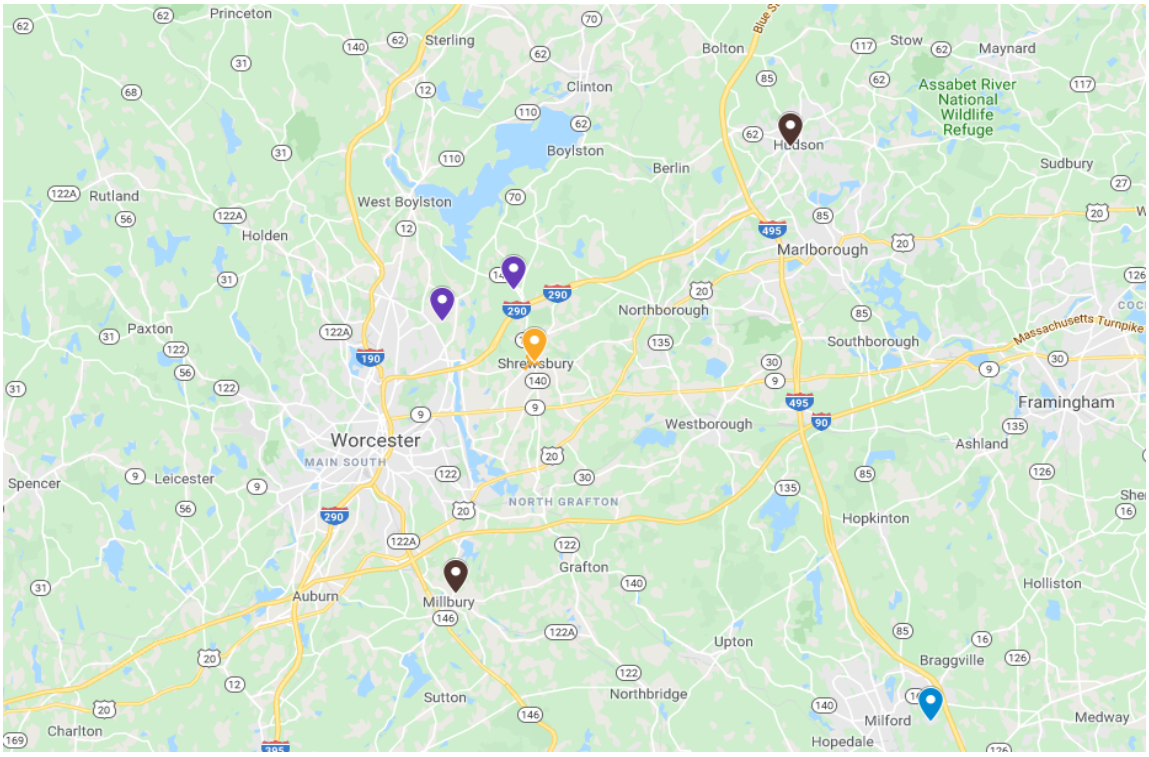

Figure 2: Shipping Facilities around Shrewsbury

This increase in heavy vehicles has impacts on traffic throughout the Town and impacts pedestrian safety in the Town Center. The economic development in the greater Worcester area will affect how the team approaches conceptual design plans and recommendations for the Town.

2.4 Case Studies

The following case studies were used to inform project methods, and summaries are provided below.

2.4.1 Summary of 2017 Corridor Study Route 140 South

The *Route 140 South Corridor Study* (MDM Transportation Consultants, Inc., 2017) was prepared by the MDM Transportation Consultants, Inc., and the area of study is Route 140 from Colonial Drive to the Main Street intersection. The corridor study was commissioned as part of a Settlement Agreement between the Town of Shrewsbury and Scannell Properties for the proposed FedEx Ground Transportation Facility. The corridor covered a two-mile section of Boylston Street (Route 140) which is classified as an urban major arterial roadway, seen in Figure 3.

Figure 3: Existing Pedestrian Facilities (MDM Transportation Consultants, Inc., 2017)

The Route 140 Corridor study found that the intersection of Grafton Street (Route 140) and Main Street is listed by the Massachusetts Department of Transportation (MassDOT) as a Highway Safety Improvement Program (HSIP) crash cluster for 2012-2014. All HSIP locations are subject to Road Safety Audits (RSA) to identify short-term and long-term safety operations for improvement. This intersection was found to have a Level of Service (LOS) of F, which indicates a high delay time.

This case study was chosen to serve as a reference for methods of studying heavy vehicle impacts, as well as analyzing crash reports for corridor safety. Additionally, the data collected in this study can be compared to traffic counts and pedestrian counts taken in this MQP.

2.4.2 Summary of 2018 Street Corridor Study Chelsea, MA

In 2018, the Beachman/Williams Street Corridor was analyzed by Stantec due to its heavy industrial use (Stantec, 2018). This corridor was selected because of the increase in heavy vehicle usage, the lack of connections to public transit, and the high number of crash clusters. The existing conditions of the corridor were analyzed, and Stantec found improvements were needed to increase safety for all modes of transportation. The Beachman/Williams Street Corridor was characterized by the various functions to address the unique needs. Four character areas were defined; Regional Industry, Industrial & Residential Transition Zone, Downtown Hub, and Mixed-Use Zone. Figure 4 shows the proximity and location of these character areas.

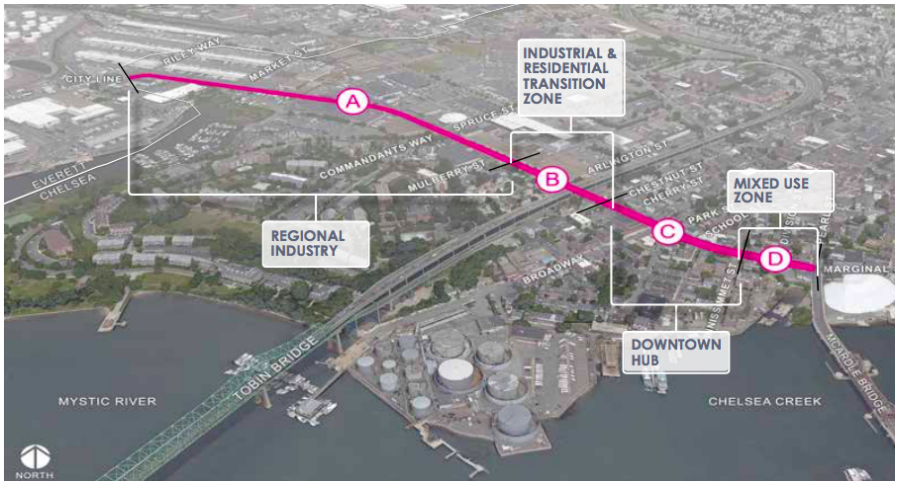

Figure 4:Beachman/William Street Corridor (Stantec, 2018)

General recommendations for the corridor were provided to address the safety issues and conflicts between different modes of transportation. Additionally, Stantec provided recommendations that were specific to each area to address the unique issues found within.

The method of creating character areas for mixed-use corridors allows for specific recommendations to be made to fit the needs of a changing environment. This will be useful as the Town Center in Shrewsbury serves many functions for the Historic District, Industry, and Municipal Buildings.

3. Methodology

This section provides an overview of the methodology that was used in the completion of the Major Qualifying Project (MQP). The team created a list of objectives to guide the methodology that will be met throughout the project. The objectives are as follows:

- Identify key problems in the Town Center
- Analyze case studies to inform results and potential solutions
- Develop potential solutions and conceptual designs
- Select final solutions by evaluating the conceptual designs

This section details the ways in which the team met these objectives.

3.1 Identify Key Problems in the Town Center

This section covers key issues found within the Town Center. This was completed by identifying resident opinions and surveying existing conditions, including traffic volumes, heavy vehicles, and pedestrians.

3.1.1 Defining the Town Center

In previous Town Center projects, the team noted that each project defined the Town Center in different ways. The intersection of Route 140 and Main Street was constant as the core intersection; however, the extent of the area was slightly different depending on the goals of the project.

One of the first steps was to define the scope of our research and data collection. Other projects, including the *Town Center Visioning Report 2016* (Horsley Witten Group, Inc. et al, 2016) and the *Town of Shrewsbury Master Plan 2019* (Horsley Witten Group, Inc., 2019), were used as a guideline for a newly defined Town Center. Using Google My Maps, the team was able to create maps for the project using aerial views. The defined Town Center can be seen in Figure 5.

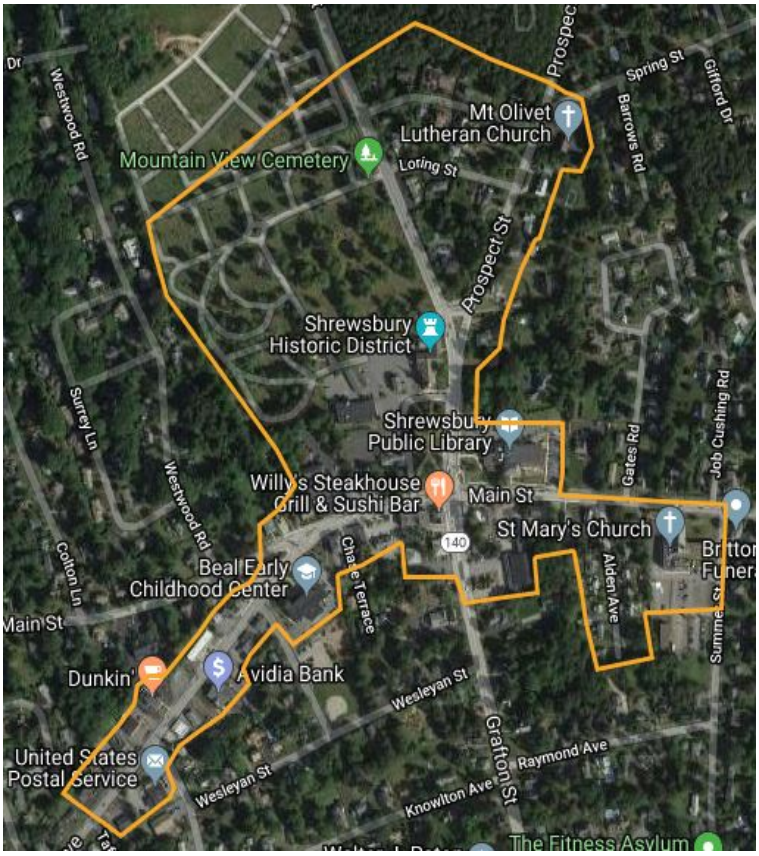

Figure 5: Town Center Area of Study

3.1.2 Character Areas

A diverse town center requires an in-depth look at the area it encompasses. Three Character Areas were defined to represent the diverse contents of the Shrewsbury Town Center. The three areas were defined as follows: Area A: Historical and Municipal Area, Area B: Residential, and Area C: Local and Chain Businesses, as seen in Figure 6.

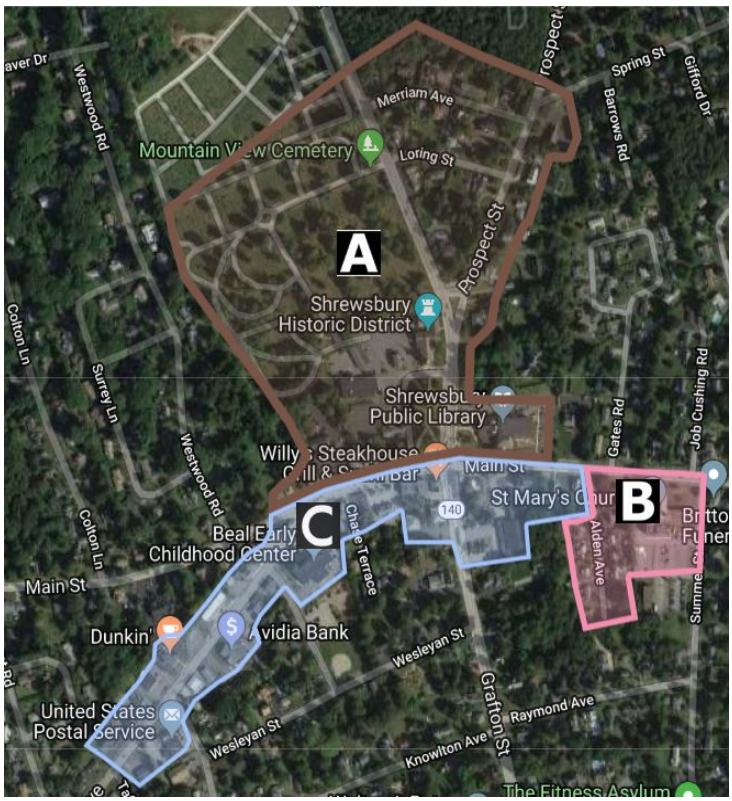

Figure 6: Three Character Areas Located in the Town Center

Area A: Historical and Municipal Area, contains the Historic District of Shrewsbury, including the First Congregational Church, the Town Common, and the Public Library. Area B: Residential contains residential housing as its most prominent feature. Finally, Area C: Local and Chain Businesses contains both local and chain businesses on Main Street and Maple Avenue.

Once the three areas were defined, information about the contents of each area was developed using data collected from previous site visits. Additionally, Google Maps was used to identify features and businesses located in each area. Finally, the team documented different needs and challenges associated with each area based on the data collected.

3.1.3 Resident and Business Owner Comments

To gain a sense of resident concerns and feedback about the Town Center, the team investigated documented information. The Town of Shrewsbury has often included residents in the planning process through public meetings and workshops. The team was able to review many documents that contained feedback from the people actively living and working in the area.

The *Town of Shrewsbury Master Plan 2016* (Horsley Witten Group Inc., et al, 2016) and the *Town Center Visioning Report 2019* (Horsley Witten Group, Inc., 2019) both contain comments from residents relating to the Town Center. A survey was sent to residents in 2018 as

part of the creation of the *Town Center Visioning Report*. This survey received over 300 responses which documented key opinions and issues that residents identified in the Town Center. Town Center meeting minutes and videos were also used to understand the resident perspective.

Additionally, the team aimed to understand the perspective of the Town Center by the businesses that are located there. In 2018, the Shrewsbury Town Center Association (STCA) was created by a group of local business owners (Shrewsbury Town Center Association, 2019). Their information is documented on the STCA's website, as well as interviews with the founders.

These groups were chosen because they have a good understanding of the day-to-day functionality of the Town Center and can identify areas of improvement. These perspectives allowed the team a longer history of the area and identified the needs and desires of the people that live and work there.

3.1.4 Document Existing Traffic Conditions

The team took Turning Movement Counts (TMC) at the core of the Town Center, the intersection of Route 140 and Main Street. This allowed the team to gain an understanding of the current traffic conditions of the intersection and to identify potential improvements. The TMCs were taken on Thursday, October 24, 2019. The morning peak hours, 7:00 AM- 9:00 AM, and afternoon peak hours, 4:00 PM- 6:00 PM, were recorded.

This data was supplemented with data collected in previous studies. For example, the *Route 140 Corridor Study* contains TMCs from the intersection of Route 140 and Main Street, collected in 2016 (MDM Transportation Consultants, Inc., 2017). These turning movement counts provided data for vehicles and pedestrians. Additionally, the Central Massachusetts Regional Planning Commission (CMRPC) provided turning movement counts. This turning movement data contained counts for passenger vehicles and heavy vehicles.

The team also utilized the Massachusetts Department of Transportation Data Management System to obtain the Annual Average Daily Traffic (AADT) (Massachusetts Department of Transportation, 2019). With this data, the volumes from three years, 2016-2018, were compared to determine a trend in Town Center vehicle volume.

3.1.5 Calculate Existing Efficiency Conditions

The Level of Service (LOS) was used to understand the traffic flow and efficiency at the core intersection. According to the 2010 *Highway Capacity Manual*, the LOS is "stated in terms of average control delay per vehicle (in seconds) during a specified time period" (Transportation Research Board, 2010). A letter grade is assigned to an intersection to score the LOS, including scores of A through F. In Figure 7, the relationship between the letter grade and the Average Control Delay (in seconds/vehicle) can be seen.

Level of Service	Average Control Delay (seconds/vehicle)	General Description
A	≤10	Free Flow
B	>10 – 20	Stable Flow (slight delays)
C	>20 – 35	Stable flow (acceptable delays)
D	>35 – 55	Approaching unstable flow (tolerable delay, occasionally wait through more than one signal cycle before proceeding)
E	>55 – 80	Unstable flow (intolerable delay)
F[1]	>80	Forced flow (congested and queues fail to clear)

Source: *Highway Capacity Manual 2010*, Transportation Research Board, 2010.
1. If the volume-to-capacity (v/c) ratio for a lane group exceeds 1.0 LOS F is assigned to the individual lane group. LOS for overall approach or intersection is determined solely by the control delay.

Figure 7: Level of Service Table (Transportation Research Board, 2010)

The McTrans Highway Capacity Software (HCS) 2010 was used to evaluate the LOS for the intersection. The two streets, Main Street and Route 140, were added to the software with their designated lanes. The peak 15-minute data from the AM and PM volume from the Turning Movement Counts on October 24th was input into the software. The signal timing was obtained from a *2002 Main Street Roadway Improvement Project*, received from MassDOT (Beta Group, et al, 2015). The LOS for the core intersection was calculated using this data and provided a deeper understanding of the operation of the intersection.

3.1.6 Crash Data Analysis

To gain an understanding of crashes at the core intersection, five years of past crash data were examined. Using the MassDOT Impact Crash Data Portal, Shrewsbury's crash data was obtained (Massachusetts Department of Transportation, 2019). The crash rate (R) was calculated using this data.

The crash rate formula was obtained from the U.S. Department of Transportation Federal Highway Administration (FHWA) (US Department of Transportation, 2019).

$$R= 1{,}000{,}000 *C/ 365*N*V$$

Where R is the crash rate of the intersection measured in crashes per million entering vehicles, C is the total number of crashes at the intersection over the time period, N is the number of years the data represents, and V is the traffic volume entering the intersection daily. To obtain V, also known as the 24-hour entering volume (V_{24}), the following formula was used:

$$V_{24} = \text{PM Peak Hour Volume} / \text{PM K Factor}$$

PM Peak Hour Volume of 3516 vehicles was obtained in the count conducted for this study. For the PM K Factor, the standard default of 0.09 was used. This value was obtained from the *Crash Rate Analysis Instructions* by MassDOT (Massachusetts Department of Transportation, 2019).

This calculated crash rate was then compared to the District Average crash rate. The District Average rate was obtained from the Crash Data Portal and allowed the team to understand how the intersection compared to District 3.

3.1.7 Discussion of Heavy Vehicles

During the traffic counts and site visits, the team made note of many heavy vehicles traveling through the intersection. To learn more about the number of heavy vehicles, the team obtained additional data from the Central Massachusetts Regional Planning Commission (CMRPC). This data provided traffic counts that were separated by vehicle classification, which assisted in comparing heavy vehicle data traveling through the intersection. These counts were taken in August, September, and October 2016 and June 2019 (Central Massachusetts Regional Planning Commission, 2019).

3.1.8 Pedestrian Analysis

To assess the Town Center in terms of pedestrian activity, data was collected about pedestrian patterns and existing pedestrian infrastructure.

During site visits, the team conducted pedestrian observations to identify patterns. A pedestrian study was collected during the October 24th, 2019 site visit at noon. One observation was conducted at the core intersection in the Town Common, and the other was conducted at the intersection of Maple Avenue and Main Street. This time was chosen based on the data collected during Stantec's *Parking Management Plan* (Stantec, 2018). This plan reported that noon is the time at which the parking lots reach their highest capacity. The pedestrian studies lasted one hour to observe patterns of activity.

Although pedestrian observations were limited, the team was able to draw conclusions based on these observations about patterns. The observed patterns were then documented using Google My Maps. Individual lines of activity were drawn, and desire lines were created as a summary to display repeated patterns of movement.

3.2 Analyze Case Studies

The team analyzed case studies to learn how similar towns or study groups dealt with issues found in the Town of Shrewsbury. The following sections summarize the case studies and their significance to the project.

3.2.1 Speed Case Study

The case study, *The Effects of a Rectangular Rapid-Flashing Beacon on Vehicle Speed*, was completed in Mundelein, Illinois (VanWagner et al., 2011). This study examined the impact

of Rectangular Rapid Flashing Beacons (RRFB) on speeding vehicles. Data was collected in the month of August on weekends along Lake Street (U.S. Route 45) by a handheld radar. This case study focused on the effectiveness of RRFB as a countermeasure for speeding.

This case study was chosen because the speed of vehicles increases the risk that pedestrians face when interacting with them. With the Town of Shrewsbury's increasing number of vehicles running through the core intersection, it is important that speed and methods of reducing speed are kept in mind. This study informed the team of methods of speed reduction in a moderately populated area.

3.2.2 Heavy Vehicle Case Study

The *Route 140 Corridor Study* was prepared for the Town of Shrewsbury in November 2017 (MDM Transportation Consultants, 2017). This document was created in response to the opening of a FedEx Ground Transportation Facility on Route 140 and a traffic impact study was completed. The new FedEx facility was "estimated to generate approximately 526 new vehicle trips during the weekday morning peak hour and 508 new vehicle trips during the weekday evening peak hour" (MDM Transportation Consultants, 2017). A capacity analysis was performed on both the current volumes and the volumes accounting for the site development.

This case study was chosen to determine the actions taken to mitigate the impact of increased heavy vehicle volumes from a commercial shipping facility. It helped to inform the team's methods for the project.

3.3.3 Pedestrian Safety Case Study

The Town of Duck, North Carolina created a document called the *Town of Duck Comprehensive Pedestrian Plan* (VHB Engineering, 2014). This plan addressed pedestrian safety and walkability. The Town of Duck implemented radar speed feedback signs, rectangular rapid flashing beacons (RRFBs), and a bike lane. This case study was used to determine a list of countermeasures that could be implemented in the Shrewsbury Town Center.

3.3 Develop Potential Solutions and Conceptual Designs

This section details the ways in which potential countermeasures were developed.

3.3.1 Countermeasures

A list of countermeasures was made through research to gain a sense of common traffic calming and pedestrian safety measures being used across different projects. The list was then categorized as follows:

- Bicycle/Pedestrian Accommodations
- Signalization

- Signage
- Parking

These categories allowed the team to understand the impact of a certain countermeasures.

3.3.2 Eliminating Countermeasures

After creating a list of countermeasures, the team considered current conditions of the Town Center and how that impacted the potential solutions. The information collected from site visits, Town documents, and case studies was used to eliminate potential countermeasures. Some of the constraints for countermeasure improvements included spatial constraints, cost, and adverse impacts on emergency vehicles.

3.3.3 Develop Conceptual Design

After the infeasible countermeasures were eliminated, the needs and challenges of the three character areas were revisited. Assumptions were made on what the priorities were for the Town based on initial conversations, the *Town Center Visioning Report 2019,* and the *Town of Shrewsbury Master Plan 2016.*

Two plans were created to present to the Town of Shrewsbury with the remaining countermeasures from the original list. The three character areas were also considered to ensure that their individual needs and challenges were met. The *Manual on Uniform Traffic Control Device* (MUTCD) is a resource created by the United States Department of Transportation Federal Highway Administration (FHWA) to set standards to "install and maintain traffic control devices" (Federal Highway Administration, 2012). The MUTCD assisted the team by defining standards for signage, pavement markings, and other traffic control devices. These standards were followed in developing conceptual designs to ensure the safety and effectiveness of traffic control.

Each plan tackled the character areas differently. This would allow the Town to express their priorities for each area and inform the team which countermeasure would be preferred. Using Adobe Photoshop 2019 and AutoCAD, the team was able to create conceptual designs allowing Plan 1 and Plan 2 to be visually represented.

3.3.4 Stakeholder Feedback

On November 21, 2019, the team met with the Town of Shrewsbury representatives Kristen Las, the Assistant Town Manager/Economic Development Coordinator; Christopher McGoldrick, the Assistant Town Planner; and Bernard Cahill, the Town Planner. The team

aimed to gain an understanding of the Town's priorities for each character area along with feedback on the two conceptual design plans.

The team presented a progress update to the Town and then presented the two conceptual designs. Each plan was reviewed by Character Area, and discussions were held about goals and priorities in the three areas. After each plan was reviewed, the team and Town representatives discussed initial thoughts. After both Plan 1 and Plan 2 were reviewed, discussions ensued about which plan or parts of a plan were favorable to the Town based on the priorities brought up.

3.4 Develop Final Plan

Based on stakeholder feedback, the research done throughout the duration of this study, and the data analysis, the team was able to create a comprehensive Final Plan and recommendations.

The comments made by the Town were weighed heavily in the final plan, as this represented the priorities of Shrewsbury. To better visualize the proposed countermeasures, Adobe Photoshop 2019, was used to create the plan. Additionally, AutoCAD was used to display the measurements taken to place countermeasures in each Character Area in accordance with the Manual on Uniform Traffic Control Device (MUTCD).

3.5 Cost Estimate

Using Massachusetts Department of Transportation (MassDOT) Construction Project Estimator tool, the team was able to develop an estimate of cost for the Final Plan (Massachusetts Department of Transportation, 2019). Andrew Truman, the Town of Shrewsbury Engineer, also assisted the team in developing a cost estimate based on Shrewsbury vendors and local materials (Truman, 2019). The measurements taken for the Final Plan in AutoCAD helped to inform the cost estimate.

4. Results

Based on the Methodology presented in Section 3, this Section outlines the results of data collection and analysis and research conducted throughout the project.

4.1 Identify Problems in the Town Center

The data presented in the following demonstrates an in-depth look at how the team was able to identify the problems in the Town Center.

4.1.1 Define the Town Center

To identify the scope for the project, the team worked to define the limits and uses of the Shrewsbury Town Center. The Town Center as defined in the *Town Center Visioning Report 2016* (Horsley Witten Group, Inc. et al, 2016) and the *Town of Shrewsbury Master Plan 2019* (Horsley Witten Group, Inc., 2019) provided a basis to assist the team in this task. The intersection of Main Street and Route 140 is the core intersection of the area, and it expands outwards from there.

The northern limit of this defined Town Center is Spring Street/Merriam Avenue and the southern limit is the Medical building at 404 Main Street. The western limit is the Post Office on Maple Avenue, containing the split at Maple Avenue and Main Street. The eastern limit is the Saint Mary School and Parish on the corner of Summer Street and Main Street. This area is shown in Figure 8.

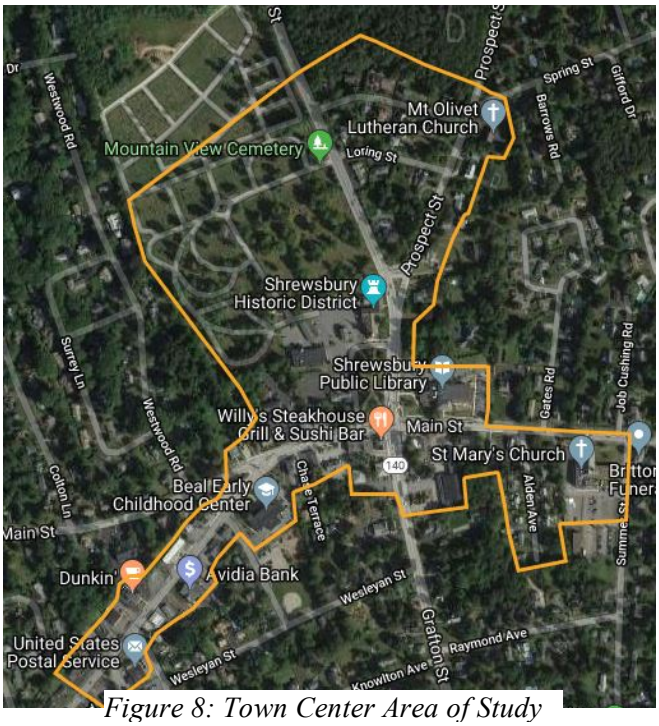

Figure 8: Town Center Area of Study

4.1.2 Character Areas

To effectively create solutions for the diverse Town Center, the team divided the study area into three Character Areas. The three areas, shown in Figure 9, are defined as Area A: Historical and Municipal Area, Area B: Residential, and Area C: Local and Chain Businesses.

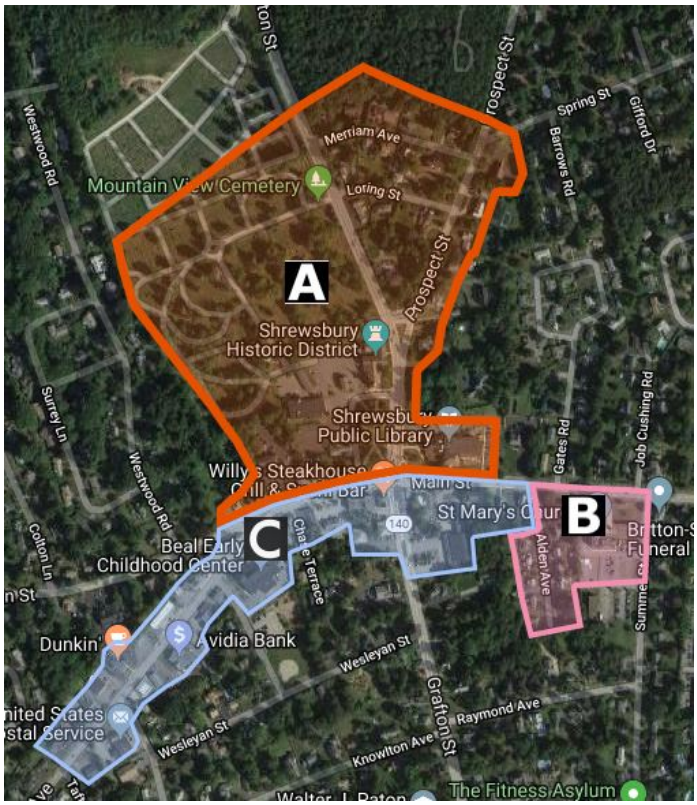

Figure 9: The Three Character Areas Located in the Town Center

The uses of each area were detailed to better understand the potential needs and desires of each. The team used Google My Maps to visualize the defined character areas.

4.1.3 Area A: Historical and Municipal

Area A begins at the core intersection and extends north to the cemetery and Prospect Park, seen in Figure 10. Area A is characterized by the Shrewsbury Municipal buildings and the Historic District, including the Shrewsbury Public Library and historic houses.

Figure 10: Character Area A: Historical and Municipal

This area is described as a "mix of old and new," as the Town works to preserve the historic aspects while also meeting the current needs of residents (Horsley Witten Group, Inc., 2019). The main features of the Historic District are the Town Common, the First Congregational Church, and the various historic homes. The Town Common provides a space for community events and gatherings, as well as containing a monument to Shrewsbury's History. Adjacent to the Common is the First Congregational Church, constructed in 1766, which acts as a focal point for the Common. The Historic District contains ornamental street lights and brick crosswalks that help to create the feel of the area. New signage or pavement markings could potentially modify the feel and cohesion of the area.

The team then defined needs and challenges that pertained to the data collected about Area A to better form specific solutions. The needs and challenges can be seen below:

Area A Needs

- Preservation of historic aspects
- Promotion of these historic attractions
- Connectivity to attractions through pedestrian walkability

Area A Challenges

- Maintaining historic character

- High traffic speeds and volumes at core intersection
- Location of Fire Department creates emergency vehicle route
- Lack of bicycle infrastructure

4.1.4 Area B: Residential

Area B is the area from Summer Street to Alden Avenue and is defined as Residential. This area can be seen in Figure 11.

Figure 11: Character Area B: Residential

The only exception to residential houses is the Saint Mary's Parish and School. There are also residences on Alden Avenue next to the Church.

There were no reported issues in Area B when reviewing the *Town of Shrewsbury Master Plan* or *The Town Center Visioning Report*. During a site visit on September 15, 2019, there were cars parked on the sidewalk preventing the easy flow of pedestrian foot traffic, which can be attributed to the church being in session. Near the Church, there were temporary "No Parking" signs posted by police that many drivers seemed to ignore. This sign is seen in Figure 12.

Figure 12: Temporary No Parking Sign (D'Agostino, 2019)

Additionally, there are flashing signs to alert drivers that they are entering a school zone located on Main Street. One of these signs is at the intersection of Summer Street and Main Street while the other sign is roughly 50 feet from the school building on Main Street, seen when exiting the Town Center. These signs, seen in Figure 13, create a 20 MPH speed limit during school hours.

Figure 13: Speed Sign at Saint Mary's Church (D'Agostino, 2019)

The speed entering the intersection of Main Street and Route 140 is 25 MPH, as posted on the streets surrounding the Town Center. This sign is not that far from the Saint Mary School, about 100 feet from the school. This can lead to confusion for the drivers when entering the Town Center. Exiting the Town Center, the speed limit is 35 MPH on Main Street. The issue is

that a driver sees this 35 MPH sign before they see the school speed limit 20 MPH when flashing sign. This leaves very little time for the drivers to slow down.

A challenge in Area B is the Worcester Regional Transportation Authority (WRTA) Bus Route 15 that runs throughout this area. The WRTA Bus Route 15 is on a flag-based system which means there is no designated bus drop off or boarding location for travelers. With no marked location for a proper drop off, the WRTA Bus can endanger or slow down traffic flow in this area.

The following summarizes the needs and challenges for Area B:

Area B Needs

- Support for pedestrian safety due to school and church
- Safety for the residents living in this area

Area B Challenges

- High vehicle speeds and volume on Main Street
- WRTA Bus Route
- Emergency vehicle route

4.1.5 Area C: Local and Chain Businesses

Area C is located between the core intersection, down Main Street and Maple Avenue, ending at the Post Office, as seen in Figure 14. This area is characterized by business, including local and chain businesses along Main Street and Maple Avenue.

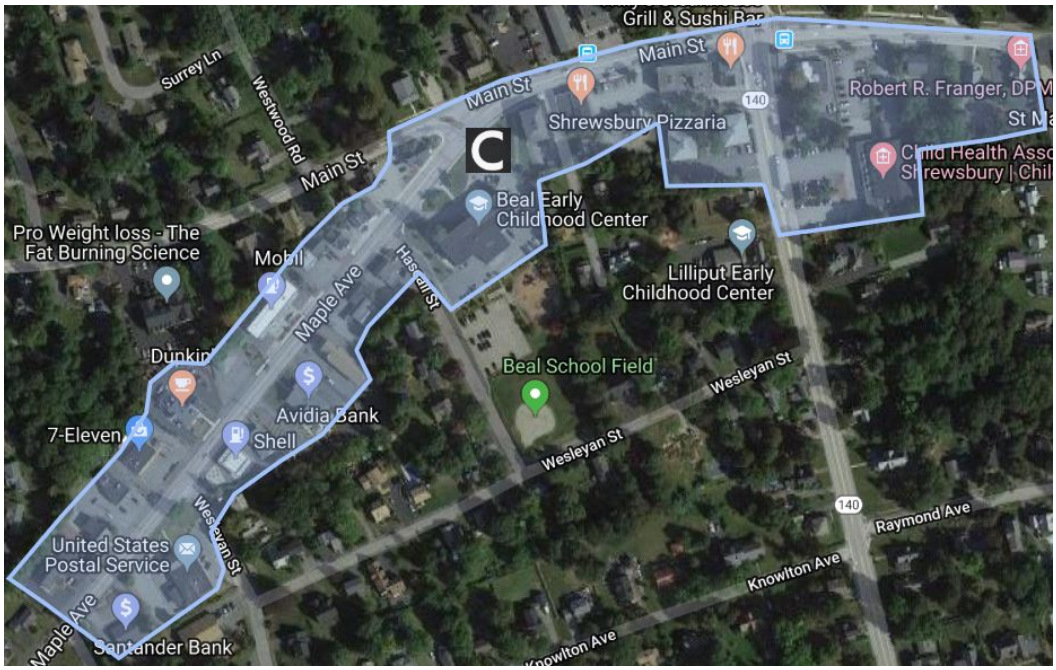

Figure 14: Character Area C: Local and Chain Businesses

There are several chain businesses located on Maple Avenue including Mobil and Shell Gas Stations, Dunkin Donuts, Avidia Bank, and a 7-Eleven. In addition to chain business, local businesses are dispersed throughout Main Street close to the core intersection and on Maple Avenue. For example, there are two restaurants, Willy's Steakhouse Grill & Sushi Bar and Amici Trattoria, located opposite from the Town Common. Additionally, there are other local restaurants and retailers along Maple Avenue.

Many of the local and chain businesses have different spatial layouts for both their setbacks and parking. The entrances to the local restaurants on Main Street are located on the sidewalk, engaging the street and creating the feel of a town center. Many of the chain businesses have large setbacks to allow for parking in front of the buildings.

There are plans for future development on the Beal School Lot which is to be redeveloped. There are plans to develop the front portion of the lot and to maintain the back of the lot as a public green (Horsley Witten Group, Inc. et al, 2016). This site and others in Area C represent an expanding Town Center with an opportunity for economic development.

The needs and challenges associated with Area C are as follows:

Area C Needs

- Increasing foot traffic to the businesses
- Supporting pedestrian safety

- Creating a vibrant center that is considered a destination

Area C Challenges

- Businesses have individual parking lots, creating many curb cuts along sidewalks
- Emergency vehicle route
- WRTA Bus Route

A summary of the needs and challenges for each area is displayed in Table 2.

Table 2: Summary of needs and challenges in character areas

Area	Needs	Challenges
A: Historic and Municipal	● Preservation of historic aspects ● Promotion of historic attractions ● Connectivity to attractions through walkability	● Maintaining historic character ● High vehicle traffic speeds and volumes ● Emergency vehicle route ● Lack of bicycle infrastructure
B: Residential	● Support for pedestrian safety at the school ● Safety for residents	● High vehicle traffic speeds and volumes ● WRTA Bus Route ● Emergency vehicle route
C: Local and Chain Business	● Increase foot traffic to businesses ● Support for pedestrian safety ● Create a vibrant Town Center that is a destination	● Individual parking lots leading to curb cuts ● Emergency vehicle route ● WRTA Bus Route

The needs and challenges of the three areas overlap. For example, all areas require support for pedestrian safety and walkability, as this is a common desire for the Town Center as a whole. Additionally, the emergency vehicle route and WRTA Bus Route 15 will impact traffic flow and traffic calming measures that can be implemented.

4.2 Resident and Business Owner Comments

Local business owners in the Town of Shrewsbury have voiced concerns about the current Town Center. In 2018, a few local business owners formed the Shrewsbury Town Center Association and their mission is to “improve, enhance and foster economic and cultural development in the Town Center district of Shrewsbury, MA” (Town Center Association, n.d.). Common themes from Business Owner comments are below:

- Desire for a walkable downtown to increase foot traffic to businesses
- Need for a vibrant Center that is seen as a destination to encourage more visitors

Residents also have desires to enhance the Town Center, and their responses are well detailed in Shrewsbury Town Documents. In the development of the *Town of Shrewsbury Master Plan* in 2016, residents were able to attend meetings and contribute to the future planning of Shrewsbury as a whole, as well as the Town Center. Additionally, the Town of Shrewsbury administered a survey in October 2018 to obtain public comment and received over 300 responses (Horsley Witten Group, Inc. et al, 2016). Common themes from Shrewsbury residents pertaining to the Town Center are below:

- Feeling unsafe as a pedestrian/bicyclist in the Town Center
- A desire to enhance the current Town Center by making it more walkable and to create a destination for residents and visitors

Both residents and business owners have a strong desire to see a walkable Town Center. They have similar visions for a thriving Town Center to promote economic growth and a sense of place in Shrewsbury.

4.3 Analyze Existing Conditions

This section details the current conditions of the area of study. The data collected and reported here include traffic volumes, intersection efficiency, crash data, heavy vehicle and pedestrian studies, and case study results.

4.3.1 Traffic Volumes

The team used the Massachusetts Department of Transportation Data Management System to obtain traffic volumes over a three-year period (Massachusetts Department of Transportation, 2019). Tables 2 and 3 present Average Annualized Daily Traffic (AADT) from 2016-2018 for Main Street and Route 140, respectively. There is a trend of growth in the AADT's of both roadways from 2016 to 2018.

Table 2: AADT- Main Street at Route 140 (vehicles/day)

2016	12600
2017	15302
2018	15348

Table 3: AADT- Route 140 (Grafton Street) at Main Street (vehicles/day)

2016	11608
2017	11736
2018	11900

To supplement this data, the team conducted Turning Movement Counts (TMC) at peak hours at the core intersection of Route 140 and Main Street. The full data set collected can be found in Appendix B. The AM (7-9AM) count of total vehicles travelling through the intersection was 4,936 vehicles. The PM (4-6PM) count of entering volume was 6,217 vehicles. This data is consistent with the AADT traffic volumes from MassDOT, as Main Street carries more vehicles than Route 140.

From the TMCs, the team was able to determine the AM Peak Hour as 7:30-8:30 AM and PM Peak Hour as 4:45-5:45 PM. Route 140 Northbound carried approximately 30% of the entering volume during both the AM and PM periods. Additionally, the Main Street Eastbound movement represented 29.73% in the AM period and 35.0% in the PM period. Some of these higher volumes on Main Street were attributed to the two current schools located on Main Street, as children were being dropped off at both the Beal Early Childhood Center and the Saint Mary's School.

The turning movement data also indicated a high percentage of heavy vehicles. The AM period had a heavy vehicle percentage of 11.69%. This percentage dropped to 3.90% in the PM period. Observations were made during the TMCs about how the turning heavy vehicles drastically slowed traffic at the intersection.

The peak hour data for both AM and PM were used to help determine the Level of Service (LOS) through the Highway Capacity Software (HCS).

4.3.2 Intersection Efficiency

The Level of Service (LOS) was used to assist the team in determining the efficiency of the intersection of Route 140 and Main Street. The results of the analysis are seen in Table 4.

Table 4: 2019 Level-of-Service for the Intersection of Route 140 and Main Street

	(8:00-8:15) AM Peak			**(5:15-5:30) PM Peak**		
	v/c^a	d^b	LOS	*v/c*	*d*	LOS
Main St EBL	0.329	35.2	D	0.265	31.3	C
Main St EBT	0.612	39.7	D	0.880	46.9	D
Main St EBR						
Main St WBL	0.070	37.6	D	0.114	34.1	C
Main St WBT	0.675	45.1	D	0.511	38.3	D
Main St WBR	0.143	33.3	C	0.122	31.7	C
Rte. 140 NBL	0.105	11.6	B	0.043	12.8	B
Rte. 140 NBT	0.158	11.9	B	0.342	16.0	B
Rte. 140 NBR						
Rte. 140 SBL	0.028	7.0	A	0.061	10.4	B
Rte. 140 SBT	0.078	5.6	A	0.089	8.3	A
Rte. 140 SBR	0.009	5.3	A	0.015	7.8	A
Overall	**25.4 C**			**29.0 C**		

a. v/c= volume to capacity ratio
b. d= delay (seconds/vehicle)

According to Table 4, the problem with this intersection occurs on Main Street. The LOS for Main Street traffic movement are lower than those of Route 140. This lowers the overall LOS to a C for both the AM and PM periods. The overall LOS is determined to be a "Stable flow" with acceptable delays, according to the *Highway Capacity Manual.* However, many of the LOS for Main Street are operating at a D score, which signifies they are "approaching unstable flow" (Transportation Research Board, 2010). As the volume is on an increasing trend, these LOS scores may begin to drop to an unstable flow, which would drastically increase delays.

4.3.3 Crash Data Results Summary

The team used the Extraction of Data Tool on the MassDOT Impact Crash Data Portal website to obtain crash data for the Town of Shrewsbury (Massachusetts Department of Transportation, 2019). The data collected ranges from January 2015 to November 2019. There

was a total of 38 crashes at the intersection of Main Street and Route 140 over the last five years, as seen in Table 5.

Table 5: Crash Data from 2015-2019 retrieved from MassDOT

Year	Non-Fatal Injuries	Fatal Injuries	Angle	Sideswipe, opposite direction	Sideswipe, same direction	Single Vehicle	Head-On	Rear-End	Rear-to-Rear	Not Reported	Total Crashes
2015	0	0	2	0	1	0	0	3	1	0	7
2016	0	0	3	1	1	1	0	2	0	0	8
2017	0	0	2	0	2	1	0	5	0	1	11
2018	0	0	3	0	1	1	1	2	0	1	9
2019	0	0	0	0	0	1	2	0	0	0	3
Total	0	0	10	1	5	4	3	12	1	2	**38**

The most frequent crash type at the intersection was rear-end crashes, followed by angle crashes over the five-year period. It is interesting to note that there were no fatal injuries that occurred at the intersection.

The calculations of the crash rate (R) are below:

V_{24}(2019) = PM Peak Hour Volume (2019) / Default K Factor 0.09 from MassDOT

V_{24} (2019) = 3516 / 0.09
V_{24} (2019) = 39066.667

R= 1,000,000 * (38) / 365* (5) * V_{24} (2019)

R= 1,000,000 * (38) / 365 * (5) * (39066.667)
R= 38,000,000 / 1825 * (39066.667)
R= 38,000,000 / 65821667.28
R= 0.5773
R= 0.58 crashes per million entering vehicles

The crash rate for the intersection of Main Street and Route 140 was 0.58 crashes per million entering vehicles. This value is lower than the District 3 average crash rate of 0.89 (Commonwealth of Massachusetts, 2019). Although there were no pedestrian-vehicle crashes at the core intersection of the Town Center, the promotion of pedestrian safety to prevent these

crashes is paramount. As traffic volume increases each year, pedestrian safety measures must be considered.

4.3.4 Heavy Vehicle Analysis

While taking turning movement counts, the team observed a high number of heavy vehicles that passed through the core intersection. Most of these heavy vehicles are traveling Northbound on Route 140. Many were commercial shipping vehicles, including FedEx, UPS, and Amazon trucks.

To determine the history of heavy vehicles in the area, data from the Central Massachusetts Regional Planning Commission (CMRPC) was analyzed. The team found a history of high heavy vehicle percentages on both Main Street and Route 140. The heavy vehicle volumes were summarized and can be seen in Table 6 below.

Table 6: Heavy Vehicle Data from CMRPC

Main Street Heavy Vehicle Data		
Date	Heavy Vehicle Volume	Heavy Vehicle Percent
8/23/16	1441	8.76%
9/1/16	686	5.90%
9/27/19	1060	6.57%
Prospect Street Heavy Vehicle Data		
Date	Heavy Vehicle Volume	Heavy Vehicle Percent
10/4/16	172	4.94%
6/20/19	115	3.45%
Route 140 Heavy Vehicle Data		
Date	Heavy Vehicle Volume	Heavy Vehicle Percent
9/15/16	1761	13.51%

Although there is less data available from Route 140, there was a high heavy vehicle percentage in 2016 at 13.51%. Typically, roadways are designed to account for 5% to 15% of traffic flow (Wolhuter, 2015). To supplement the CMRPC data, the team calculated 11.96% of heavy vehicles for the AM peak period from the Turning Movement Count. These two values fall on the higher side of the typical percentage considered for heavy vehicle movement. The PM peak period heavy vehicle percentage drops down to 3.90%, as this is outside of the heavy

vehicles 7 AM- 3 PM schedule. It should be noted that school buses and Worcester Regional Transit Authority Buses are included in the heavy vehicle counts.

To determine the sources of these heavy vehicles, the team looked to visualize the locations of commercial shipping facilities in the area. A map was created in Google My Maps to display the locations of the large facilities, as seen in Figure 15.

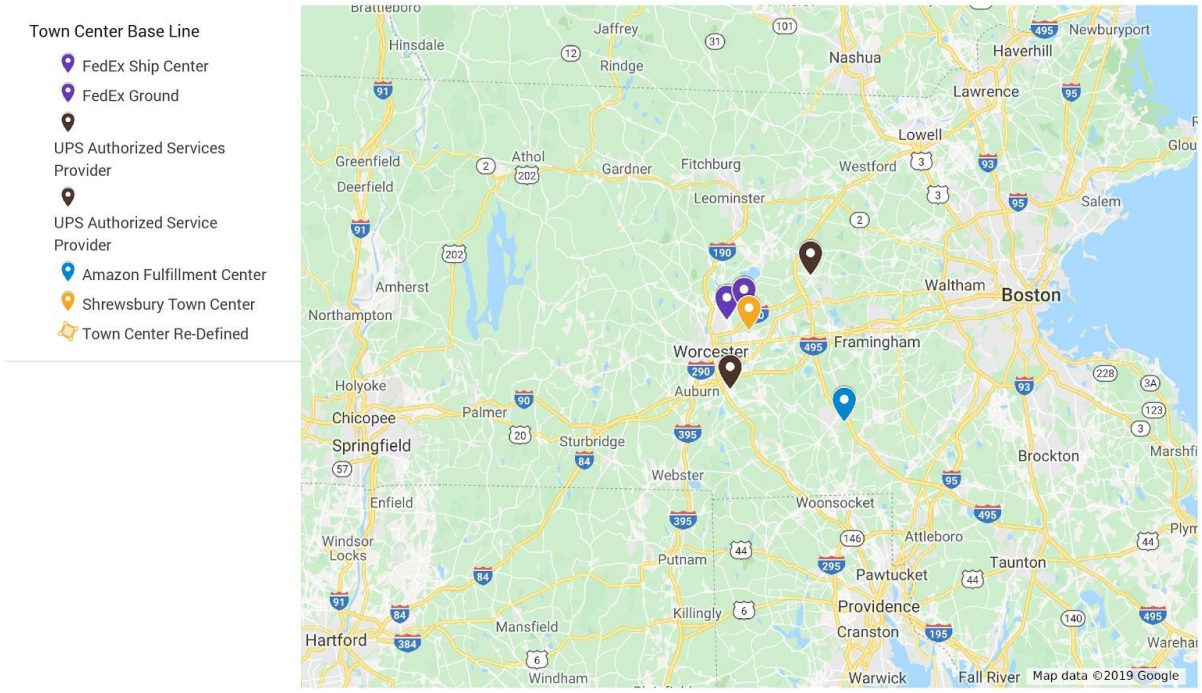

Figure 15: Shipping Facilities around Shrewsbury

The Town Center is marked with a yellow pin. It is also important to note that another shipping facility has been proposed in the Town of Grafton, located south of Shrewsbury. The Town Center of Shrewsbury is surrounded by many large shipping facilities, including FedEx, Amazon, and UPS. It is important to note that this map only includes large commercial shipping facilities that see high heavy vehicle usage. The smaller stores excluded from this map also create increased traffic from shipping.

The team spoke with Richard Rydant from the Central Massachusetts Regional Planning Commission (CMRPC) to discuss heavy vehicles traveling on Route 140. He provided an overview of the growing shipping industry and directed the team to the CMRPC *Freight Planning Progress Report* (Central Massachusetts Regional Planning Commission, 2019). This report provides a broad view of the heavy vehicle patterns and routes in the larger Central Massachusetts Area, seen in Figure 16.

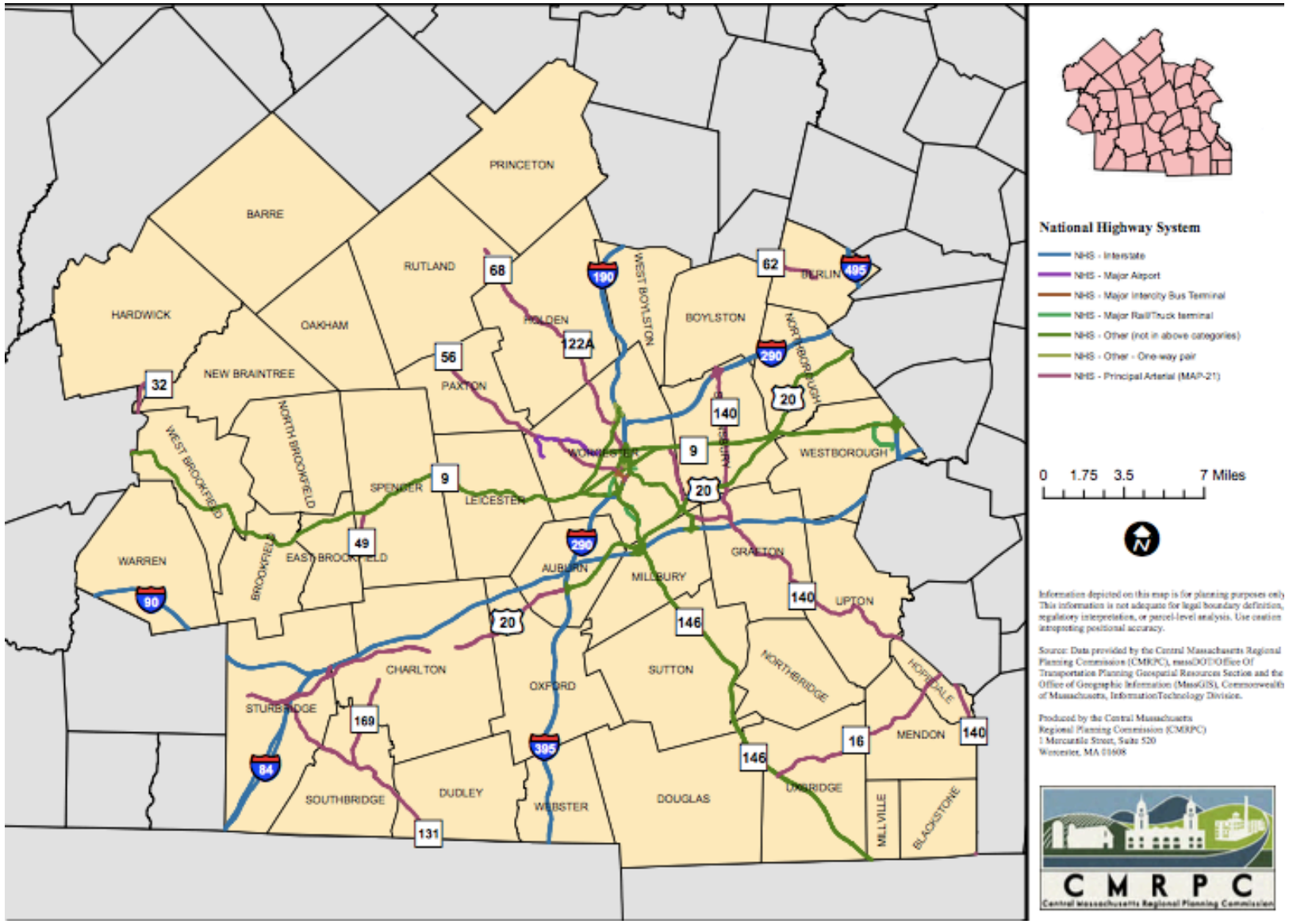

Figure 16: National Highway System showing Route 140 in Shrewsbury (Central Massachusetts Regional Planning Commission, 2018)

The *Freight Planning Progress* report also states that there are regional planning efforts to account for the increase in shipping facilities that address both safety and economic considerations. In Figure 15, Route 140 is a Principal Arterial Road that connects to I-290 in the National Highway System.

Route 140 is an important route for commercial shipping vehicles and plays a role in the National Highway System as a whole. The National Highway System is comprised of roads that benefit the economy and mobility. The purpose of a Principal Arterial Road, like Route 140, is to "provide access between an arterial and a major port, airport, public transportation facility, or other intermodal transportation facility" (Federal Highway Administration, 2019). In addition, this road runs through the heart of Shrewsbury, bringing high volumes into the Town Center. This information, combined with visualizing the locations of shipping facilities, provided the team with important insight on the number of heavy vehicles traveling through the Shrewsbury Town Center.

4.3.5 Pedestrian Study

Pedestrian observations were conducted during two site visits to the Shrewsbury Town Center. Patterns of pedestrian activity were noted in these observations. The first site visit contained informal pedestrian observations, while the second contained a formal observation time.

Desire lines were used to visualize patterns in pedestrian activity. First, individual pedestrian movements were added to a map using the tool Google My Maps. Then, a summary or desire lines were made to represent patterns of movements among pedestrians.

Area A: Historical and Municipal

Individual observations for Area A are displayed in Figure 17. There were many pedestrians traveling through the core intersection.

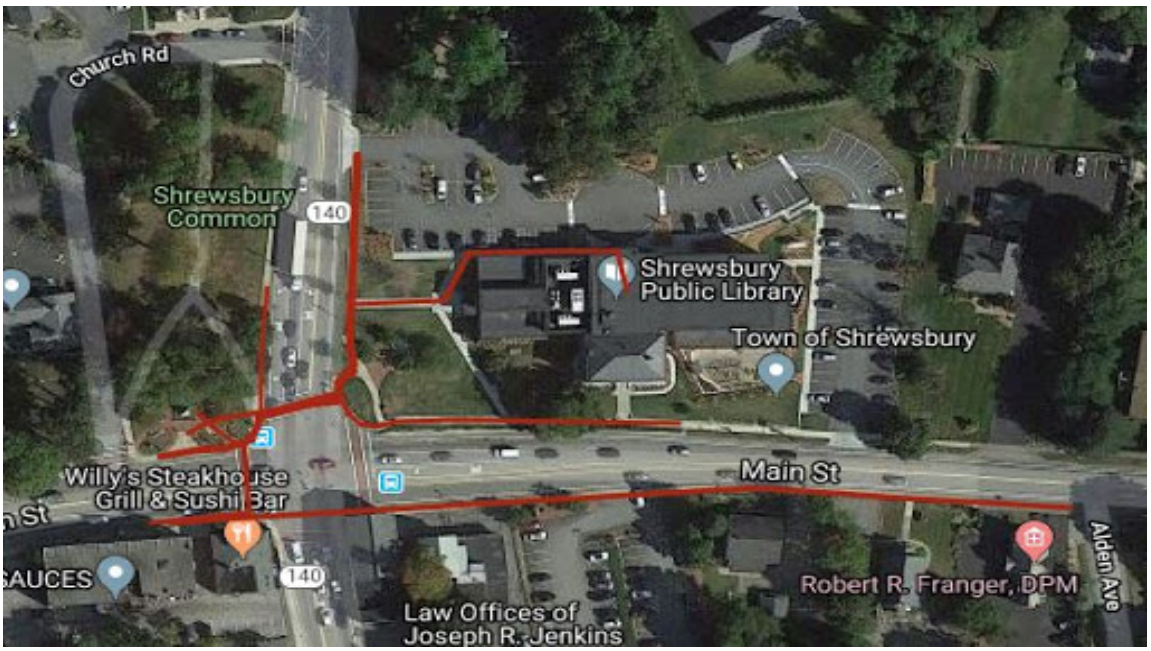

Figure 17: Individual Pedestrian Observations for Area A

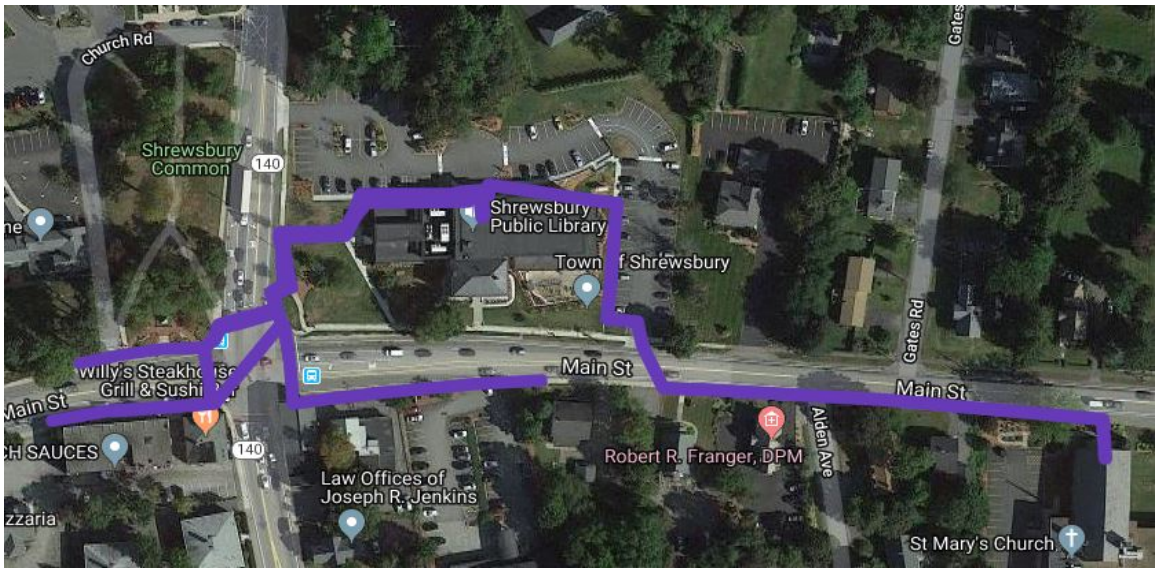

Figure 18: Area A desire lines based on pedestrian observations

Area A is shown in Figure 18 with thick purple desire lines. The above image shows that much of Area A's pedestrian activity occurs around the Shrewsbury Public Library. Many

students came to the Town Library from the nearby schools and the chain businesses on Main Street.

Area B: Residential

The desire lines in Figure 20 were created based on individual movements in Figure 19.

Figure 19: Pedestrian activity in Area B

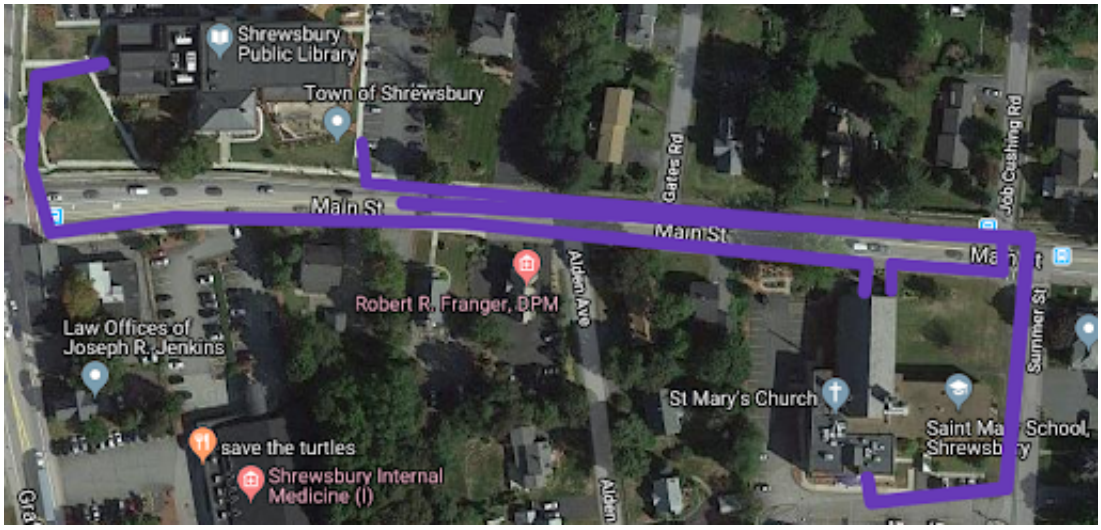

Figure 20: Area B pedestrian desire lines

Area B saw many pedestrians coming to and from the Church and then to the Shrewsbury Public Library. The majority of pedestrians seen in this area were those that attended school at the Saint Mary's School or parents accompanying their children. This was noted to be an area of importance to support pedestrian safety because of the population walking in it.

Area C: Local and Chain Business

The green line in Figure 21 denotes bicycle users, as this was the only area that bicycle usage was observed. The pink line near the 7-Eleven store denotes that those pedestrians were picked up by a Worcester Regional Transit Authority (WRTA) Bus.

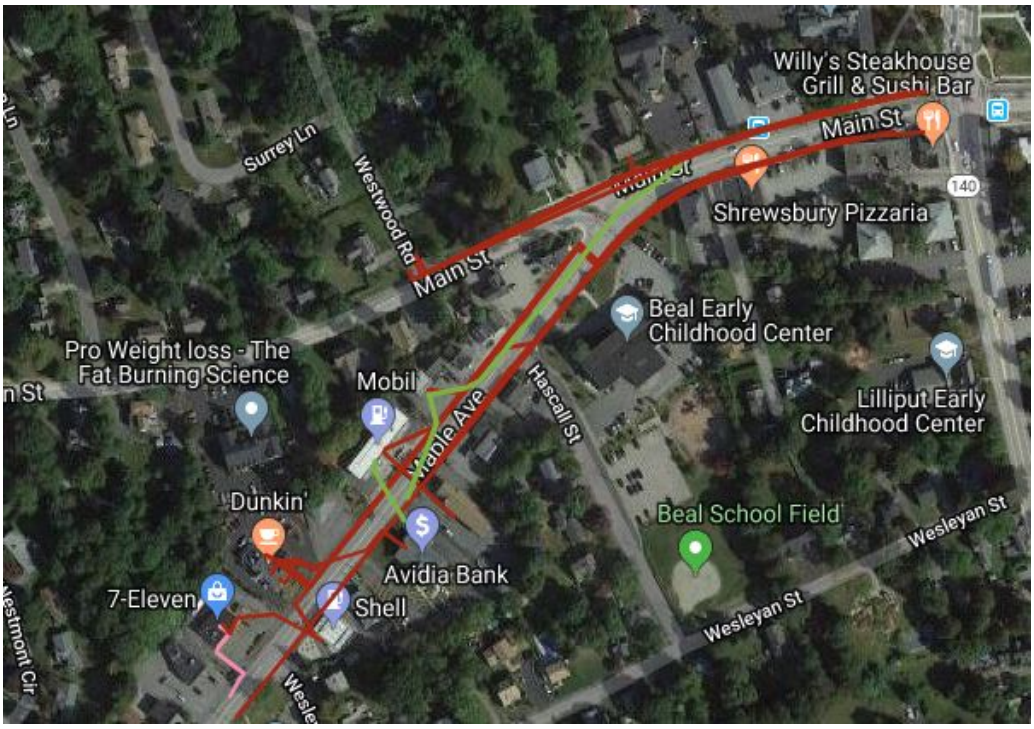

Figure 21: Pedestrians and bicycle activity in Area C

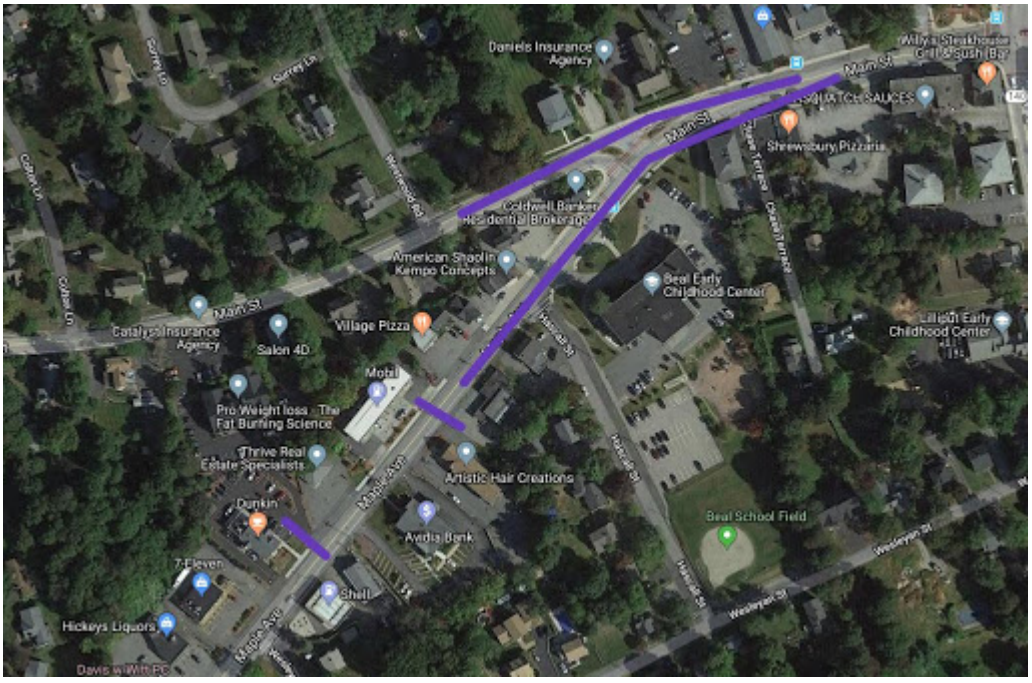

Figure 22: Area C desire lines

Area C contained the most pedestrian activity observed than any of the other areas. In Figure 22, the purple lines are desire lines showing the general flow of pedestrian traffic traveling across Maple Avenue without using a crosswalk. Many of the pedestrians were coming to the chain businesses from the core intersection.

During this observation, 11 pedestrians of the 31 observed (35 percent) did not use a crosswalk to travel to the other side of the street. An additional three pedestrians used the crosswalk but did not wait for the associated walk signal at Main Street and Maple Avenue. This was a potential area that could benefit from an additional crosswalk or promotion of the existing crosswalks to ensure that pedestrians can safely cross the street and pedestrian infrastructure is available in desired areas.

The pedestrian desire lines and observations show the areas that require additional pedestrian and bicycle accommodations. The desire lines helped to assist in placement of this infrastructure and helped to better understand the pedestrian usage and activity in the Town Center.

4.4 Research and Case Studies

This section details the findings and results of the analyzed case studies.

4.4.1 Case Study 1: High Speeds and Traffic Volumes

According to *The Effects of a Rectangular Rapid-Flashing Beacon on Vehicle Speed* (VanWagner, et al, 2011), the Rectangular Rapid Flashing Beacons (RRFB) had a positive effect on reducing speeding vehicles. This study informed the team that RRFBs are effective in promoting pedestrian safety through reducing vehicle speeds. RRFBs could be placed in the Town Center of Shrewsbury to reduce speed and support pedestrians.

4.4.2 Case Study 2: Heavy Vehicles

The results of the *Route 140 Corridor Study* were used when examining heavy vehicle percentages traveling through the core intersection (MDM Transportation Consultants, 2017). As a result of that study, it was found that traffic would increase due to the influx of heavy vehicles at this facility. Therefore, changes must be made to existing infrastructure to ensure minimal delays and safety for all roadway users.

One recommendation from the study was to signalize the intersection located adjacent to the new facility. This result shifted our team's focus to the signal timing at the core intersection. The study stressed the importance of well-timed signalization to decrease delays. From this result, the team planned to gain information about the current signal timing and make modifications to decrease delays.

4.4.3 Case Study 3: Pedestrian Safety

Town of Duck *Comprehensive Pedestrian Plan* (VHB Engineering, 2014) discussed the use of Rectangular Rapid Flashing signs for crosswalks and Radar Speed Feedback signs to inform drivers of their speed versus the speed limit of the road. The Town of Duck found these countermeasures to improve feelings of overall safety for pedestrians. Both traffic calming methods are plausible for the Town of Shrewsbury.

4.5 Develop Potential Solutions

The team consulted with experts and did extensive analysis of case studies to gain an understanding of successful countermeasures and potential solutions.

4.5.1 Countermeasures

Throughout the research stage of the project, a countermeasure list was created. The different countermeasures were then categorized into five groups. This can be seen in Table 7.

Table 7: Countermeasures and Improvements

Category	Countermeasure	Area of Impact
Bicycle/ Pedestrian Accommodation	Shared Bicycle Lane	Bicycle Accommodation
	Rectangular Rapid Flashing Beacon	Pedestrian Safety
	Advanced Yield Markings	Pedestrian Safety
Signal Improvements	Modified Signal Timing (Rte. 140 and Main)	Mobility
	Audible Crosswalks (Accessible Pedestrian Signals)	Pedestrian Accommodation
Signage	Radar Flashing Speed Signs	Vehicle Speeds
	Historic District/Town Center Entrance Sign	Unified Town Center
Parking	Promotion of On-Street Parking	Park-and-Walk Environment

These categories assisted the team in determining areas of impact that each countermeasure could have on the Town Center.

4.5.2 Eliminating Infeasible Solutions

To narrow down the list of countermeasures, the team determined many infeasible solutions and eliminated from the countermeasure list.

When evaluating pedestrian and bicycle accommodations, a segregated bicycle lane was eliminated due to space constraints. Additionally, any raised crosswalks or speed bumps to slow traffic speed were eliminated. This is because the Shrewsbury Fire Station is located on Church Road next to the Town Common. Speed bumps and raised crosswalks can slow down emergency vehicles. Many roadway geometry changes were also eliminated because of the existing infrastructure and current lane widths. Some of these eliminated roadway geometry changes included modifying road widths and widening sidewalks.

Audible Crosswalks, also referred to as Accessible Pedestrian Signals (APS), were eliminated. The signal controller would have to be fully replaced to contain this feature. The cost to install the APS was taken into consideration when evaluating potential solutions.

For heavy vehicles, a reroute plan was deemed infeasible for this project. Route 140 is a Massachusetts State Road and part of the National Highway System. Therefore, to prohibit heavy vehicle passage on Route 140, the Town of Shrewsbury must propose an alternate route for these vehicles. The team determined that there is not an adequate route for the vehicles traveling north to south.

4.5.3 Develop Conceptual Designs

To develop conceptual designs with the remaining countermeasures, the team revisited the challenges and needs of each Character Area. Countermeasures for each area were selected based on these determined needs and challenges to best serve the diverse Town Center. The countermeasures were also selected from those that were not determined infeasible to ensure that the plans were viable.

Two plans were created based on the specific Character Area with the intent of being presented to the Town. The two plans were created to assist the team in determining the Town's top priorities for the Town Center.

Figure 23: Plan 1 Overview

For Plan 1, shown in Figure 23, the team put a focus on traffic calming measures and prioritized safety. For Area A, a radar flashing feedback speed sign would be added to the Town Center Entrance. This sign is not cohesive with the historic character of the area, but serves as a method of reducing traffic speed. Area B would contain a rapid flashing beacon (RRFB) and regular crosswalks for side streets to support pedestrian safety. Area C would contain No Parking Signs at the business driveways on Main Street to indicate the presence of on-street parking.

Plan 2 was created to highlight different potential priorities of the Town of Shrewsbury. An overview of Plan 2 can be seen in Figure 24.

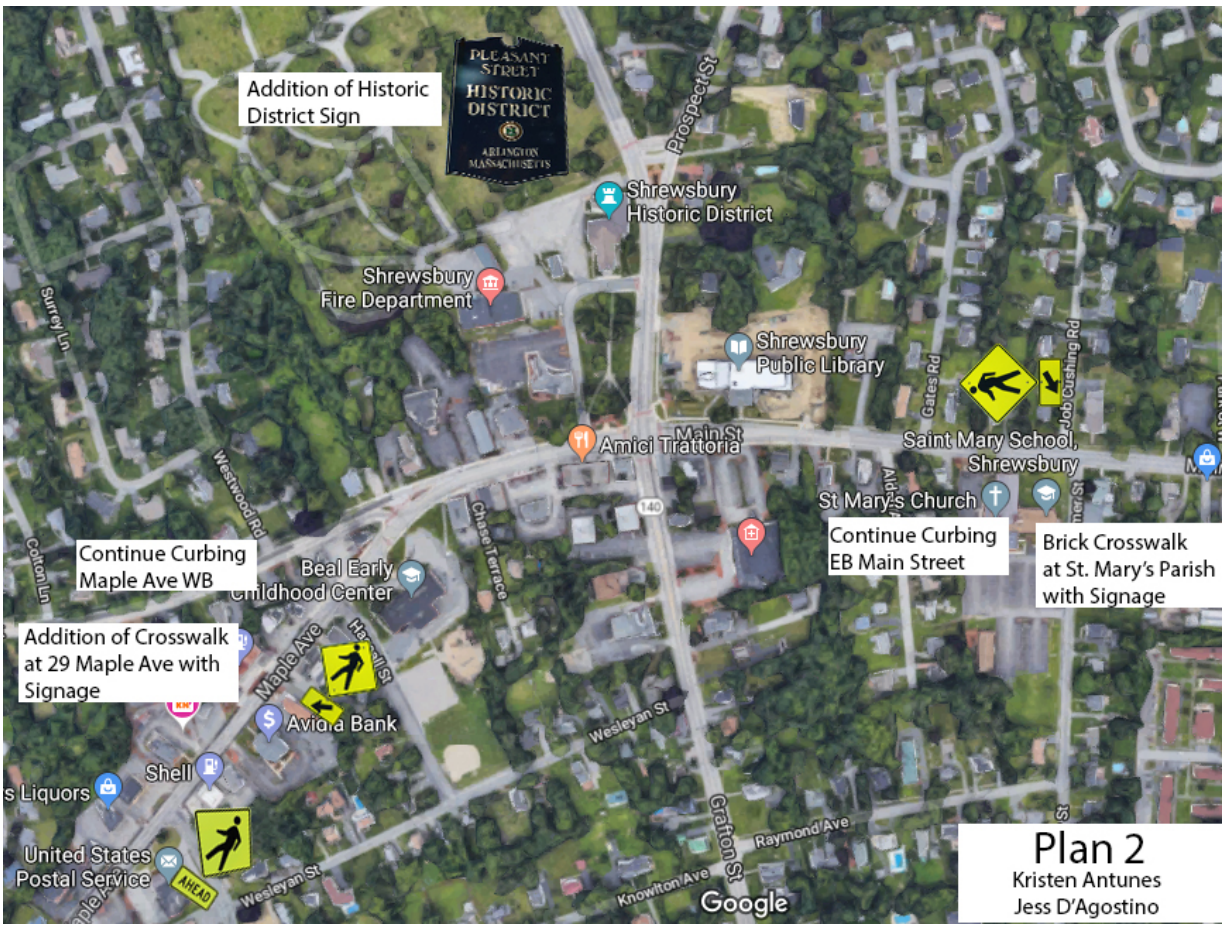

Figure 24: Plan 2 Overview

For Plan 2, the team focused on each area's needs while still addressing the challenges within each. In Area A, a historic district sign would be installed to alert drivers that they were entering the Town Center and to promote the historic attractions. This sign would be designed to match the current aesthetic of the area. Area B would contain a brick crosswalk at the intersection of Main and Summer Street. This brick crosswalk would be cohesive with the other Town Center crosswalks and would be highly visible to drivers. The curb in front of the Saint Mary's Parish would also be extended to support pedestrians. Area C would contain an additional crosswalk located at the Mobil Gas Station with appropriate updated signage. Like Area B, the sidewalk would be extended on business plazas located on Maple Avenue.

4.5.4 Stakeholder Feedback

Plan 1 and Plan 2 were presented in a meeting with representatives of the Town to gain insight on the Town Center priorities. After each plan was presented, the Town gave feedback on the countermeasures in each area. A summary of the feedback and priorities for each area can be seen in Table 8.

Table 8: Town priorities for the Center

Area	**Priority**
Area A	Reduce traffic speeds entering the Town Center
Area B	Enhance the crosswalk at the intersection of Summer and Main Street by the Saint Mary's School
Area C	Encourage more pedestrians to utilize the crosswalks on Maple Avenue

These representative also expressed their past success with certain countermeasures. For example, the Town recently installed Rectangular Rapid Flashing Beacons (RRFB) at the Saint John's High School on Main Street. The Town is also currently using a Radar Speed Feedback Sign, which has been moved around the Town.

Additionally, some proposed countermeasures were eliminated based on the Town's feedback. For example, the brick crosswalk was eliminated because the Town representatives expressed concern about the sustainability of this material at the proposed location. The high volumes and high heavy vehicle percentage could potentially cause the bricks to be broken down overtime and make maintenance costs higher. The parking signs were eliminated because there were concerns about confusion from drivers about where parking was allowed.

The feedback from the Town, supplemented by the case studies and data analysis, allowed the team to make decisions for a final plan. For the full meeting minutes, see Appendix C.

4.6 Selection of Final Plan

The priorities determined from the meeting with the Town were used to develop a Final Plan. The Final Plan contains countermeasures featured in both Plan 1 and Plan 2 to highlight the most effective countermeasures for the Town Center.

4.6.1 Summary of Final Plan

The Final Plan blends parts of the conceptual plans, Plan 1 and Plan 2, together to meet the Town's priorities for the Town Center. An overview for the Final Plan can be seen in Figure 25.

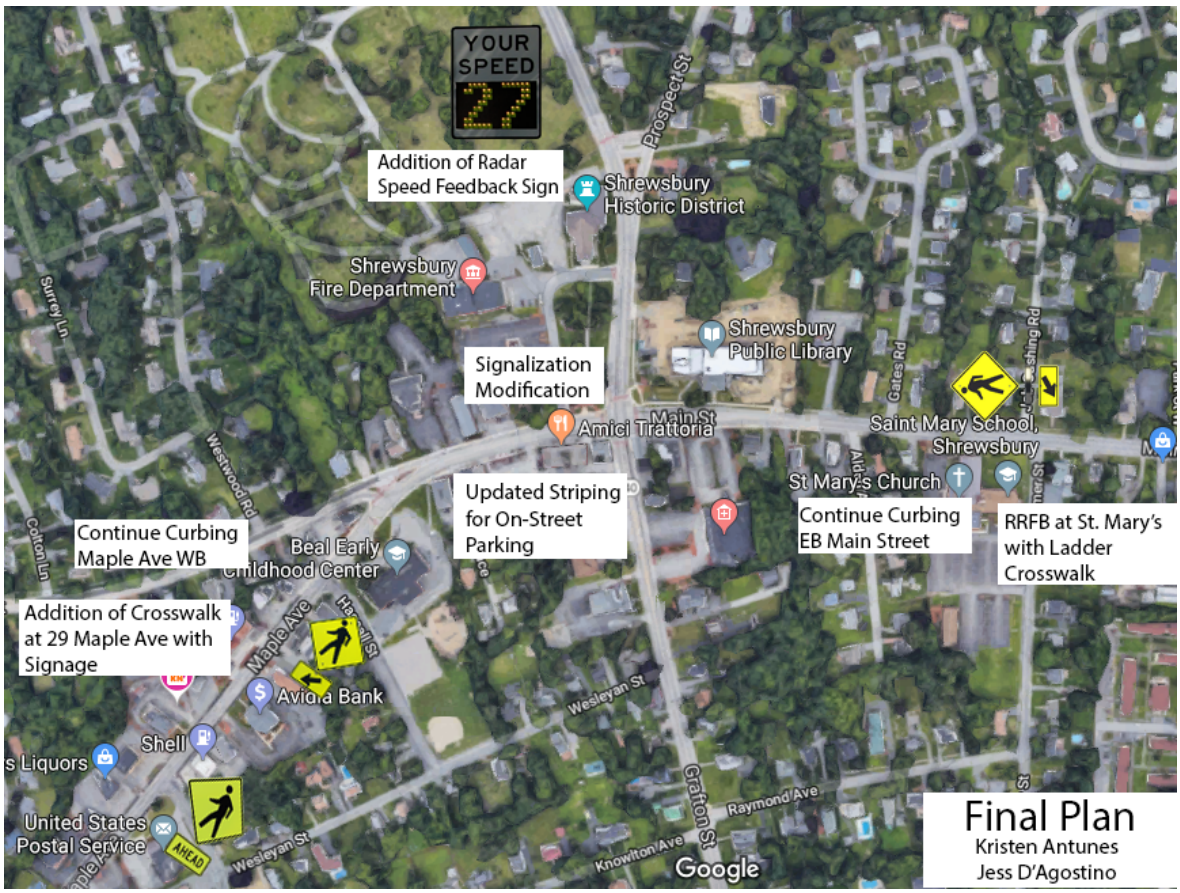

Figure 25: Final Plan Overview

The Final Plan carefully outlines the countermeasures used for each individual character area and what the countermeasure does to improve said area.

Area A: Historical and Municipal

Signal Timing Changes

Based on the analysis performed in the Highway Capacity Software (HCS), signal timing improvements can be made to decrease approach delays and increase the intersection's Level of Service (LOS). The morning peak time was the focus of these improvements due to the high percentage of heavy vehicles traveling through the intersection. It is necessary to decrease delay times at the intersection to minimize emissions from these heavy vehicles.

Based on the Turning Movement Counts (TMCs) and the current signal timing, the team found that time can be reallocated to increase intersection efficiency. The left turn volumes on Main Street Eastbound and Westbound were too low for the green time allocated for those movements. Therefore, it is recommended that time from the protected left turn be reallocated to the through movement. The full HCS reports can be found in Appendix D.

This reallocation of green time decreases the approach delays for Main Street and increases the overall level of service. Table 9 shows the decrease in approach delay for Main Street Eastbound and an increase in the approach LOS.

Table 9: Delay and LOS Improvement Main St. EB

Approach	Delay (sec/vehicle)	LOS
Current Main St. EB	38.1	D
Modified Main St. EB	**28.6**	**C**

Similarly, Table 10 shows the improvements to the Main Street Westbound delay and the increase in approach LOS from a D to a C.

Table 10: Delay and LOS Improvement Main St. WB

Approach	Delay (sec/vehicle)	LOS
Current Main St. WB	41.6	D
Modified Main St. WB	**31.4**	**C**

These small signal timing modifications in the AM period help to decrease overall delays and increase efficiency at the core intersection. The total overall LOS for the intersection remained at a C; however, the delay time decreased. The original intersection delay was 29.0 seconds/vehicle and after the signal timing modifications, decreased to 21.9 seconds/vehicle. This will decrease vehicle idling time in the Town Center, thus improving air quality.

Radar Speed Feedback Sign

The Town's Radar Speed Feedback Sign should be placed on Route 140, north of the intersection of Route 140 and Main Street. This proposal can be seen in Figure 26.

Figure 26: Before installation (left) and after installation of Radar Speed Feedback Sign

Currently, drivers are maintaining high speeds, as many are exiting I-290 and traveling down a wide, state road. The placement of this sign will alert drivers that they are entering the Town Center and they must reduce their speed. Per the *Manual on Uniform Traffic Control Devices* (MUTCD), the digital sign must be yellow numbers on a black background at a 12-inch LED height. This Feedback sign also must be installed in conjunction with a Speed Limit Sign.

Area B: Residential Zone

Enhance Crosswalk at Summer Street and Main Street

The crosswalk located at the intersection of Summer Street and Main Street supports pedestrians at Saint Mary's School and residents living in this area. Currently, the crosswalk only consists of two parallel lines to alert vehicles of the potential presence of pedestrians. To better support pedestrians using this crosswalk, the team proposes the addition of three Rectangular Rapid Flashing Beacons (RRFB) and two ladder crosswalks, seen in Figure 27. The RRFBs would be activated solar-powered, reducing the amount of work needed to install them at the site.

Figure 27: Before proposed crosswalk improvements (top) and after crosswalk improvements (bottom)

The crosswalk was shifted to ensure that there would no longer be space constraints and ramps could be added to ensure compliance with the American Disabilities Act (ADA). A second ladder crosswalk was added across Summer Street to continue the path to the Saint Mary's School. The rapid flashing beacons will all be connected so a pedestrian is able to travel from Main Street to the school lot.

Area C: Local and Chain Businesses

Continuation of Sidewalk

The numerous curb cuts along Maple Avenue deter pedestrian activity, as they feel unsafe in these areas. Two plazas with large expanses of parking lot have been chosen for a continued sidewalk. The plazas are located at 14-16 Maple Avenue and 26 Maple Avenue, seen in Figure 28.

Figure 28: Before addition of proposed sidewalk (left) and after addition of sidewalk (right)

The sidewalk should be continued across the parking lots to support pedestrians and signify a lot entrance for vehicles. The Town typically uses a 30-foot driveway for businesses and this standard was used to calculate the total amount of sidewalk required.

Figure 29: Placements for Continuing Sidewalks

Figure 29 displays the added sidewalks on the two Maple Avenue Plazas. A total of 135 feet of sidewalk was added with a 30-foot driveway for entering and exiting vehicles. Continuation of the sidewalks would help to reduce confusion for drivers and allow pedestrians to feel safer walking in the area.

Addition of Crosswalk on Maple

Based on the pedestrian observations in the Town Center, a third crosswalk on Maple Avenue would support pedestrians in Area C. Currently, there are two crosswalks located on Maple Avenue. However, many pedestrians were crossing without a crosswalk, so an additional crosswalk should be added to reflect these desires. The crosswalk can be seen in Figure 30.

Figure 30: Before additional crosswalk (left) and after additional crosswalk (right)

This crosswalk is located 400 feet from the crosswalk at 40 Maple Avenue and 460 feet from the crosswalk located at the intersection of Maple Avenue and Main Street. This location also has an existing streetlight above it, which ensures the crosswalk will be visible at night. Updated signage will also be added to Maple Avenue, and the MUTCD was used to design the signage layout.

Figure 31: W11-2 Pedestrian Sign (left) and W16-9P Down Pointing Arrow Sign (right)

On both sides of the crosswalk, W11-2 Pedestrian signs will be added with a W16-9P Down Pointing Arrow sign to alert drivers of pedestrians, shown in Figure 31. Additionally, 300 feet before the ladder crosswalk, Pedestrian Ahead Signs will be installed to alert drivers that they are approaching the location.

Figure 32 shows the existing crosswalks in red and the addition of the new crosswalk in blue, while updated signs are displayed in orange.

Figure 32: Placement of New Crosswalk on Maple Avenue

The four updated signs alert drivers that they are approaching a crosswalk and give the crosswalk greater visibility. The addition of the crosswalk will encourage pedestrians to use a crosswalk. With pedestrians using the crosswalks there is less chance for accidents to occur, which increases the safety of the area.

Updated Striping for On-Street Parking

To meet the Town's desire of a park-and-walk Center, existing on-street parking on Main Street should be promoted. There is striping currently that resembles a shoulder with unregulated parking. To alert drivers of on-street parking, 22-foot horizontal striping should be added. This addition can be seen in Figure 33.

Figure 33: Before the updated striping (top) and after the updated striping (bottom)

A total of nine spots can be indicated with striping in the current space. By adding these designated spots, parking will be more visible to drivers. Additionally, these spots are centrally located in the Town Center and would promote drivers to park in a spot and walk to their destination.

Figure 34: Placement of updated parking spots

Figure 34 shows the addition of nine parking spots along Main Street. Each spot is noted in red and is 22 feet in length.

4.6.2 Cost Estimate

The Massachusetts Department of Transportation (MassDOT) Construction Project Estimator tool as well as information provided to the team by Andrew Truman from the Town of Shrewsbury were used to develop the cost estimate.

Area A would have very minimal costs associated with the proposed improvements. The Town currently has a Radar Speed Feedback Sign that has been moved around the Town. The only cost associated would be an employee of the Shrewsbury Department of Public Works (DPW) to relocate the sign. Additionally, the signal timing changes would require the DPW to modify the timing. Therefore, there are no material costs associated with the chosen countermeasures in Area A.

A preliminary cost estimate was developed for the remaining areas. Some items, including the Painted Crosswalks and RRFBs, contain both the material cost and the cost of installation. The signage items only reflect the material cost of the item. The team rounded up to create a more conservative cost estimate within each area.

The cost breakdown for Area B is in Table 11, and the cost estimate for Area C is located in Table 12.

Table 11: Area B: Residential Cost Estimate

Item	**Quantity**	**Unit**	**Unit Price**	**Total Price**
Rectangular Rapid Flashing Beacon (RRFB)	3	ea.	$12,500	$38,000
Granite Transition Curb for Wheelchair Ramps Straight (4)	62	FT	$50	$3,000
Concrete Wheelchair Ramp (4)	39.22	SY	$92	$3,600
Painted Crosswalk	2	ea.	$1,200	$2,400
			Total Price	$47,000

Table 12 Area C: Local and Chain Business

Item	**Quantity**	**Unit**	**Unit Price**	**Total**
Ladder CW Striping	1	ea.	$1,200	$1,200
Concrete Sidewalk- 26 Maple Ave	70	FT	$30	$2,100
Concrete Sidewalk- 14-16 Maple	65	FT	$30	$2000
W11-2 Pedestrian Sign 30 x 30" (4)	24	SF	$19	$500
W16-7P Down pointing Arrow 24 x 12" (2)	4	SF	$19	$80
W16-9P Ahead 24 x 12" (2)	4	SF	$19	$80
Concrete Wheelchair Ramp (2)	19.61	SY	$92	$1,800
Parking Space Striping 12-inch Reflectorized white Line (Painted)	88	FT	$2	$200
			Total Area C	**$7,960**

The total cost estimate for all Town Center improvements is in Table 13.

Table 13: Total Cost Estimate

Area	**Cost**
Area A	$0
Area B	$47,000
Area C	$7,960
Total	**$54,960**

The total cost of the Final plan is $54,960 with Area B being the most expensive to install at $47,000 and Area A the least expensive with a cost of $0.

5. Recommendations

After learning the Town's area priorities, examining each area's needs, and analyzing research of various projects, the team has developed a set of final recommendations. These recommendations aim to address the walkability issues in the Shrewsbury Town Center. The final plan is broken down into recommendations for each Character Area; Area A: Historical and Municipal, Area B: Residential, and Area C: Local and Chain Businesses. The team recommends that the Final Plan in the Results Section be implemented to improve pedestrian safety and walkability in the Town of Shrewsbury. This plan is outlined in Section 4.6.

Much of the roads involved are state owned and would need state approval for installing any improvements; thus the team would recommend that the Town look into the Massachusetts Complete Funding Streets Program. Because municipalities that apply for the state-run program Massachusetts Complete Streets Funding Program Portal must have a Prioritization Plan, the Town of Shrewsbury has this document showing they are pursuing state funding. The Town has the *Shrewsbury Complete Streets Priority Plan Tier II* (McGoldrick, Christopher., & Town of Shrewsbury Massachusetts., 2018). The team recommends that the parts of the Final Plan are added to the Town's Complete Streets Priority Plan.

Future Considerations

Future considerations were developed for the Town in areas that would assist in meeting their long-term goals.

Wayfinding

The Town of Shrewsbury is currently working on wayfinding signs throughout the Town Center to promote walkability. The team proposes that the on-street parking, located on Main Street, be included in the current wayfinding plans to promote the park-and-walk culture that is desired. Additionally, historic attractions, such as the Town Common, the First Congregational Church, and the various historic houses, should also be included in the plans.

Bus Route Improvements

Currently, the Worcester Regional Transit Authority (WRTA) bus operates on a flag system with no designated stop. The team proposes that additional data be collected, in conjunction with the WRTA, on the usage of the Route 15 Bus. This data should be used to determine a common location for drop-off and pick-up, and a bus shelter could be added. The addition of a formalized stop and bus shelter would promote residents and visitors to utilize this service.

Bicycle Infrastructure

The team was unable to collect enough bicycle data in the Town Center due to time and weather constraints. A study on bicycles should be conducted to determine proper bicycle

infrastructure in the Town Center. There is potentially space for the addition of bicycle lanes on Maple Avenue and Route 140; however, additional data must be collected.

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Appendix

Appendix A: Project Proposal

Safety and Walkability in the Shrewsbury Town Center

By Kristen Antunes and Jessica D'Agostino

Date: October 10, 2019
Sponsor: Stantec
Advisors: Professor Leonard Albano and Professor Suzanne LePage

Table of Contents

Capstone Design Statement

This Major Qualifying Project (MQP) focuses on assessing the walkability and pedestrian safety in the Town Center of Shrewsbury. The Town has been working to enhance the walkability of the Downtown area, also known as the Town Center. The Town of Shrewsbury is also focusing on making the Town Center a destination for residents and visitors. The team aims to continue these efforts in creating conceptual designs and recommendations for pedestrian safety and walkability. This will be done by analyzing the existing conditions to determine key problems with the area and working closely with both Stantec and the Town of Shrewsbury to meet the needs of the Town Center. This project has several design constraints including economic, environmental, social and political, ethical, health and safety, and sustainability. By considering the constraints, this project will satisfy the Worcester Polytechnic Institute (WPI) criteria for Accrediting Engineering Programs by the Accreditation Board for Engineering and Technology (ABET). The following examines the eight constraints related to this project:

Economic

Funding for civil engineering and planning projects is an important factor. Many of the projects currently running in the Town of Shrewsbury are funded through grants from the federal government, and therefore have standard regulations that come from sources like the Federal Highway Admiration (FHWA). A cost analysis is often associated with projects to ensure that each proposed fit within a budget.

Environmental

With many of the projects funded through federal grants, most, if not all projects have an environmental component to them to ensure no or limited damage to the environment occurs during the build. An environmental analysis of the area is completed during the design phase, to make sure that the proposed project would not interrupt naturally occurring things like rain runoff. Another thing to consider is whether the proposed project plan would cause long-term detrimental effects and how to prevent these issues from arising.

Social and Political

The team will work to obtain what the citizens want out of the project. The team will work closely with the Town of Shrewsbury and our sponsor, Stantec, to gain an understanding of what the town needs. Looking through the *Town of Shrewsbury Master Plan 2016* and the *Town Center Visioning Report 2019,* the team can learn about the opinions and concerns of citizens of Shrewsbury.

Ethical

This project will abide by the American Society of Civil Engineers (ASCE) Code of Ethics for all civil engineers. It is paramount that engineers follow the Code of Ethics to ensure that they are maintaining the safety and welfare of the public, honesty, competence, professionalism, and professional development.

Health and Safety

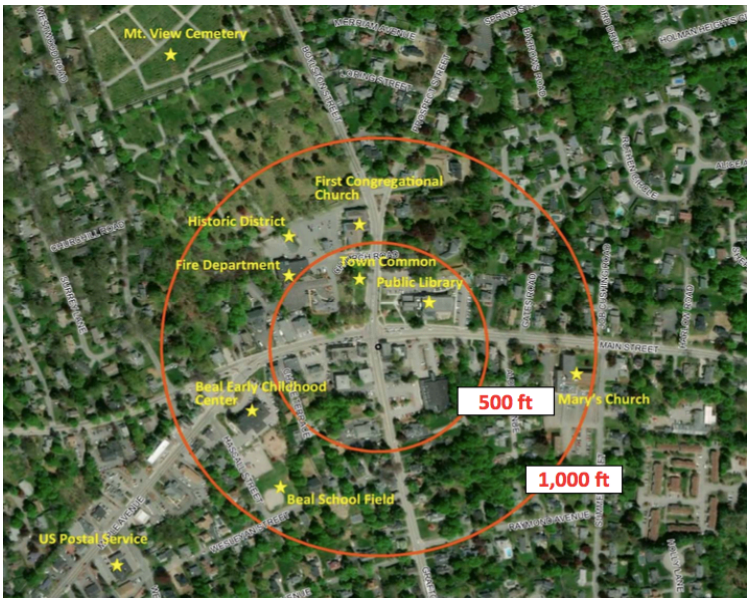
The project aims to address pedestrian safety by focusing on traffic calming measures and walkability in the Town Center. The team will work with both the Town of Shrewsbury and Stantec to ensure that all aspects of safety are being considered in the final project.

Sustainability

This project aims to improve walkability and pedestrian safety in a growing downtown environment. The team will consider potential changes and development in the area to ensure that the recommendations address current and future needs.

1. Introduction

Shrewsbury is located in Worcester County, which is centrally situated within the heart of Massachusetts. The Downtown area of Shrewsbury contains the town's Historic District, as well as local and chain businesses. The intersection of Route 140 and Main Street is geographically considered the Town Center and is adjacent to the Town Common and the Public Library, as seen in Figure 1.



There have been concerns from residents of Shrewsbury and visitors to the Town Center for pedestrian safety and walkability due to automobile congestion and heavy vehicle traffic. For example, heavy vehicles that are traveling to shipping distribution centers pass through the intersection of Route 140 and Main Street, creating an unsafe feeling for pedestrians. Additionally, there is no on-street parking for much if not all main roadways in the Limited Business zoning area that encompasses the Town Center.

There is a desire from the Town to make improvements to pedestrian and bike infrastructure and to make the Town Center a walkable destination. This is exemplified in the *Shrewsbury Master Plan* that was published on March 3, 2016, and the May 28, 2019 *Town Center Visioning Report*. The *Town of Shrewsbury Town Center Parking Management Plan,* completed in December 2018, reported that while there is plenty of parking for individual businesses, there appears to be little public parking available. Additionally, the Town hopes to promote an environment of parking centrally and walking to destinations to reduce the need to drive from one destination to another.

Shrewsbury has potential development projects in process within the Town Center, including the Beal Early Childhood Center Building Redevelopment project. The site is located in the Town Center and is to be redeveloped, which could enhance the feel and functionality of the area. In the development process, the town stresses the importance of making the Town Center feel like a community (Horsley Witten Group, Inc., 2019 May 28). As the Downtown

Area continues to develop, walkability and pedestrian safety are paramount to the success of the Center.

With these problems and potential changes to the Town Center in mind, this project aims to increase pedestrian safety and walkability in the Shrewsbury Town Center. To achieve this, the following objectives will be met:

- Conduct case studies of Pedestrian Area studies
- Identify key problems in the Shrewsbury Town Center
- Develop potential solutions and conceptual designs
- Select final solutions by evaluating conceptual design based on the needs of the Town and design criteria, as well as stakeholder feedback
- Develop final recommendations and complete a written report and presentation to project sponsors and representatives of Shrewsbury

2. Background

The following sections provide an overview of the problems associated with the Town Center, including bicycle and pedestrian safety, as well as future development goals and projects in Shrewsbury. Additionally, it describes the case studies used to inform project methods.

2.1 Pedestrian and Bicycle Mobility in Downtown Shrewsbury

Through the *Town of Shrewsbury Master Plan 2016*, and *the Town Center Vision Report 2019,* resident comments can be found relating to the Town Center. Residents of Shrewsbury have addressed their concerns over pedestrian safety walkability and traffic flow in the Town Center.

The *Town of Shrewsbury Master Plan 2016* focuses on the overall improvement of Shrewsbury for short and long-term plans. The *Master Plan* contains goals for a more walkable Town Center in Shrewsbury. It notes the challenges associated with pedestrian travel in the Town Center area, notably at the intersection between Grafton Street (Route 140) and Main Street. To increase pedestrian safety, the *Master Plan* describes the Town's desire to not widen the roads further and to address issues with signal timing and coordination (Horsley Witten Group, Inc., RKG Associates, Inc. & McMahon Associates, Inc., 2016, March 3). Another goal in the Master Plan is to decrease the number of curb cuts to reduce pedestrian and vehicle conflicts. Finally, another goal detailed is to examine parking regulations in the Town Center to promote residents and visitors to walk around the area (Horsley Witten Group, Inc., RKG Associates, Inc. & McMahon Associates, Inc., 2016, March 3).

The *Town Center Vision Report* collected public data through various means, one of which was an electronic survey sent out in October 2018. This survey had 340 responses with a great majority having concern over the traffic flow and pedestrian safety (Horsley Witten Group, Inc., 2019, May 28). In the *Vision Report*, residence and business owners are quick to point out that there are issues with the traffic and the local economy is underperforming. Many buildings that support a walkable environment do not actually comply with the Limited Business (LB)

zoning that the Town Center is currently zoned as. Wayfinding signs have been proposed as a suggestion to improve the Town Center and currently the Town of Shrewsbury is looking into ways of installing these signs (Horsley Witten Group, Inc., 2019, May 28). There are different traffic calming suggestions that the report gives to not only help traffic flow but to also improve safety for pedestrians and potential bicycle users.

2.2 Shrewsbury Development Goals

The Town of Shrewsbury has goals for continual development of the Town Center, which are outlined in the *Visioning Report,* and the *Master Plan*. In future development, the Town would like buildings to promote the historic character. Additionally, the new buildings should engage the street and design of the facade and streetscape should be considered in the development process.

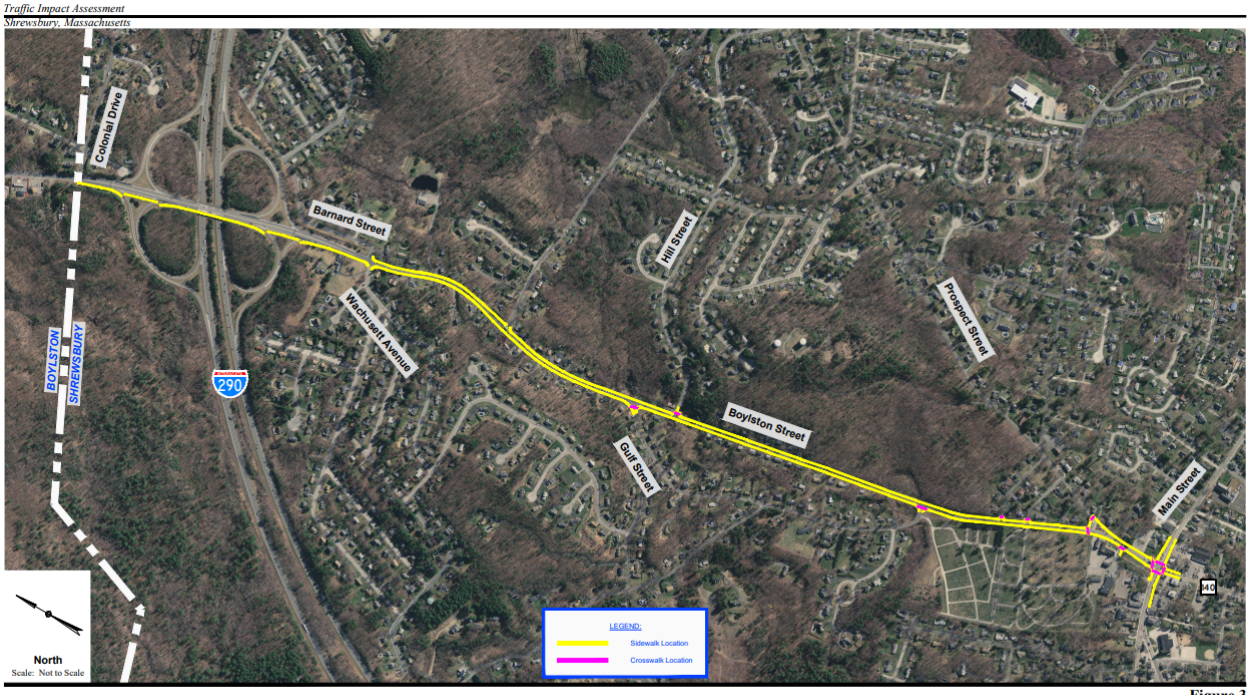
There are currently developing projects that could shape the Town Center. For example, the Beal Early Childhood Center is in the process of being redeveloped. This building is located in the Town Center. Resident surveys and comments have informed a development policy that will be communicated to the property developers of this site. The addition to the Town Center should "include uses that will increase foot traffic and draw visitors from other parts of Shrewsbury and beyond" (Horsley Witten Group, Inc., 2019, May 28). The new development should provide parking opportunities that can be used for the Town Center as a whole. These future development projects are intended to increase pedestrian traffic and could potentially modify the ways in which the current Town Center functions.

2.3 Pedestrian Area Case Studies

The following case studies were used to inform project methods and summaries are provided below.

2.3a Summary of 2017 Corridor Study Route 140 South

The Route 140 South Corridor Study was prepared by the MDM Transportation Consultants, Inc. and it covered Boylston Street (Route 140) from Colonial Drive to the Shrewsbury Town Center Grafton Street (Route 140) and Main Street intersection (MDM Transportation Consultants, Inc., 2017, November). The corridor study was commissioned in part of a Settlement Agreement between the Town of Shrewsbury and Scannell Properties #267 LLC for the proposed FedEx Ground Transportation Facility. The corridor covered a two-mile section of Boylston Street (Route 140) which is classified as an urban major arterial roadway (MDM Transportation Consultants, Inc., 2017, November).



MDM TRANSPORTATION CONSULTANTS, INC.
Planners & Engineers

Figure 3
Existing Pedestrian Facilities

This study conducted by MDM Transportation Consultants, Inc. found that there were no facilities for bicycles along the studied corridor area. Each intersection on the corridor was studied and analyzed in the report including the intersection of Route 140 with Main Street, which is within the study area of this MQP (MDM Transportation Consultants, Inc., 2017, November).

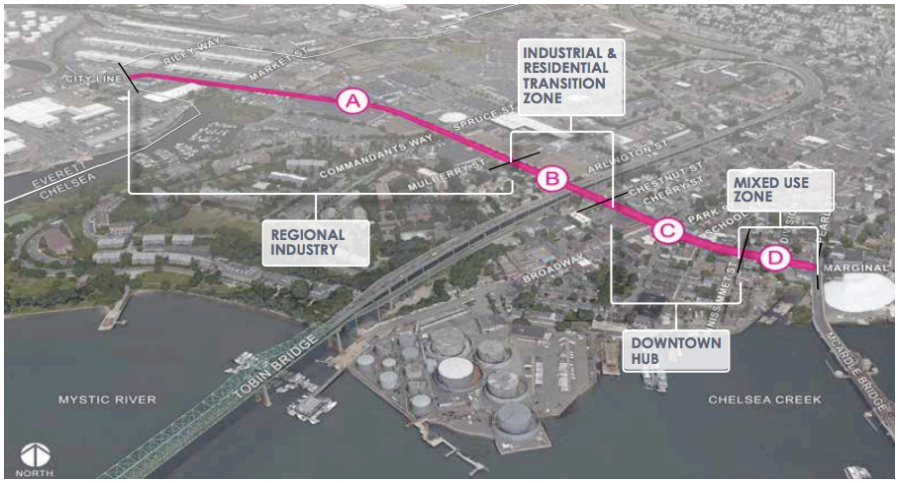
The Route 140 Corridor study found that the intersection of Grafton Street (Route 140) and Main Street is listed by the Massachusetts Department of Transportation (MassDOT) as a Highway Safety Improvement Program (HSIP) crash cluster for 2012-2014. All HSIP locations are subject to Road Safety Audits (RSA) to identify short term and long-term safety operations for improvement (MDM Transportation Consultants, Inc., 2017, November). This particular intersection was found to have a Level of Service (LOS) of "F". LOS "F" is the worst rating and means that there is over a 50-second delay for a non-signalized movement but since the intersection of Route 140 and Main Street is signalized the delay is 80 seconds or more of no movement (MDM Transportation Consultants, Inc., 2017, November).

Since our team will be looking closely at Grafton Street (Route 140) and Main Street intersection it is important to see the data collected from this study to compare it to the findings that our team will be collecting. There are traffic counts and even a pedestrian bicycle count found in the 140 Corridor Study that could be useful for the MQP.

2.3b Summary of 2018 Street Corridor Study Chelsea, MA

In 2018, the Beachman/Williams Street Corridor was analyzed by Stantec due to its heavy industrial use. This corridor was selected because of the increase in heavy vehicle usage,

the lack of connections to public transit, and the high number of crash clusters (Stantec, 2018). The existing conditions of the corridor were analyzed and Stantec found improvements were needed to increase safety for all modes of transportation. The Beachman/Williams Street Corridor was characterized by the various functions to address the unique needs. Four character areas were defined; Regional Industry, Industrial & Residential Transition Zone, Downtown Hub, and Mixed Use Zone. Figure 3 shows the proximity and location of these character areas.



General recommendations for the corridor as a whole were provided to address the safety issues and conflicts between different modes of transportation. Additionally, Stantec provided recommendations that were specific to each area to address the unique issues found within. The first area, Character Area A or Regional Industry, contains industrial uses with high volumes of heavy vehicles serving produce production and distribution facilities. Character Area B, Industrial & Residential Transition Zone, is a transition between different land uses. This area contains residential spaces and is located between industrial property and the Downtown area. Character C, The Downtown Hub, contains businesses and heavy pedestrian, with connections to MBTA public transit. The final area, Character Area D, is the Mixed-Use Zone. This area consists of a mix of commercial, industrial, and residential uses (Stantec, 2018). The method of creating character areas for mixed-use corridors allows for specific recommendations to be made to fit the needs of a changing environment. This will be useful as the Town Center in Shrewsbury serves many functions for the Historic District, Industry, and Municipal Buildings.

3. Methodology

This section gives an overview of the methodology that will be used in the completion of the Major Qualifying Project (MQP). The team created a list of objectives to guide the methodology that will be met throughout the project. The objectives are as follows:

- Identify key problems in the Town Center
- Conduct case studies of Pedestrian Area studies
- Develop potential solutions and conceptual designs
- Select final solutions by evaluating conceptual design based on the needs of the Town and design criteria, as well as stakeholder feedback
- Develop final recommendations and complete a written report and presentation to project sponsors and representatives of Shrewsbury

This section details the ways in which the team will meet these objectives.

3.1 Identify Key Problems in the Town Center

To identify key problems in the Town Center, the team analyzed the *Town of Shrewsbury Master Plan 2016* and the *Town Center Visioning Report 2019*. With the knowledge from the report and the Master Plan, it was clear to the team that a study on pedestrians and general traffic flow needed to be conducted. To focus the Major Qualifying Project (MQP), a traffic and pedestrian study at the intersection of Route 140 and Main Street will be conducted. The team will travel to the Town Center intersection during two peak hours on a weekday and on the weekend. The Town can assist us in identifying a weekend day that will provide us with the most useful data. The team will be collecting traffic and pedestrian counts to compare to existing data that has been collected in other Downtown projects.

3.2 Conduct Case Studies of Pedestrian Area Studies

The team will conduct a case study analysis on existing area studies that are focused at a neighborhood level. These studies will include those of pedestrian safety improvements and pedestrian area studies. The team will compile a list of case studies found online or through a compilation of past projects from Stantec or the Town of Shrewsbury. These case studies will be reviewed during our project work to provide us with insight into the challenges associated with these types of projects. Additionally, this will assist us in determining potential solutions that can be applied to the Shrewsbury Town Center.

3.3 Develop Potential Solutions and Conceptual Designs

The team will develop potential solutions and conceptual designs after identifying the key problems and conducting research. We will create designs that take into account the data collected and the information from the case studies. The team will use a tool such as Streetmix to display the conceptual designs (Streetmix., 2019). We will then seek input from Shrewsbury

representatives to assess the feasibility and usefulness of the designs to the Town. Each design drawing plan will have a cost analysis portion that will show an estimate of what each proposed plan will cost. A breakdown of the elements that would be used will be included with the cost analysis of each of the proposed plans.

3.4 Develop Final Design Based on Feedback

To choose a final design for the Town Center, we will evaluate our potential designs based on certain criteria to meet the needs of the Town. We will evaluate based on the different types of transportation used in the Town Center, like pedestrians, automobiles, and bicycles.

The criteria for choosing the final design solution are as follows:

- Safety: Pedestrian safety is very important in the development of the Town Center to ensure that it is a walkable environment.
- Accessibility: The designs should be accessible to all residents and visitors to the Town Center.
- Feasibility and Constructability: The designs and recommendations should be within the limitations and constraints of the Town of Shrewsbury.
- Social Implication to the Town Center: These design improvements should be aligned with the economic, historic, and social goals set by the Town of Shrewsbury.
- Cost: The cost should be deeply considered so there is the greatest benefit to the Town.

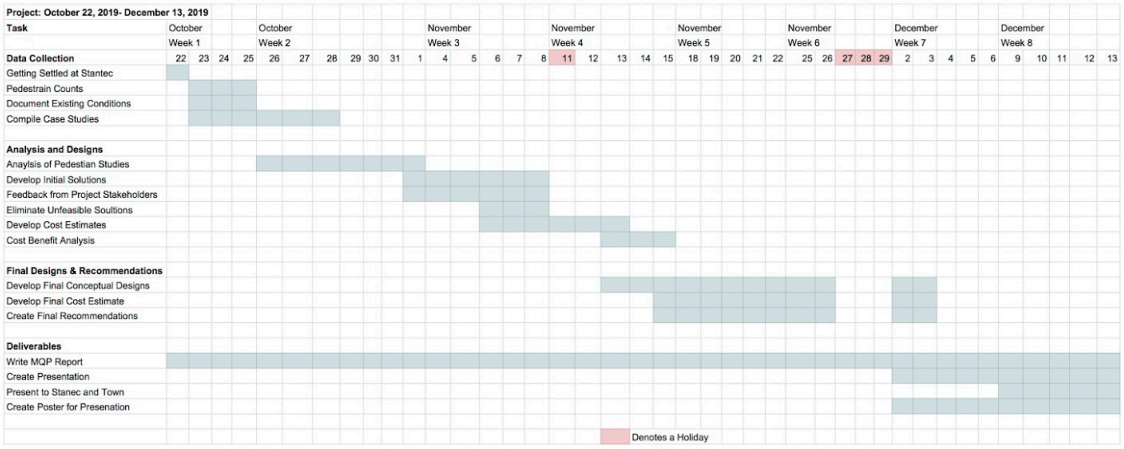
The design that meets the criteria will be chosen as the final design.

The final design will be drafted using software like AutoCAD Civil 3D to effectively convey the project designs. Additionally, GIS mapping will be used to display data and provide a larger context to the Town Center. Based on the final design and anticipated construction materials and the other installations, a final cost estimate will be provided.

3.5 Develop Final Recommendations

At the end of the project, the team will produce and present our project deliverables. This will include design drawings to enhance pedestrian safety and estimates for the proposed plan. This will be summarized in a final proposal that will be submitted to Worcester Polytechnic Institute (WPI), Stantec, and the Town of Shrewsbury. A final presentation will also be presented to Stantec and the Town, as well as a project poster presented in April at WPI.

A schedule for our project timeline can be seen below in Figure 4.



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Appendix B: Turning Movement Counts

Note: The peak hour values are highlighted in gray.

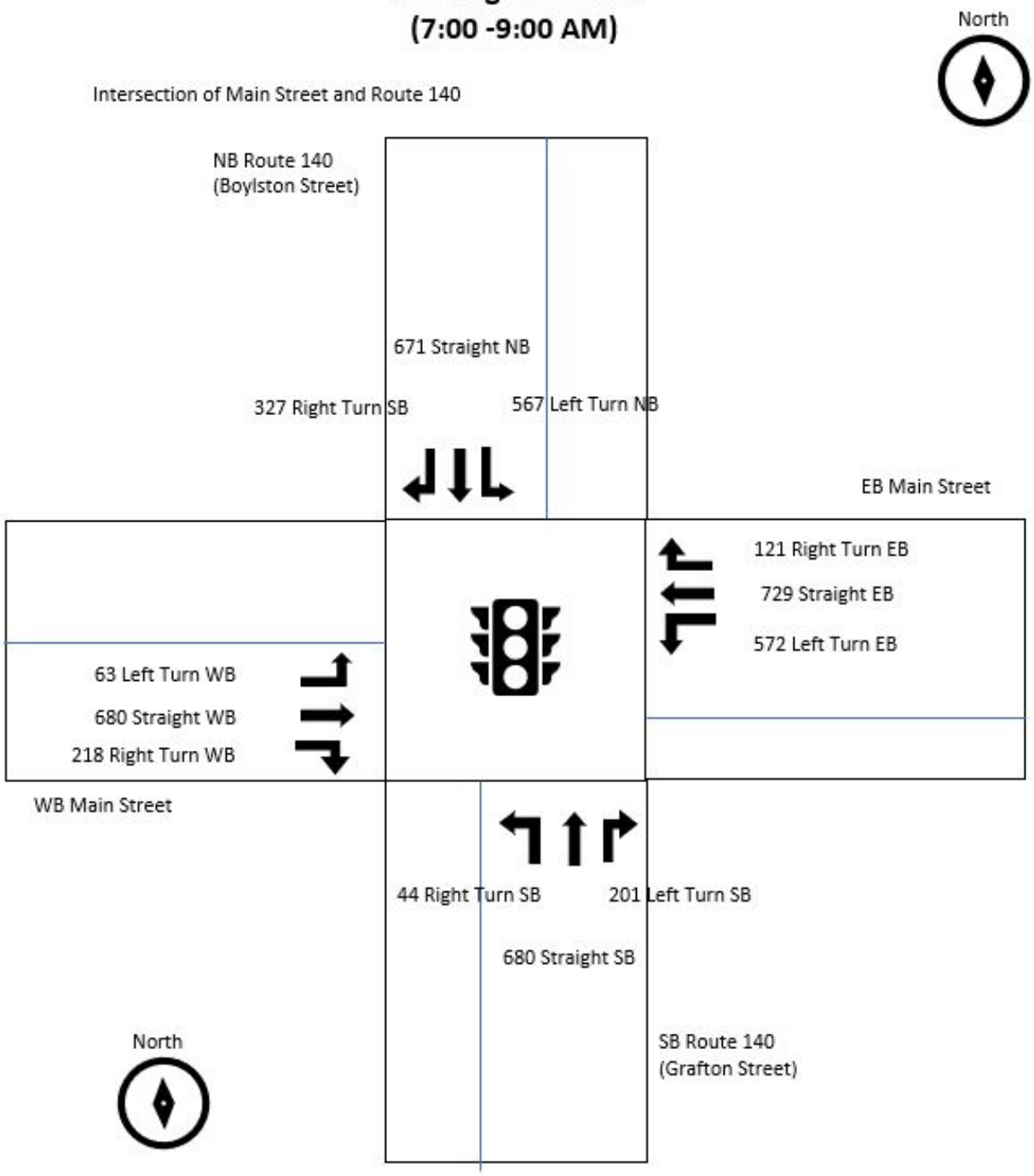
AM Peak Hour Traffic Counts- Intersection of Main St and Route 140

Time Period	Route 140 NB					Route 140 SB					Main St EB					Main St WB					Total
	R	S	L	P	HV	R	S	L	P	HV	R	S	L	P	HV	R	S	L	P	HV	
7:00 AM- 7:15AM	46	75	69	0	10	3	79	23	0	7	11	86	76	0	9	23	86	5	0	6	582
7:15 AM- 7:30AM	48	68	75	1	19	7	86	32	0	4	15	79	71	0	7	21	78	6	0	2	586
7:30 AM- 7:45AM	47	77	81	0	13	5	89	28	0	8	10	96	69	0	10	27	95	11	1	7	635
7:45 AM- 8:00AM	51	76	78	0	16	5	96	39	0	7	10	98	77	0	7	36	83	14	0	5	663
8:00 AM- 8:15AM	40	94	74	2	17	9	90	21	0	10	19	111	73	1	11	33	90	10	2	7	664
8:15 AM- 8:30AM	33	91	61	0	15	6	81	16	0	15	20	109	71	0	6	29	82	5	0	9	604
8:30 AM- 8:45AM	32	96	65	2	13	5	85	19	0	11	17	99	71	0	9	24	79	7	2	5	599
8:45 AM- 9:00AM	30	94	64	0	14	4	74	23	0	10	19	114	64	0	7	25	87	5	1	4	603
TOTAL	327	671	567	5	117	44	680	201	0	72	121	792	572	1	66	218	680	63	6	45	**4936**
		NB	31.29%				SB	18.90%				EB	29.73%				WB	20.07%			
Peak Sums:	171	338	294	2	61	25	356	104	0	40	59	414	290	1	34	125	350	40	3	28	**2566**
Total Trucks:	300																				
Truck Percent:	11.69%																				
PHF:	0.97																				

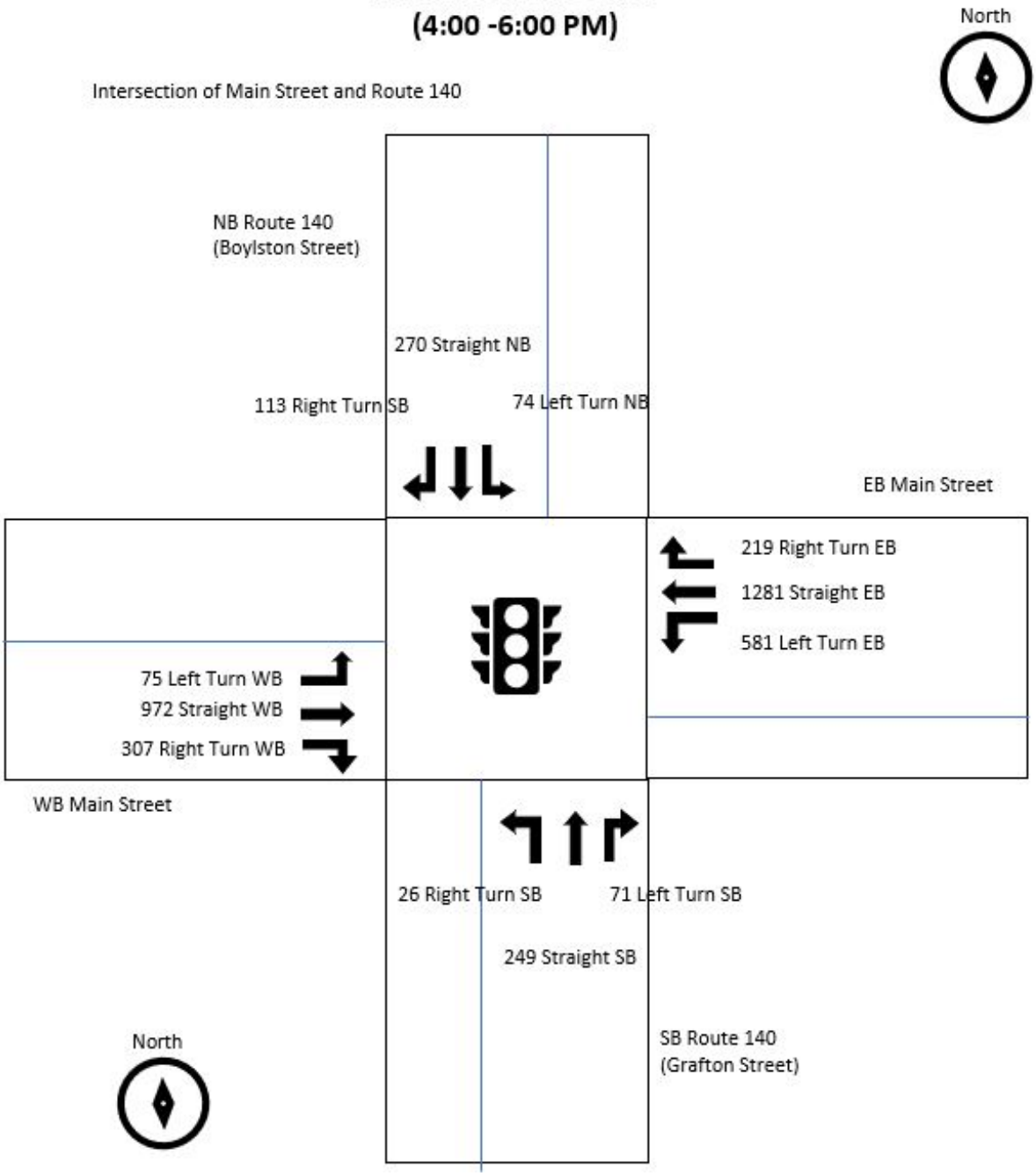
PM Peak Hour Traffic Counts- Intersection of Main St and Route 140

Time Period	Route 140 NB					Route 140 SB					Main St EB					Main St WB					Total
	R	S	L	P	HV	R	S	L	P	HV	R	S	L	P	HV	R	S	L	P	HV	
4:00PM-4:15PM	29	81	32	1	18	10	80	17	3	9	29	106	64	3	6	34	113	7	0	4	602
4:15PM-4:30PM	43	83	21	12	22	8	76	20	3	11	19	102	57	5	7	41	110	12	5	4	592
4:30PM-4:45PM	41	106	21	11	12	8	93	34	0	12	27	134	74	5	8	37	109	10	0	4	694
4:45PM-5:00PM	49	169	51	1	7	3	108	40	0	12	25	204	81	0	6	38	114	11	0	1	893
5:00PM-5:15PM	60	179	42	7	10	6	98	28	0	4	50	203	86	1	2	41	145	11	2	2	949
5:15PM-5:30PM	85	184	28	9	14	13	90	32	0	5	19	267	71	0	2	36	133	13	0	2	971
5:30PM-5:45PM	38	110	37	2	14	7	99	32	0	5	22	126	76	5	1	35	116	5	3	1	703
5:45PM-6:00PM	33	206	31	1	14	7	80	34	0	8	28	139	72	4	3	45	132	6	0	0	813
TOTAL	113	270	74	24	52	26	249	71	6	32	219	1281	581	23	35	307	972	75	10	18	6217
		NB%	29.4%				**SB%**	15.81%				**EB%**	35.0%				**WB%**	19.9%			
Peak Sums:	232	642	158	19	45	29	395	132	0	26	116	800	314	6	11	150	508	40	5	6	**3516**
Total Trucks:	137																				
Truck Percent:	3.90%																				
PHF:	0.93																				

Morning AM Count
(7:00 -9:00 AM)



Afternoon PM Count
(4:00 -6:00 PM)



Appendix C: Meeting Minutes

Meeting Minutes from November 21, 2019 with Town of Shrewsbury

A meeting was held on Thursday, November 21st, 2019in the Shrewsbury Town Hall. Worcester Polytechnic Institute (WPI) Undergraduate Civil Engineering Students, Kristen Antunes, and Jessica D'Agostino, met with Town of Shrewsbury representatives: Kristen Las, the Assistant Town Manager/Economic Development Coordinator; Christopher McGoldrick, the Assistant Town Planner; and Bernard Cahill, the Town Planner. An overview of the team's progress to date was discussed with visual aid of PowerPoint Slides.

The main purpose of the meeting was to gain an understanding of the Town's priorities for each Character Area in the Town Center. Two opposing conceptual plans were presented to the Town Representatives by the WPI Students. Using Adobe Photoshop 2019, the team was able to show what each Character Area would look like with the countermeasure implemented. Each plan was shown separately, and feedback was collected, which is summarized below.

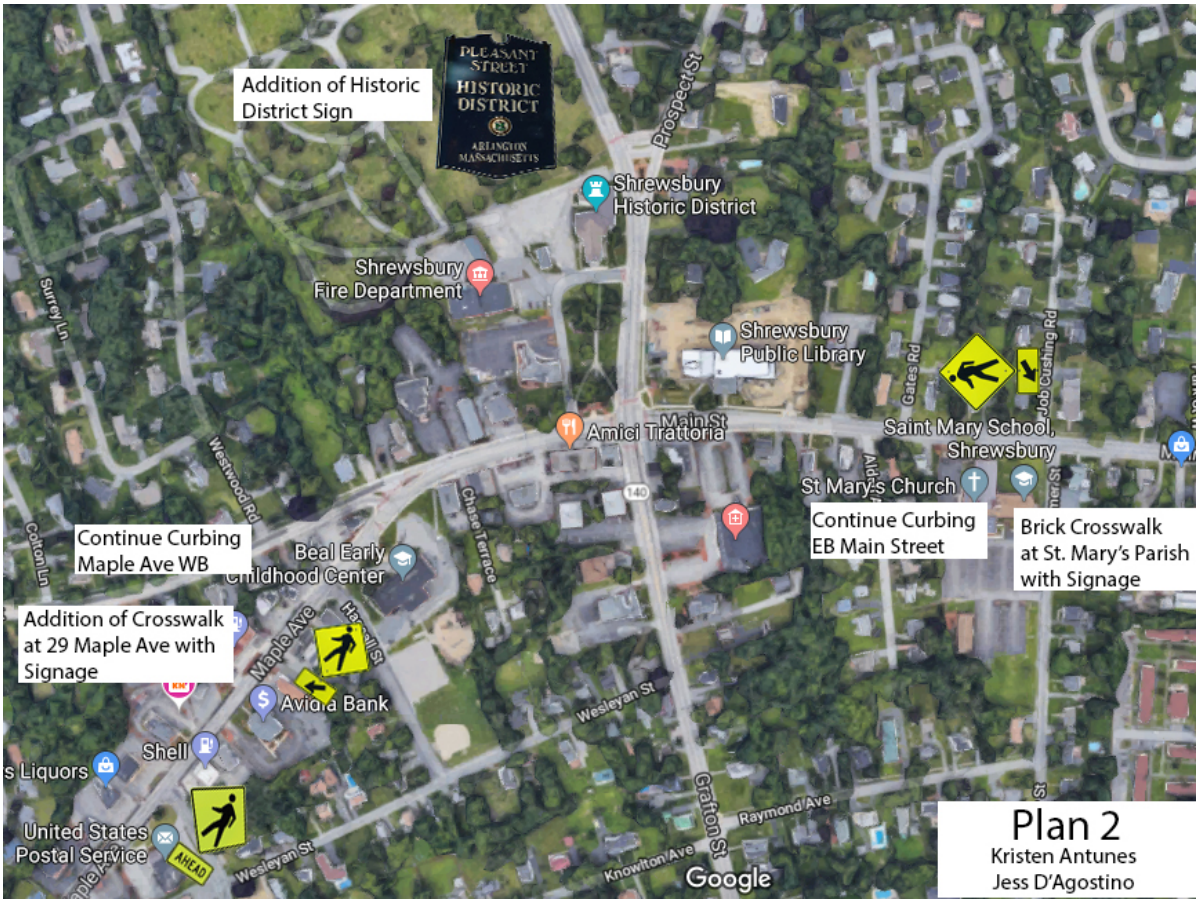
Feedback on Plan 1

Ms. Las stated that she liked the proposed improvements to Area A and Area B even stating that the Town has a speed limit feedback sign but has been moving it around the Town.

Mr. McGoldrick and Mr. Cahill both voiced their agreement on liking the proposed improvements to Area A and Area B.

Ms. Las was the one who spoke about recent success from Rectangular Rapid Flashing Beacons (RRFB) at a different school location. Mr. McGoldrick noted that since they have recently worked with the Massachusetts Department of Transportation (MassDOT) they would not have any problem working with them again; this was agreed upon by Mr. Cahill.

When discussing Area C parking signs and potential striping all three Town Representatives were hesitant about this topic. Ms. Las said that no parking signs might deter drivers from seeing that there is parking in front of the stores on Main Street. Mr. Cahill said that while there were no regulations right now for that specific area, the Town would have to have a public discussion. Ms. Las and Mr. McGoldrick both agreed that a public forum would need to be held before any regulations or signs were to be placed. Without putting up signs, painting stripe lines for specific parking places was a compromised suggestion amongst the Town representatives.



Feedback on Plan 2

For Plan 2 Area A, Ms. Las noted that there was a smaller sign placed further north on Route 140 (Boylston Street) that welcomed people into the Town Center. For Area B Plan 2, Mr. Cahill stated that he liked the idea of brick at the crosswalk that would be placed at the Summer Street and Main Street intersection; however, he had concerns about maintenance costs. Mr.

Goldrick liked the idea of the brick seeing as it was a different material to alert a driver they just drove over a crosswalk. Ms. Las said that they did use a material similar to the texture of brick but was not brick. Ms. Las said that Frederick Mosely from Stantec would know the material from the Burns Bridge project completed in 2008. For Area C Plan 2, Ms. Las noted that the Town was already working with MassDOT to place another crosswalk on Maple Avenue. Both Mr. Cahill and Mr. McGoldrick stated that it might be a good idea for the WPI Students to contact people in the Department of Public Works (DPW). Ms. Las suggested contacting the town engineer Andrew Truman who works in the DPW.

Overall Feedback

After the feedback on the two conceptual plans, the discussion then opened up to talk about some future plans that could be done in the Town. Ms. Las asked the WPI Students if they had the *Shrewsbury Complete Streets Priority Plan Tier II* (McGoldrick, Christopher.,& Town of Shrewsbury Massachusetts., 2018 December 13), for which the students said they did not. Mr. McGoldrick was tasked with emailing the students with the document which he did shortly after the meeting was adjourned. Providing a bicycle lane from Maple Avenue north along Route 140 was discussed. Ms. Las pointed out that bicyclists use this path to get to the Wachusett Reservoir. Mr. McGoldrick said one of the projects the Town was working on was Wayfinding signs and that they were still figuring out placements for the signs. Another item that came up was potentially working with the Worcester Regional Transportation Authority (WRTA) to establish a bus stop area either on Maple Avenue or Main Street. Mr. Cahill and Ms. Las stated that the students might want to share their information with Central Massachusetts Regional Planning (CMRPC); specifically, the pedestrian observation data that could be useful to them. Ms. Las said that if there were more time for the project that they would have had another meeting with the Town Engineer, the chief of police and their contact from the District 3 MassDOT in attendance.

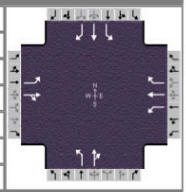
The meeting was adjourned at 2:30 PM with the promise from the WPI Students to extend an invitation to the Town to come to the project presentation held at Stantec in the Burlington, MA Office on December 5th, 2019 which they did. The WPI Students also extended an invitation to the Town of Shrewsbury representatives to come to the April 23rd presentation held at WPI in Kaven Hall.

Appendix D: Highway Capacity Software Reports

Intersection Existing Conditions

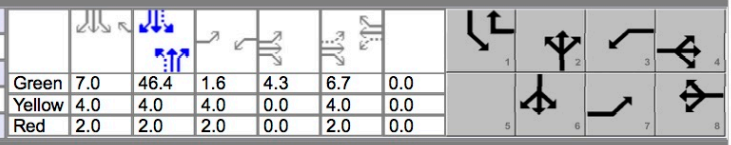
HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	10/31/2019	Area Type	Other
Jurisdiction		Time Period		PHF	0.97
Intersection	Route 140 (Grafton St)	Analysis Year	2019	Analysis Period	1> 7:00
File Name	Route 140 and Main AM LOS.xus				
Project Description	Peak AM Interval				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	73	111	19	10	90	33	74	94	40	21	90	9

Signal Information			
Cycle, s	90.0	Reference Phase	2
Offset, s	0	Reference Point	End
Uncoordinated	No	Simult. Gap E/W	Off
Force Mode	Fixed	Simult. Gap N/S	Off



Green	7.0	46.4	1.6	4.3	6.7	0.0
Yellow	4.0	4.0	4.0	0.0	4.0	0.0
Red	2.0	2.0	2.0	0.0	2.0	0.0

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	7	4	3	8		2	1	6
Case Number	1.1	4.0	1.1	3.0		6.3	1.0	3.0
Phase Duration, s	11.9	17.0	7.6	12.7		52.4	13.0	65.4
Change Period, (*Y*+*Rc*), s	6.0	6.0	6.0	6.0		6.0	6.0	6.0
Max Allow Headway (*MAH*), s	3.7	3.7	3.7	3.7		0.0	3.7	0.0
Queue Clearance Time (g_s), s	5.4	8.4	2.5	6.4			2.4	
Green Extension Time (g_e), s	0.0	0.3	0.0	0.3		0.0	0.0	0.0
Phase Call Probability	0.85	0.96	0.23	0.96			1.00	
Max Out Probability	0.37	0.00	0.00	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	7	4	14	3	8	18	5	2	12	1	6	16
Adjusted Flow Rate (*v*), veh/h	75	134		10	93	34	76	138		22	93	9
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1757	1783		1757	1845	1567	1249	1701		1707	1792	1519
Queue Service Time (g_s), s	3.4	6.4		0.5	4.4	1.7	2.8	3.9		0.4	1.7	0.2
Cycle Queue Clearance Time (g_c), s	3.4	6.4		0.5	4.4	1.7	2.9	3.9		0.4	1.7	0.2
Green Ratio (*g*/*C*)	0.14	0.12		0.09	0.07	0.15	0.52	0.52		0.62	0.66	0.66
Capacity (*c*), veh/h	229	219		147	137	239	723	876		779	1182	1002
Volume-to-Capacity Ratio (*X*)	0.329	0.612		0.070	0.675	0.143	0.105	0.158		0.028	0.078	0.009
Available Capacity (c_a), veh/h	308	543		311	473	524	723	876		1260	1182	1002
Back of Queue (Q), veh/ln (50th percentile)	1.5	2.9		0.2	2.1	0.6	0.8	1.4		0.1	0.6	0.1
Queue Storage Ratio (*RQ*) (50th percentile)	0.00	0.00		0.05	0.55	0.16	0.21	0.00		0.04	0.00	0.00
Uniform Delay (d_1), s/veh	34.6	37.4		37.4	40.6	33.1	11.3	11.5		6.9	5.5	5.2
Incremental Delay (d_2), s/veh	0.7	2.2		0.2	4.6	0.2	0.3	0.4		0.0	0.1	0.0
Initial Queue Delay (d_3), s/veh	0.0	0.0		0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Control Delay (*d*), s/veh	35.2	39.7		37.6	45.1	33.3	11.6	11.9		7.0	5.6	5.3
Level of Service (LOS)	D	D		D	D	C	B	B		A	A	A
Approach Delay, s/veh / LOS	38.1	D		41.6	D		11.8	B		5.8	A	
Intersection Delay, s/veh / LOS	24.7						C					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.3	B	2.5	B	2.4	B	2.2	B
Bicycle LOS Score / LOS	0.8	A	0.7	A	0.8	A	0.7	A

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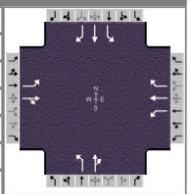
Modified Signal Timing Report

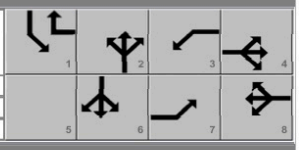
HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	10/31/2019	Area Type	Other
Jurisdiction		Time Period		PHF	0.97
Intersection	Route 140 (Grafton St)	Analysis Year	2019	Analysis Period	1> 7:00
File Name	New Route 140 and Main AM LOS.xus				
Project Description	Peak AM Interval				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	73	111	19	10	90	33	74	94	40	21	90	9

Signal Information										
Cycle, s	90.0	Reference Phase	2							
Offset, s	0	Reference Point	End	Green	7.0	38.2	1.8	5.0	15.0	0.0
Uncoordinated	No	Simult. Gap E/W	Off	Yellow	4.0	4.0	4.0	0.0	4.0	0.0
Force Mode	Fixed	Simult. Gap N/S	Off	Red	2.0	2.0	1.5	0.0	1.5	0.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	7	4	3	8		2	1	6
Case Number	1.1	4.0	1.1	3.0		6.3	1.0	3.0
Phase Duration, s	12.3	25.5	7.3	20.5		44.2	13.0	57.2
Change Period, (*Y*+*Rc*), s	5.5	5.5	5.5	5.5		6.0	6.0	6.0
Max Allow Headway (*MAH*), s	3.9	3.8	3.9	3.8		0.0	3.9	0.0
Queue Clearance Time (g_s), s	5.0	7.7	2.4	6.0			2.5	
Green Extension Time (g_e), s	0.0	0.3	0.0	0.3		0.0	0.0	0.0
Phase Call Probability	0.85	1.00	0.23	1.00			1.00	
Max Out Probability	1.00	0.00	0.01	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	7	4	14	3	8	18	5	2	12	1	6	16
Adjusted Flow Rate (*v*), veh/h	75	134		10	93	34	76	138		22	93	9
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1757	1783		1757	1845	1567	1249	1701		1707	1792	1519
Queue Service Time (g_s), s	3.0	5.7		0.4	4.0	1.5	3.4	4.6		0.5	2.1	0.2
Cycle Queue Clearance Time (g_c), s	3.0	5.7		0.4	4.0	1.5	3.4	4.6		0.5	2.1	0.2
Green Ratio (*g*/*C*)	0.26	0.22		0.19	0.17	0.24	0.42	0.42		0.52	0.57	0.57
Capacity (*c*), veh/h	370	396		284	307	383	610	722		661	1020	864
Volume-to-Capacity Ratio (*X*)	0.203	0.339		0.036	0.302	0.089	0.125	0.191		0.033	0.091	0.011
Available Capacity (c_a), veh/h	403	578		415	496	544	610	722		1006	1020	864
Back of Queue (*Q*), veh/ln (50th percentile)	1.3	2.5		0.2	1.8	0.6	1.0	1.9		0.2	0.8	0.1
Queue Storage Ratio (*RQ*) (50th percentile)	0.00	0.00		0.03	0.31	0.10	0.27	0.00		0.05	0.00	0.00
Uniform Delay (d_1), s/veh	26.0	29.5		30.0	32.9	26.3	15.9	16.2		10.5	8.8	8.4
Incremental Delay (d_2), s/veh	0.2	0.4		0.0	0.4	0.1	0.4	0.6		0.0	0.2	0.0
Initial Queue Delay (d_3), s/veh	0.0	0.0		0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Control Delay (*d*), s/veh	26.3	29.9		30.0	33.3	26.3	16.3	16.8		10.6	9.0	8.4
Level of Service (LOS)	C	C		C	C	C	B	B		B	A	A
Approach Delay, s/veh / LOS	28.6	C		31.4	C		16.6	B		9.2	A	
Intersection Delay, s/veh / LOS	21.9						C					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.3	B	2.4	B	2.4	B	2.2	B
Bicycle LOS Score / LOS	0.8	A	0.7	A	0.8	A	0.7	A

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