Park Avenue Redesign:
Final Report

A Major Qualifying Project Submitted to the Faculty of Worcester Polytechnic Institute in Partial Fulfillment of the requirements for the Bachelor of Science Degree

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Abstract

This project, on behalf of Stantec, Inc., aimed to redesign a section of Park Avenue in Worcester, MA with the goal of improving safety, efficiency, accessibility, and appearance. Existing conditions were documented and crash rate, level-of-service (using HCS 2010), and benefit-cost analyses were conducted. Potential improvement options were identified, evaluated, and the most viable were selected. Recommendations include: specific countermeasures and improvements to meet the goals, and suggested future actions for the continuation of this project.

Executive Summary

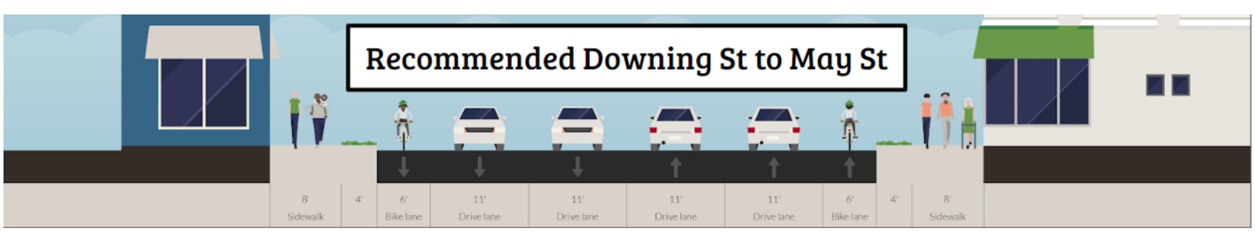
Park Avenue is a heavily trafficked through street located in the center of Worcester, MA. The corridor is designed with preference to vehicular traffic, but is lined with businesses and residences that promote access through other forms of transportation. The City of Worcester has identified Park Avenue as a corridor in need of improvements. This project focuses on a section of Park Avenue from Maywood Street to Chandler Street that includes four signalized intersections, four travel lanes, on-street parking, and minimal pedestrian and bicycle accommodations.

The goal of this Major Qualifying Project (MQP) was to prepare a list of recommendations for Stantec, Inc. and create a conceptual design based on these recommendations. This team evaluated existing safety and efficiency data along with site conditions to determine potential countermeasures and improvements for the project section.

The solutions determined in this project were required to follow the guidelines set forth by the MassDOT and the City of Worcester. Stantec provided the team with reports that displayed basic guidelines and procedures for conducting analysis of safety and efficiency conditions and showing results. Local, state, and federal funding can be requested in the future to complete the project. For this reason, necessary design guidelines and requirements were considered throughout the project to increase the possibility of funding in the future.

Turning Movement Count data was collected from Stantec, which provided the peak hour traffic counts for vehicles, bicycles, pedestrians, and heavy vehicles at each of the four signalized intersections. With this data, existing and future efficiency conditions for the project section were determined using Highway Capacity Software 2010. The MassDOT website provided the Traffic Count Database System and Crash Portal that were necessary resources for determining the existing traffic volumes and crash rates along the Park Avenue corridor.

Based on this data, countermeasures and improvements for each target location were identified and evaluated. Some potential options were eliminated based on space constraints, affordability, practicality, and existing and projected traffic volumes. The countermeasures and improvements remaining after the evaluation process were developed into a list of recommendations and incorporated in a conceptual design. The conceptual design was created with the use of AutoCAD Civil 3D and Streetmix. This team's recommendations along with sample design images include:



Proposed Downing St to May St Cross Section looking north

Proposed Downing St to May St Plan

Recommendations:

- Parking - Remove on-street parking along portions of the project section.
- Bicycle Accommodations - Add designated bicycle accommodations.
- Lane Widths - Widen travel lanes where space is available.
- Vegetation - Add four-foot vegetation buffers along the sidewalks.
- Pedestrian Accommodations - Maintain pedestrian accommodations and install a Rectangular Rapid Flashing Beacon at the intersection of Park Avenue and Parker Street.
- Lane Configuration - Redefine the lane configuration at the intersection of Park Avenue and May Street on the eastbound approach.
- Signage Improvements - Update and install signage along the section.

Future Considerations:

- Data Collection - Collect updated data concerning the efficiency, safety, and measurements of the project section.
- Signal Improvements - Explore the possibility of coordinating intersections throughout entire corridor. Conduct signal warrant analysis for certain signalized (Park Avenue and Downing Street) and unsignalized intersections (Park Avenue and Parker Street).
- Public Parking Lot - Evaluate options for potential municipal parking lot.

Acknowledgments

The success of this project would not have been possible without the resources and opportunities afforded by Worcester Polytechnic Institute (WPI) and Stantec, Inc. We would like to thank WPI and Stantec as well as some key individuals whose support and guidance greatly aided in the completion of this project. First, we would like to thank to our WPI project advisors, Leonard Albano and Suzanne LePage who offered continual support and feedback throughout the course of this project. We would also like to thank Stantec personnel, Frederick Moseley, Alan Cloutier, Jennifer Ducey, Alex Simpson, and Jamie Falise for providing valuable insight into the areas of traffic, transportation planning, and landscape architecture. Additionally, we would like to thank Erica Lotz for welcoming us into the Stantec office and providing support throughout our time there.

Authorship

This MQP report was completed through the joint effort of each team member. Each team member was responsible for writing and editing the paper as a whole, as well as occasionally writing independently. Team member Peter Carosa was primarily responsible for creating data tables and writing about project funding and existing conditions. Colin Claus also wrote about existing conditions as well as recommendations and future considerations. Kimberly Guthrie wrote about the case studies, evaluating and selecting countermeasures and improvement options, and the conceptual design.

Capstone Design Statement

This project focused on the Park Avenue corridor between Maywood Street and Chandler Street in Worcester, Massachusetts. This team redesigned this section of Park Avenue, thereby satisfying the needs of the City, as well as the requirement of students completing a Major Qualify Project (MQP) with a capstone design element prior to graduation. These requirements are set forth by Worcester Polytechnic Institute (WPI) to fulfill the criteria for Accrediting Engineering Programs by the Accreditation Board for Engineering and Technology (ABET). ABET has provided a series of student outcomes for accredited programs. Outcome C of the 2018-2019 Criteria states that graduates have “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability” (ABET, 2017). The following examines the eight constraints related to this project:

- Economic: Most transportation projects receive funding from multiple levels of government (local, state, and federal). For the City of Worcester and Stantec to implement any of the recommended improvements, this team researched potential funding options. Further, a scoring system was developed to quantify the benefits and costs of each improvement option before making final recommendations.
- Environmental: This project considered the environmental impact of all improvement concepts and worked to mitigate these impacts. In cases where possible, this project aimed to improve the environmental conditions along this corridor by adding vegetation and reducing impermeable surfaces.
- Social and Political: This team became familiar with regulations and community objectives at the city and state level. The final recommendations of this team are in compliance with such regulations and take the needs of stakeholders into consideration. Chiefly, this team addressed the needs of Park Avenue users by promoting the safe and efficient utilization of Park Avenue by all modes of transportation and users no matter their socio-economic status.
- Ethical: This project abides by the ASCE Code of Ethics for all civil engineers so as not to damage the reputation of WPI or Stantec.
- Health and Safety: This project addresses safety concerns by focusing on the improvement of dangerous intersections and sections of roads with high crash rates and poor traffic designs. Countermeasures were ranked based on their ability to reduce the number of crashes at a given location so as to improve the safety of this project section.
- Constructability: This team determined the most effective improvement options by examining the overall cost of the improvement and the space required for its implementation.
- Sustainability: Long-term improvement concepts were presented by this team with the goal of addressing present and future needs for the corridor. The final design and recommendations account for future traffic demands and population growth to ensure efficient use of Park Avenue over time.

Professional Licensure Statement

A professional engineer must, "Hold paramount the safety, health, and welfare of the public," in all cases where they may be affected by any engineering project (National Society of Professional Engineers, 2017). Before acquiring such responsibility through licensure, an engineer must undergo extensive training in their respective fields.

To become a licensed engineer, one must first graduate from a university that is accredited by the state licensing board in the state where an engineer is seeking licensure. When a studying engineer is within one semester of graduating, they may pursue an Engineer-in-Training (EIT) certification. In order to receive this license, a studying engineer must pass the Fundamentals of Engineering Exam (FE), which is administered by the National Council of Examiners for Engineering and Surveying (NCEES) and tests basic engineering knowledge. The second and final exam required to receive a professional engineering license is the Principles and Practice of Engineering Exam (PE). Each state licensing board administers their own PE, therefore, each state differs slightly in terms of required knowledge and experience. However, each state requires that, after successfully completing the FE, an Engineer-in-Training must complete four years of professional experience in their respective field under a licensed engineer. (National Society of Professional Engineers, 2017).

When an engineer passes their PE Exam and becomes licensed, they are able to take on new responsibilities within the workplace, such as reviewing drawings and designs for approval. In order to maintain the professional engineering license, an engineer is responsible for engaging in opportunities for professional development through continued education courses or other opportunities for professional development in their respective field (National Society of Professional Engineers, 2017).

Through the completion of this project, our team was able to learn valuable skills relating to teamwork and professional practice as entry-level engineers.

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1. Introduction

Park Avenue is a heavily trafficked road that runs through the center of Worcester, MA. Comprised of four lanes of two-way traffic and occasional turning lanes, Park Avenue is designed with preference to through traffic with sidewalks, bus stops, and stretches of on-street parking. Additionally, Park Avenue is lined with businesses and apartments, resulting in traffic from vehicles, bicycles, pedestrians, and transit. Although Park Avenue is utilized by a diverse group of users, the current safety conditions suggest that it is ineffective at serving all of these populations. This is evident due to the fact that four intersections along this section of road were identified by the Massachusetts Department of Transportation (MassDOT) as hazardous based on the number of collisions (Top Crash Locations 2016).

This project focused specifically on the section of Park Avenue from Maywood Street to Chandler Street, presented in Figure 1. This section was identified by the City of Worcester as an area in need of improvements (F. Moseley, email communication, November 20, 2018). Tasked with initiating such improvements, this team chose to focus on the issues of accessibility, appearance, safety, and efficiency on this section of road.

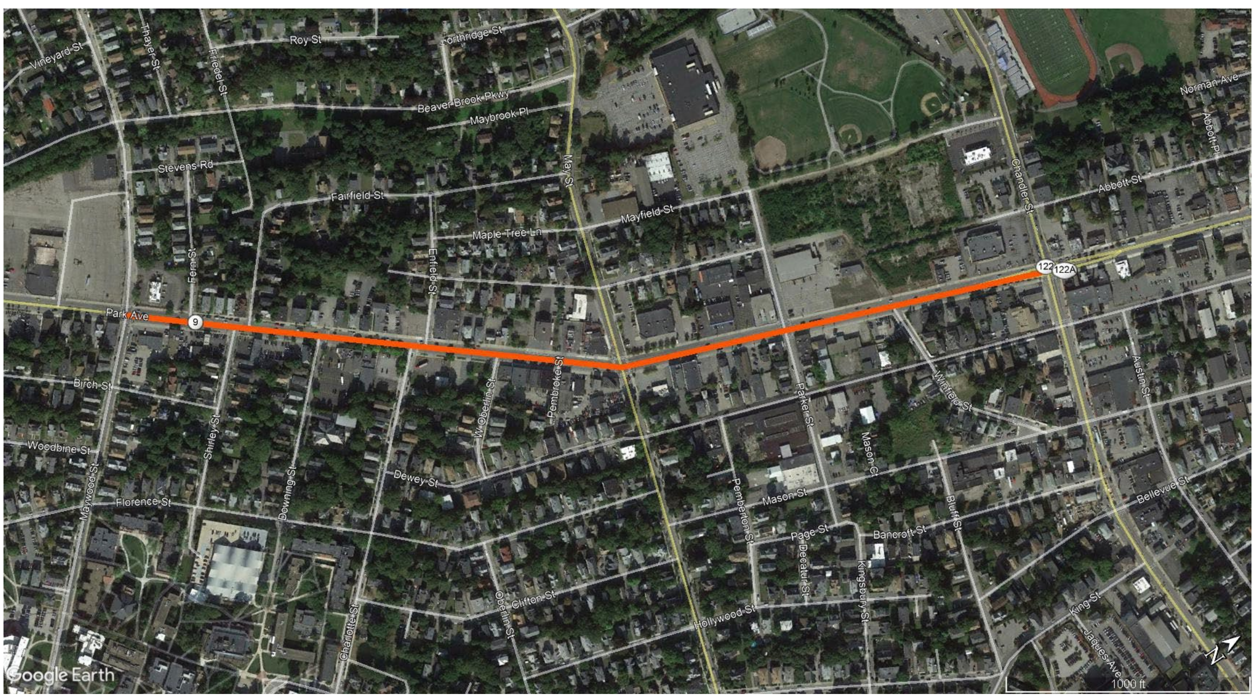

Figure 1: Project Map, Park Avenue from Maywood Street to Chandler Street (Google Earth)

Observations suggest the current layout of this section of road presents numerous safety concerns for all users. For example, this portion of Park Avenue has little to no parking signage. As a result, cars are often parked over curbs and travel lanes. This lack of clear signage is dangerous to traveling vehicles as well as pedestrians accessing these parked vehicles. Similarly, there is an absence of clearly designated areas for buses to pull over on Park Avenue. This, combined with the dangerous on-street parking, limits mobility for larger vehicles, such as buses, and often results in slowed or stopped traffic. Another example is traffic slow-downs due to left turns at intersections without left turn lanes. The lack of left turn lanes on Park Avenue greatly contributes to the backups and delays during peak travel times. Without such lanes, through traffic is required to merge into the right lane, if it is not hindered by the presence of a bus or illegally parked vehicle.

In addition to safety concerns, the current layout of Park Avenue does not align with the surrounding land use. The section of Park Avenue from Maywood Street to Chandler Street in particular lacks vegetation and pedestrian-vehicle buffers; traits which help a busy street, like Park Avenue, better align with surrounding residential communities. A more welcoming atmosphere could mean increased business for the companies lining Park Avenue as well as a more engaged community.

Considering these problems, an improvement concept for Park Avenue between Chandler Street and Maywood Street was developed. The desired outcomes were to achieve eligibility for MassDOT and Massachusetts Complete Street Program funding, improve vehicular and pedestrian safety, improve access to public transportation, improve efficiency of the roadway, and increase vegetation. To achieve the vision of this project, a list of objectives were identified, including:

- Researching and compiling existing conditions, traffic and safety data, MassDOT and City of Worcester regulations for transportation projects, and case studies of similar projects
- Analyzing data to identify problems with the corridor
- Determining potential countermeasures and improvements
- Assessing the countermeasures and improvements
- Recommending the most efficient countermeasures and improvements based on the previous analyses
- Developing a final design for the corridor that incorporates the recommended improvements
- Finalizing a written report and presentation

2. Background

The purpose of this section is to provide an overview of the project history, context, funding options and design approach of the City of Worcester and Stantec. It details how the project came to be, and the potential funding options based on its location, roadway classification, and improvement approach. Additionally, this section describes the methods by which the City of Worcester and Stantec carry out transportation design.

2.1 Project History and Context

Stantec's involvement in this project began with an evaluation of signal timing at intersections across the City of Worcester. In the past decade, Stantec was tasked with this evaluation in order to determine the potential for signal improvements. During this time, MassDOT requested that Stantec also prepare a cost estimate for upgrades along Park Avenue from Gold Star Boulevard to Stafford/Main Street. Based on Stantec's cost estimate and MassDOT's Transportation Improvement Program (TIP) budget, it was determined that improvements along Park Avenue would need to be broken down into smaller projects. Thus, this team was tasked with identifying improvement concepts for the section of Park Avenue between Maywood Street and Chandler Street.

Park Avenue, from Maywood Street to Chandler Street, is under the jurisdiction of the City of Worcester. As such, any modifications to this section of road must be in compliance with the City's planning goals. Worcester is currently in the process of developing a master plan. Until that document becomes available, Worcester's goals for transportation improvements can be derived from their Complete Streets Policy (City of Worcester Complete Streets Policy, 2017).

The term, "Complete Street" is a designation given to a street that serves all users no matter age, ability, or mode of transportation. The following factors drive the design of a complete street: number and types of users, available right of way, safety amenities, community needs, parking needs, utilities, public transit, and historic or sensitive land uses (Rabito, n.d.). Complete Streets are a strategy being utilized by urban planners to improve city streets to address issues of safety, congestion, multimodal transportation options, and greenhouse gas emissions (Rabito, n.d.).

2.2 Funding

The majority of transportation projects are funded with a combination of multiple levels of funding, from local, state, and federal sources. According to the Central Massachusetts Regional Planning Commission (CMRPC), Park Avenue is a Federal Aid eligible road that can receive federal funding through a variety a federal highway improvement programs (Federal Aid Eligible Road System, 2006). Some key federal highway programs that provide funding for transportation improvement projects in Massachusetts include, the Federal Highway Administration (FHWA), National Highway Performance Program (NHPP), Highway Safety Improvement Program (HSIP), Transportation Alternatives Program (TAP), and Transportation

Improvements Program (TIP). Most federal funding that is issued through these programs is matched at the state and local levels (Funding Considerations, n.d.). The State TIP for Massachusetts is a list of projects that will occur within the next four consecutive years of roadway construction. The Office of Transportation Planning prepares this list yearly (State Transportation Improvement Program, n.d.).

For a project to be eligible for funding from MassDOT or the Massachusetts Complete Street Program, it must meet requirements set by the State of Massachusetts. MassDOT requires a series of forms to be completed to receive State and Federal aid. The first form is the Project Need Form (PNF), which collects preliminary information about the proposed project. Next, the Project Initiation Form (PIF) would be completed providing general information, project costs and responsibilities, and the project description. Assuming the project is approved and these forms are accepted, the Central Massachusetts Metropolitan Planning Organization (CMMPO) will decide on sources of funding and possible TIP year.

Designs incorporating Complete Streets only have special funding at the state level, since there is no federal legislation regarding Complete Streets. The Massachusetts 2014 Transportation Bond Bill allows MassDOT to allocate $12.5 million for the first two years (2016-2018) of their Complete Streets Funding Program (Complete Streets Funding Program Guidance, 2016). The program requires each municipality to register, undergo training, send a letter of intent, submit a Complete Street policy, and create a priority list of potential projects. The City of Worcester's Complete Street Policy was accepted by MassDOT in February 2018. The city is currently completing a priority list. In order to receive aid from the Massachusetts Complete Street Program, projects must be in accordance with the City of Worcester's Complete Street Policy.

2.3 The Worcester City and Stantec Approach

As a Worcester City roadway, Park Avenue must conform to Worcester's design objectives for transportation improvements. As previously stated, such objectives can be derived from Worcester's Complete Streets Policy. Further, review of ongoing projects within the City of Worcester can similarly provide insight into the City's transportation improvement goals.

This section describes two active projects within the City of Worcester as well as a corridor study performed by Stantec. This corridor study was selected to serve as a reference for Stantec's approach to transportation improvements.

2.3.1 Case Study - Main Street Reimagined, Worcester, MA

In the summer of 2018, Worcester began a redesign of Main Street between Madison Street and Court Street. With a budget of $11 million, the City aims to "create a theme, sense of place, increased walkability, and vibrancy along the Main Street corridor through public art while taking into consideration connectivity between primary public art nodes" (Main Street Reimagined 2019). In order to achieve this vision, the City of Worcester hired the Urban Culture Institute to work in conjunction with the Worcester Cultural Coalition. Together, these groups identified three key themes to incorporate into the Main Street design to reflect Worcester's history. These themes are creativity, innovation, and revolution (Main Street Reimagined | Worcester, MA n.d.).

2.3.2 Case Study - Kelley Square Improvement Project, Worcester, MA

Kelley Square is a series of unsignalized intersections that connect Worcester's local streets in the Canal District to I-290. When compared to locations elsewhere in Massachusetts, Kelley Square was determined to have the highest crash rate (About the Worcester Kelley Square Improvement Project n.d.). The City of Worcester and MassDOT are working together to develop an improvement plan for this dangerous area. The MassDOT claims the improvement concept will:

- Address safety and navigation problems for motorists, cyclists, and pedestrians
- Support the local businesses and residents who call Kelley Square their home
- Include streetscape elements to make Kelley Square an attractive and comfortable place to visit
- Improve connection between the Canal District and Green Island neighborhoods (About the Worcester Kelley Square Improvement Project n.d.).

Presently, Kelley Square has a series of issues that may contribute to its high crash rate. These issues include a lack of bicycle accommodations, wide pavement with minimal delineations for traffic movement, and space constraints (Kelley Square Improvement Project 2018). In order to address these issues, the City of Worcester and MassDOT sought the feedback from local residents. After receiving such feedback, it became clear that there were common concerns among the public. The chief concerns were as follows:

- Do what's necessary but do as little as possible
- Maintain neighborhood connectivity
- Make bicycle and pedestrian accommodations/routes
- Maintain business access
- Be sensitive to parking
- Utilize the place making approach (Kelley Square Improvement Project 2018)

2.3.3 Case Study - Beacham/Williams Street Corridor Study, Chelsea, MA

In June of 2018, Stantec produced a study of the Beacham/Williams Corridor in Chelsea, MA. This location was identified as in need of improvements due to the growth in heavy vehicle traffic as well as a lack of accommodations for bicyclists (Stantec 2018). In order to best accommodate user needs, Stantec broke the Beacham/Williams corridor into four character areas, see Figure 2.

Figure 2: Beacham/Williams Corridor Character Areas (Stantec 2018)

Character area A was the largest of the areas identified by Stantec and was characterized as "Regional Industry." This classification was based on the high concentration of production and distribution centers which support the local and regional community. The next area, Zone B, or the "Industrial & Residential Transition Zone" was characterized as such due to the presence of residential clusters and its location between the industrialism of Zone A and Downtown feel of Zone C. Character area C was classified as a "Downtown Hub" as a result of the small commercial businesses present in the area and high volumes of pedestrian traffic. The final area, D, or the "Mixed Use Zone" contains many of the characteristics of zones A, B, and C, such as small businesses and residences. Stantec utilized these unique character areas to make targeted recommendations which aimed to address safety issues, accommodate multiple users, and support regional connections while preserving site-specific operations (Stantec 2018).

2.3.4 Local Access Score

Local Access Score is a tool developed by the Metropolitan Area Planning Council (MAPC) in Massachusetts. The tool evaluates roadways in major metropolitan areas across the state of Massachusetts by using a travel demand algorithm. Using population data and known point of interests (schools, shops, restaurants, parks, and transit stations), the algorithm estimates the average daily number of trips per household, common destinations of those trips, and the most direct routes connecting households to their destinations. GIS data that scores urban streets based on demand for various forms of transportation is the result of these estimations. The goal of this tool is to help communities identify areas with the greatest need for pedestrian and bicycle accommodations, as well as aid municipalities planning for the Complete Streets program. The GIS data can be downloaded or accessed in the form of an interactive map on the MAPC's website.

A screenshot of this map is shown in Figure 3. This map includes restaurants, retail businesses, major roads, Massachusetts municipalities, open space, water bodies, and a Local Access Score. There are five different scores that are calculated: composite, walking, bicycle, walk to school, and sidewalk gap. The composite score is an overall demand for both walking pedestrians and bicyclists. The walking score estimates the demand of roadways by pedestrians based on trips within a couple miles of their homes. The bicycle score estimates the bicyclists' demand for roadways, but considers longer trips than the walking score. The walk to school score identifies critical road segments that students would use to travel from their house to school. Finally, the sidewalk gap score uses known infrastructure data to signify whether or not roadways have sidewalk on both sides combined with the aforementioned composite score.

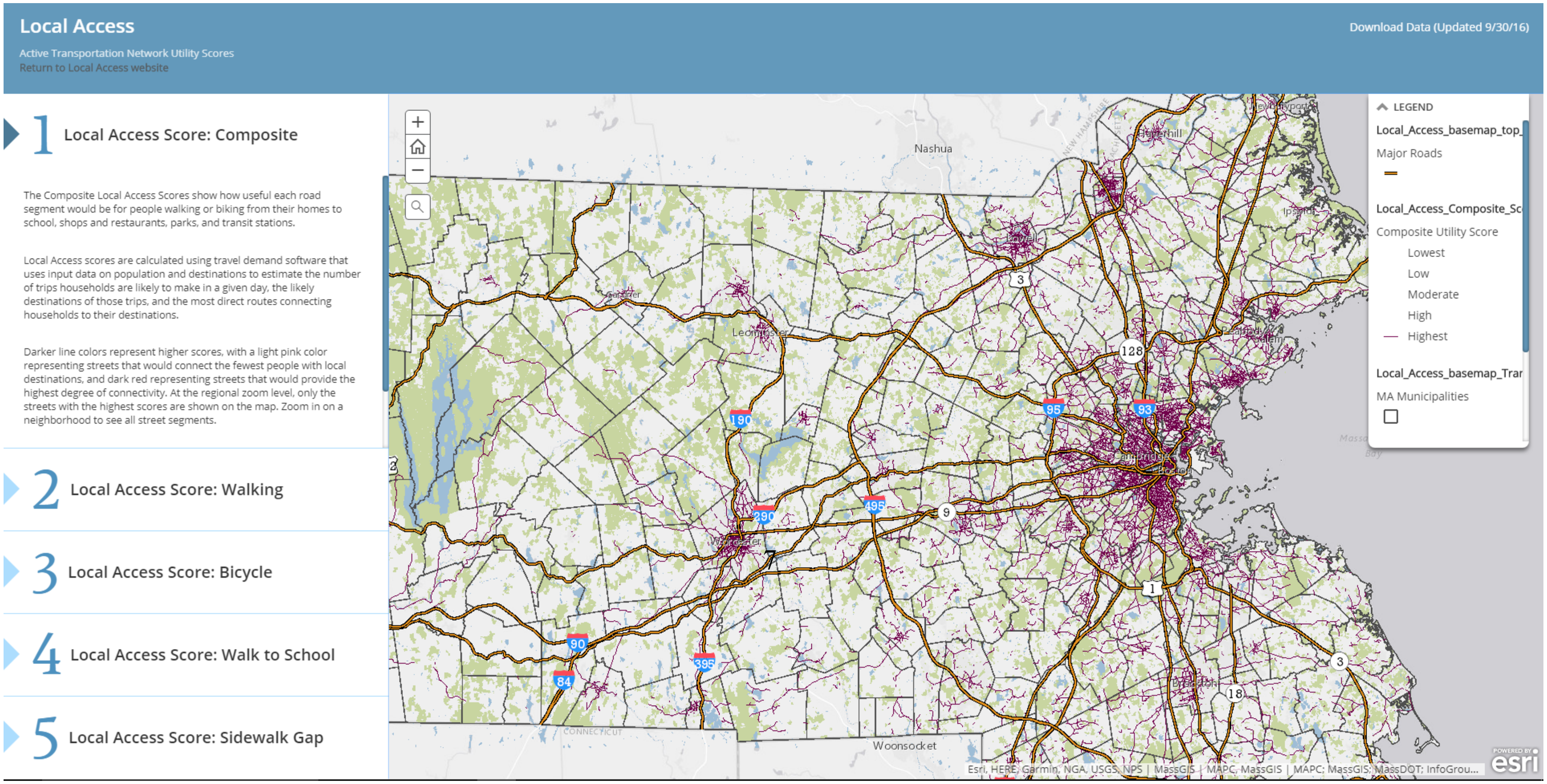

Figure 3: Local Access Score Interactive Map

3. Methodology

The vision of this project was to develop an improvement concept for Park Avenue between Chandler Street and Maywood Street. The desired outcomes were to improve vehicular and pedestrian safety, improve access to public transportation, improve efficiency of the roadway, and increase vegetation. Within this section are the methods used to achieve these outcomes. These methods primarily consisted of:

- Compiling case studies to identify potential improvement concepts
- Evaluating the site's existing conditions
- Identifying countermeasures and improvements
- Evaluating and comparing all countermeasures and improvements
- Determining final recommendations
- Developing a conceptual design for the section of Park Avenue between Maywood Street and Chandler Street

Specific details regarding the methodology for each desired outcome are expanded upon further in this section.

3.1 Research Case Studies

At the start of this project, Stantec provided information on four projects they completed within the past fifteen years. These projects ranged from corridor studies to design submittals. Each of the project documents were reviewed and one of the four projects was selected to be used as a case study. This project was selected based on its similarity to Park Avenue and recent development.

In addition to Stantec-provided studies, information was collected on projects within the City of Worcester to be used as case studies. After reviewing projects on the City of Worcester's website, two projects were selected based on their active status, clarity in terms of design objectives, and applicability to Park Avenue.

3.2 Document Existing Conditions

This section details the approach used when documenting and evaluating the site's existing conditions as well as how background information was collected.

3.2.1 Site Layout and Characteristics

Over the course of this project, numerous site visits were performed to collect information regarding the corridor's existing conditions. Initially, a virtual tour of the site via Google Maps and Google Street View was used to gain a basic understanding of the project location. Additionally, two formal in-person site visits were performed where photos were taken to document the site's existing conditions. Outside of these formal visits, members of this team traveled through the corridor at various times including the PM peak hour.

Massachusetts's online geographic information system (GIS) was used to evaluate conditions that could impact Park Avenue's redesign. This system, known as OLIVER, allows the user to view existing conditions, such as flood zones and habitats of rare species across Massachusetts (OLIVER: MassGIS's Online Mapping Tool 2018). Identifying these constraints as well as other environmental constraints within the project limits was a primary focus when using OLIVER.

Another noteworthy resource that was consulted during the research stage of this project was the Worcester Regional Transit Authority (WRTA). The WRTA was contacted via email with a request for bus ridership data along this section of Park Avenue.

3.2.2 Calculate Existing Traffic Volume Conditions

For the analysis conducted in this project, all traffic volume data was adjusted to 2016 for existing safety conditions and 2018 for existing efficiency conditions. Therefore any data presented in the year 2016 was used for safety analysis, and any data presented in the year 2018 was used for efficiency analysis.

The MassDOT hosts a series of databases on their website. The Traffic Count Database System (TCDS) includes data from traffic counts conducted across Massachusetts. Two sets of traffic count data were collected for northbound and southbound along Park Avenue: one for the roadway section between Maywood Street to May Street, and the other for the roadway section between May Street and Chandler Street. These traffic counts provided annual average daily traffic (AADT) information.

Stantec provided turning movement counts from a study they performed in 2013 on all four of the signalized intersections (F. Moseley, email communication, November 27, 2018). These turning movement counts included peak hour volumes that accounted for passenger vehicles, heavy vehicles, pedestrians, and bicyclists. PM peak hour volumes were then used to calculate the intersections' 24-hour entering volumes (V_{24}) using the following equation:

$$V_{24} = \text{PM Peak Volume} \div \text{PM K Factor of } 0.09 \text{ (MassDOT, 2018)}$$

For the safety calculations conducted in this project, the AADT and V_{24} values needed to be converted to 2016. This was done because the most recent crash data available was from 2016. Therefore, any traffic volumes from 2013 would need to be updated to 2016 in order to be used with 2016 crash data. Since the calculated AADT was for 2013, the value was adjusted for growth using 1% from 2013 to 2016. A 1% growth factor was deemed as accurate based on two continuous traffic counts along I-290 that framed this project section. These counts showed that Worcester has been experiencing a 1% annual growth in traffic. This value was used to calculate the V_{24} in 2016 using the formula:

$$V_{24\,(2016)} = V_{24\,(2013)}\,(1 + r)^n$$

Where r is the growth rate of 1%, and n is the number of years between 24-hour entering volumes (V_{24}).

Sample calculation, Intersection of Park and Chandler:

$V_{24\,(2013)}$ = (PM Peak Volume)/(0.09) = (11,513)/(0.09) = 127,922
$V_{24\,(2016)} = V_{24\,(2013)}\,(1 + r)^n = 127{,}922\,(1 + 0.01)^3 = 131{,}798$

The calculated 2016 V_{24} was then corrected using the MassDOT seasonal and axle factors through the following equation:

Corrected $V_{24\,(2016)} = V_{24\,(2016)}$ * Seasonal Factor * Axle Factor

Where:
Seasonal correction factor = 0.94 for an urban principal arterial in September (MassDOT, 2017)
Axle correction factor = 0.96 for an urban principal arterial (MassDOT, 2017)

Sample calculation, Intersection of Park and Chandler:
Corrected $V_{24\,(2016)}$ = $(V_{24\,(2016)})(0.94)(0.96) = (131{,}798)(0.94)(0.96) = 118{,}935$

For the efficiency calculations conducted in this project, the V_{24} values needed to be converted to 2018. This was done because this team felt that the existing conditions of Park Avenue would be more accurately represented. When conducting HCS analysis for the existing efficiency conditions, it was unnecessary for the team to input AADT data for the roadway sections. Therefore, this team does not provide any calculations for this data in this section. The data for traffic volumes entering the signalized intersections was necessary for HCS analysis and therefore was adjusted using the 1% annual growth rate for the efficiency analysis. Specifically, the peak 15-minute volumes for the AM and PM peak hour were adjusted in order to be input into the Highway Capacity Software 2010. The volumes were calculated for the existing conditions in 2018. These calculations are discussed further in Section 3.2.4.

3.2.3 Calculate Existing Safety Conditions

Three different types of safety measures were calculated to evaluate the current safety conditions of the site. These measures included: Average Crash Rates, Equivalent Property Damage Only (EPDO) crash rates, and Relative Severity Index (RSI). A value for these measures was calculated for each of the target locations within the project limits.

The Crash Portal on the MassDOT website provides lists of crash data that can be collected using various filters including an area filter. The area filter was used to obtain crash data for specific intersections and roadway segments along Park Avenue. The polygon drawn to collect crash data for the entire corridor, Maywood Street to Chandler Street, is shown in Figure 4. The specific areas selected for each intersection and segment can be found in Appendix B.

Figure 4: Crash Area from Maywood Street to Chandler Street, Project Section

Data was limited to the most recent three-year span that at the time of acquisition was 2014-2016. For this reason, the AADT and V_{24} values previously calculated for 2016 in Section 3.2.2 were used in order to stay consistent with the years for the crash data. The 2016 crash rates for each target location were calculated using the following equations:

Intersection Crash Rate = (A * 1,000,000) $(A * 1{,}000{,}000) \div (V_{24} * 365)$$V_{24\,(2016)}$ * 365)
Roadway Segment Crash Rate = (A * 1,000,000) ÷ ($V_{24\,(2016)}$ * L * 365)

Where:
A = Average crashes per year
V_{24} = 24-hour entering volume for intersection
AADT = Annual average daily traffic for a roadway segment
L = Length of the roadway segment

The crash data was sorted using spreadsheets in order to create crash severity tables and crash type tables. Crash severity tables were developed to determine the Equivalent Property Damage Only (EPDO) for each target location. The team used MassDOT suggested weights of 12 PDOs for fatal crashes, 3 PDOs for crashes resulting in injuries, and 1 PDO for property damage only crashes (Herbel, Laing, & McGovern, 2011).

Sample EPDO Calculation, Intersection of Park and Chandler:
EPDO = (12 * 0 fatal) + (3 * 1.67 injury) + (1 * 15.33 property damage)
EPDO = 20.33 EPDO/yr

There were several severity categories with varying factors and costs associated with them: fatal, incapacitating injury, non-incapacitating injury, possible injury, and no apparent injury. Based on these factors and costs, the EPDO Cost was calculated for each target location. The unit costs in Table 1 were obtained from FHWA's Crash Costs for Highway Safety Analysis (Harmon, Bahar, & Gross, 2018).

TABLE 1 – HSM Crash Unit Costs (2016 dollars)

Crash Severity	Economic Crash Unit Cost	QALY Crash Unit Cost	Comprehensive Crash Unit Cost	EPDO Weights
Fatal (K)	$1,688,100	$4,052,000	$5,740,100	568
Disabling injury (A)	$151,000	$153,400	$304,400	30
Evident injury (B)	$56,800	$54,400	$111,200	11
Possible injury (C)	$38,500	$24,200	$62,700	6
PDO (O)	$8,700	$1,400	$10,100	1

Source: *Harmon, Bahar, & Gross, 2018*

Sample EPDO Cost Calculation, Intersection of Park Avenue and Chandler Street:
Cost = ($5,740,100 * 0) + ($304,400 * 0) + ($111,200 * 0.33) + ($62,700 * 1.33) + ($10,100 * 15.33)
Cost = $275,533.33/yr

The crash type tables were developed to determine which crash types were prevalent for each target location. These tables also allowed the team to calculate the Relative Severity Index (RSI) costs for each location. Each crash type had a cost associated with it that was used to determine the total cost of the target location per year. The costs are shown in Table 2 and were obtained from the FHWA's Crash Costs for Highway Safety Analysis (Harmon, Bahar, & Gross, 2018). The obtained costs were originally in 2001 dollars. To adjust the values in the table from 2001 to 2016 dollars, the annual average Consumer Price Index (CPI) data from the U.S. Bureau of Labor Statistics was used. The annual average CPI in 2001 was 177.1, and the value in 2016 was 240.007 (U.S. Bureau of Labor Statistics, 2019). By dividing the 2016 CPI by the 2001 CPI, a multiplying factor of 1.3552 to adjust the RSI cost to 2016 dollars was calculated.

TABLE 2 – HSM Crash Unit Costs by Type (2016 dollars)

Crash Type	Economic Crash Unit Cost	Comprehensive Crash Unit Cost
Rear-End, Signalized Intersection	$22,600	$36,200
Read-End, Unsignalized Intersection	$14,800	$17,900
Sideswipe/Overtaking	$23,900	$46,100
Angle, Signalized Intersection	$33,000	$64,100
Angle, Unsignalized Intersection	$40,200	$82,800
Pedestrian/Bike at an Intersection	$98,700	$215,300
Pedestrian/Bike, Non-Intersection	$146,100	$390,200
Head-On, Signalized Intersection	$21,100	$32,700
Head-On, Unsignalized Intersection	$32,700	$64,400
Fixed Object	$53,700	$128,300
Other/Undefined	$33,100	$74,700

Source: *Harmon, Bahar, & Gross, 2018*

Sample RSI Cost Calculation, Intersection of Park and Chandler:
RSI Cost = ($26,700 * 6.67) + ($34,000 * 3) + ($47,300 * 4.33) + ($158,900 * 0.67) + ($24,100 * 0) + ($94,700 * 2.33) + ($55,100 * 0)
RSI Cost = $811,867.00/yr
RSI Cost (2016 CPI adjusted) = $1,100,300.00/yr

3.2.4 Calculate Existing Efficiency Conditions

Level of Service (LOS) was calculated to evaluate the efficiency of the four intersections and three roadway sections. LOS is designated as a letter grade between Level "A" and Level "F" with "A" being optimal and "F" being failure. LOS measures the effectiveness for peak-hour traffic operating conditions, while considering traffic type, traffic volume, traffic speed, and traffic control devices. An LOS score of "D" or above is usually considered as acceptable for corridors similar to Park Avenue with heavy traffic and multiple signalized intersections separated by short distances (Highway Capacity Manual, 2010). Scores of "E" and "F" are considered to be failing and in need of improvement. Intersection LOS is determined by an average control delay for an entering vehicle. A table depicting the Control Delays associated with each LOS score is provided in Table 3.

TABLE 3 – Intersection Level-of-Service Criteria

Level of Service	Signalized Control Delay (seconds/vehicle)
A	Less than or equal to 10.0
B	10.1 – 20.0
C	20.1 – 35.0
D	35.1 – 55.0
E	55.1 – 80.0
F	Greater than 80.0

Source: *Highway Capacity Manual* 2010

In this table, any delay greater than 80.0 sec/veh is considered an “F” for LOS. This can be misleading since an intersection could have a delay of 90 sec/veh or 200 sec/veh and still be considered an “F.” In this way, the lower end of the table does not accurately represent the true LOS of the intersection. As a result, some refer to a score of “F” greater than 150 seconds to be a ‘deep’ “F” that is in need of improvement. For a ‘deep’ “F,” it is important to improve the delay time although the LOS score may remain as an “F.” An intersection with a delay of 90 sec/veh is more reasonable than an intersection with a delay of 180 sec/veh.

HCS 2010, a software program created by McTrans, was used to conduct this analysis. The software follows the methodologies set forth in the *Highway Capacity Manual 2010* (HCM). Of the multiple components included in HCS 2010, HCS Streets was the utilized component. HCS Streets can handle individual signalized intersections and entire corridors (a group of signalized intersections). The four signalized intersections between Chandler Street and Maywood Street were added to an HCS Street file and arranged with their correct geometry, widths, and distances using a scaled screenshot from Google Earth. The roadway sections were automatically generated based on the intersections and required some slight altering of settings, such as lane width and parking.

After setting up the corridor, the traffic volumes for the AM and PM peak 15-minute periods were adjusted from 2013 to 2018 based on the 1% annual growth factor previously determined in Section 3.2.2. The AM and PM peak values were collected from the TMC data provided by Stantec. No AADT values were input for the roadway sections as HCS 2010 calculates the LOS for these sections based on the efficiency of the signalized intersections.

The efficiency of the project section was presented in the year 2018 in order to accurately portray the existing conditions along the section. Once adjusted, the traffic demands were input for each leg of each intersection. The percent heavy vehicles, number of bicyclists, pedestrians, buses during the peak hour, and speed limit were also input for each leg. Next, the phasing movements were set and the signal timing (green maximum, yellow phase, red clearance, green minimum, and passage time) was input for each intersection.

3.3 Analyze Existing Conditions

After calculating existing site conditions, the results were compared to similar locations. This section details the specific methods used to analyze the safety and efficiency conditions.

3.3.1 Compare Safety Conditions

The existing safety performance conditions for the corridor were analyzed by the team. Crash rates for each target location were analyzed and compared with statewide and district averages displayed by MassDOT. The average crash rates at signalized intersections were 0.78 and 0.89 for statewide and District 3, respectively. District 3 represents the central region of Massachusetts. The average crash rates for roadway sections statewide and by roadway class were 2.27 and 3.49 for statewide urban roads and for urban principal arterials, respectively.

3.3.2 Compare Efficiency Conditions

Lincoln Street is a corridor similar to Park Avenue that serves as a highly trafficked through street in Worcester. This corridor has multiple signalized and unsignalized intersections that have been analyzed through traffic studies. Stantec (formally Fay, Spofford & Thorndike at the time) conducted a study on a section of Lincoln Street similar to this project's target section that included traffic efficiency analysis. The team compared LOS data from their project with the data provided in the Lincoln Street report.

In Stantec's Lincoln Street report, they include a future no-build efficiency case to show how the corridor will be affected if no changes are made. A similar future traffic growth analysis for the year 2030 with no-build conditions was conducted for Park Avenue. Traffic growth patterns around Worcester were examined through the MassDOT TCDS. An annual growth factor of 1% was determined using two continuous counts along I-290 both North and South of the project location. This factor was applied to the peak AM and PM 15- minute traffic periods from the TMC tables in order to adjust the traffic volumes. With this, an analysis of the 2030 no-build conditions for the project limits was created.

3.4 Identify Countermeasures and Improvements

This section details the steps taken to identify the optimal countermeasures and improvement options for the Park Avenue corridor.

3.4.1 Accessibility

Accessibility was prioritized by looking at multiple accommodations for all modes of transportation. In order to identify options for improving accessibility on Park Avenue, this team met with Alan Cloutier, a senior transportation engineer at Stantec. In addition to his design experience, Alan leads Complete Streets training for the public. The purpose of this meeting was to discuss options for applying the Massachusetts Complete Streets methodology to improve accessibility on Park Avenue.

3.4.2 Appearance

When evaluating options for improving the appearance of Park Avenue, this team met with Stantec's Jamie Falise, a landscape architect. This meeting was intended to provide insight into options for increasing vegetation along Park Avenue.

3.4.3 Safety

The crash tables were analyzed to look for prevalent crash types that could be reduced with certain types of countermeasures. Countermeasures were selected based on their predicted ability to reduce the number of crashes per year at a target location. A crash reduction factor (CRF) is a percentage of crashes that can be prevented by implementing a certain countermeasure. CRFs were found using the CMF Clearinghouse on the FHWA website (Crash Modification Factors Clearinghouse, n.d.). It is important to note that each target location is unique, so, as a result, countermeasures were selected based on their ability to improve the specific location.

3.4.4 Efficiency

HCS analysis provided current LOS data for the corridor. This data highlighted sections of the corridor that are failing or in danger of failing in the case where no improvements are made and traffic volumes continue to grow at the current rate. For this reason, a variety of improvements to each intersection were evaluated that aimed to improve the efficiency of the corridor. Complete Street designation was also strongly considered when determining these improvements.

3.5 Evaluation

This section details the process used to compare countermeasures and improvements and evaluate their benefits.

3.5.1 Eliminate Infeasible Options

After identifying a variety of potential countermeasures and improvements, the clearly infeasible options were eliminated. Some of the reasons that resulted in options to be eliminated included exorbitant costs that did not provide any benefit, could not fit within the spatial constraints, adversely affected given traffic volumes, and lack of practicality. This process was completed earlier on to ensure that all of the countermeasures and improvements being reviewed would be viable for the Park Avenue corridor.

3.5.2 Benefit Cost Analysis

The CRF calculation results were utilized to determine the benefit, or money saved by preventing crashes, as a result of implementing a given countermeasure or improvement. This value was calculated by multiplying the number of crashes prevented by the cost associated with each crash type. The cost of each countermeasure and improvement was determined using MassDOT's Construction Cost Estimator (Construction Project Estimator, n.d.). Since temporary work zone traffic control costs and police detail costs are typically separate line items and are not reflected by the Construction Cost Estimator, a similar Stantec project was utilized as a model for predicting those costs. The percentage of temporary work zone traffic control costs within the overall construction cost for these Stantec projects was calculated, and that same percentage was applied to each construction cost for this project. Based on these similar projects approximately 10% of the overall construction cost was for temporary work zone traffic control. Each construction cost was also increased by an additional 10% to account for the cost of a police detail during construction. This value was provided by Stantec and is a company standard. So, costs taken from the Construction Cost Estimator were multiplied by 1.2 to account for these temporary work zone traffic control costs and police detail costs. Then, the calculated benefit was divided by the calculated cost. Resulting values greater than one suggest the improvement is worthwhile, and values less than one suggest implementing the countermeasure or improvement is not worth the cost.

3.5.3 Scoring Rubric

After a discussion with this team's advisors and sponsor, it was determined a scoring rubric would be best to compare the countermeasures and improvements. This rubric would provide a quantitative measure that could be used to compare the impact of each countermeasure and improvement. Each countermeasure and improvement was given a score of 1-5 in five categories, Accessibility, Appearance, Affordability, Safety, and Efficiency. Within each of these categories a "1" was given to countermeasures and improvements that would have a negative impact, "2" for a slight negative impact, "3" for no impact, "4" for a slight positive impact, and "5" for a positive impact. For the purpose of this project, Accessibility was defined as, ability and ease for bicycles, pedestrians, patrons, and residents to reach their desired destination. Appearance was defined as, visual appeal that leads to a more welcoming atmosphere. Affordability scores were sourced from the Benefit-Cost results where:

TABLE 4 – Affordability Scores

Score	Benefit-Cost (B/C) Ratio
1	Less than 0.5
2	0.5 – 1.0
3	Equal to 1.0
4	1.0 – 2.0
5	Greater than 2.0

Countermeasures and improvements that did not have a measurable benefit were given an Affordability score of 1. Safety scores were determined based on the number of crashes prevented, calculated using the method discussed in section 3.2.3: Calculate Existing Safety Conditions, where:

TABLE 5 – Safety Scores

Score	Number of Crashed
1	8 – 15 Caused
2	1 – 7 Caused
3	0 Caused or Prevented
4	1 – 7 Prevented
5	8 – 15 Prevented

These crash values were selected based on the calculated crashes prevented for each countermeasure and improvements. The greatest number of crashes prevented was 15, therefore 15 was set as the maximum number of crashes prevented by a given countermeasure or improvements. Lastly, the efficiency score was derived from LOS data. Specifically, the impact each countermeasure or improvement would have on control delay times was used to create this score. Where:

TABLE 6 – Efficiency Scores

Score	Delay Time
1	Increased by more than 20 seconds
2	Increased by 1 – 19 seconds
3	No change
4	Decreased by 1 – 19 seconds
5	Decreased by more than 20 seconds

These values were selected because delay times vary by approximately 20 seconds between level of service scores (e.g. a control delay of 15s would have a "B" for level of service, while a delay of 35s would be a "C").

3.6 Selection

The primary tool utilized during the selection process was the scoring rubric that was developed to evaluate the impact of each potential improvement option. The total score of each countermeasure and improvement was reviewed as well as the individual scores for each category. During this evaluation process, countermeasures and improvements were selected based on their ability to best meet the goal of improving accessibility, appearance, affordability, safety, and efficiency. These countermeasures and improvements were also selected based on their ability to be implemented cooperatively, within the limited space along Park Avenue.

3.7 Conceptual Design

After finalizing the recommended countermeasures and improvements along the corridor, a conceptual design was developed to display those options. The intent of this preliminary design was to provide a visual representation of the recommendations for Park Avenue and be built upon later by Stantec. AutoCAD Civil 3D and the online tool Streetmix were used to create this conceptual design (Streetmix, n.d.). AutoCAD was used to create a plan view of the site with proposed changes. An orthoimage was imported into the design software to be used as a to-scale map underlay. This image was retrieved from the MassGIS 2013/2014 Ortho Mosaic Downloader (2013/2014 Ortho Mosaic Downloader, n.d.). On top of this image, a sketch of recommended improvement options was created. Further, these recommendations were labeled and dimensioned. Additionally, Streetmix was utilized to create cross sections of the proposed updates to Park Avenue. These cross sections were created by inserting and dimensioning roadway features. Each of these designs is presented in Section 4.7: Conceptual Design.

4. Results

Based on the methods outlined in Section 3, data was acquired and organized to present the findings of this project. Throughout this section the team:

- Examined case studies
- Documented and analyzed existing conditions
- Identified and evaluated potential countermeasures and improvements,
- Selected the most viable solutions for this project section
- Created a conceptual design with the use of AutoCAD Civil 3D and Streetmix.

4.1 Case Studies

This section presents the findings acquired through the discussed methods. Such findings include observations, calculations, and applicable research outcomes.

4.1.1 Case Study - Main Street Reimagined, Worcester, MA

Worcester's Main Street Reimagined project was an excellent source for Worcester City transportation design objectives. Specifically, the themes of creativity, innovation, and revolution identified by the Urban Culture Institute were taken into consideration throughout all stages of this project. Additionally, as part of the information collected on this project, a 75% design submittal was acquired. This submittal acted as a reference to the team when assessing different improvement concepts that could be used for Park Avenue.

4.1.2 Case Study - Kelley Square Improvement Project, Worcester, MA

Due to the high crash rate within the Kelley Square area, the Kelley Square Improvement Project largely focused on safety improvements. As a result, this project was referenced for potential safety countermeasures and improvements. Additionally, this project received extensive public feedback which provided an overview of popular concerns among the Worcester City public. This feedback was referenced throughout the countermeasure and improvement evaluation process in an effort to effectively meet the needs of the public. Specifically, improving Park Avenue's appearance was maintained as a high priority, even though increasing vegetation did not yield a high score in the scoring rubric, as utilizing a "place making" approach was important to the public for the Kelley Square project.

4.1.3 Case Study - Beacham/Williams Street Corridor Study, Chelsea, MA

The Beacham/Williams Street Corridor Study by Stantec greatly aided in the initial stages of this project. Chiefly, the identification of character areas was extremely helpful when documenting the existing condition of Park Avenue. Further, due to the diverse set of land uses along the Beacham/Williams Street Corridor, varied recommendations were made based on the identified character areas. This method of formulating recommendations based on land use was utilized when identifying countermeasures and improvements for the purposes of this project.

4.2 Existing Conditions

This section outlines the existing conditions data collected by the team along Park Avenue from Chandler Street to Maywood Street. The site layout, existing traffic volumes, and existing safety and efficiency conditions were determined in this section.

4.2.1 Site Layout and Characteristics

In order to best understand the current state of Park Avenue, this team carried out a series of site visits. These site visits provided essential information regarding the character, land use, and layout of Park Avenue. In addition to site visits, GIS software such as Google Earth was utilized to view orthoimagery and street view.

4.2.1.1 Maywood Street to Chandler Street, Project Section

Park Avenue can be accessed by vehicles through one of the numerous crossroads, few of which have traffic signals. Bicyclists and pedestrians also have access to Park Avenue via sidewalks, which line the street on both sides. Bus stops also line the section from Maywood Street to May Street, but, based on observation, are not always accessible due to poorly parked vehicles. In the fall of 2018, the City of Worcester carried out routine improvements to Park Avenue (Moosey, 2018). While these improvements ensure that Park Avenue remains functional, they do not aim to restructure the flow of traffic or alter accessibility for users.

In an effort to differentiate road segments between Maywood Street and Chandler Street, three predominant character areas were identified. These areas included a Residential Zone between Maywood Street and Downing Street, a Commercial and Residential Transition Zone between Downing Street and May Street, and a Commercial Zone between May Street and Chandler Street. These areas are labeled as such in Figure 5.

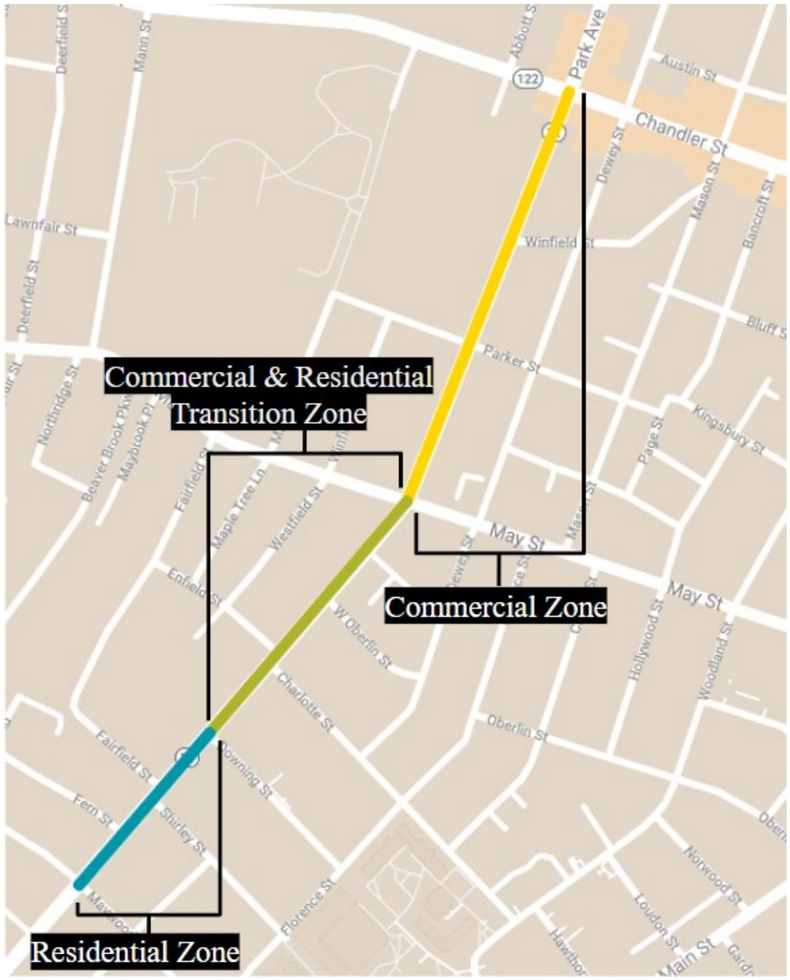

Figure 5: Park Avenue Character Areas

It is important to note that these classifications are not exclusive. The Commercial Zone contains some residences and the Residential Zone contains some businesses. The purpose of these classifications was to identify chief land use themes along each section within the project limits.

MAPC's Local Access Score was also utilized to determine the demand for pedestrian and bicycle facilities. Based on the Local Access Score Map, shown in Figure 6, the section of Park Avenue from Maywood Street to Chandler Street has the highest relative demand for pedestrian and bicycle accommodations.

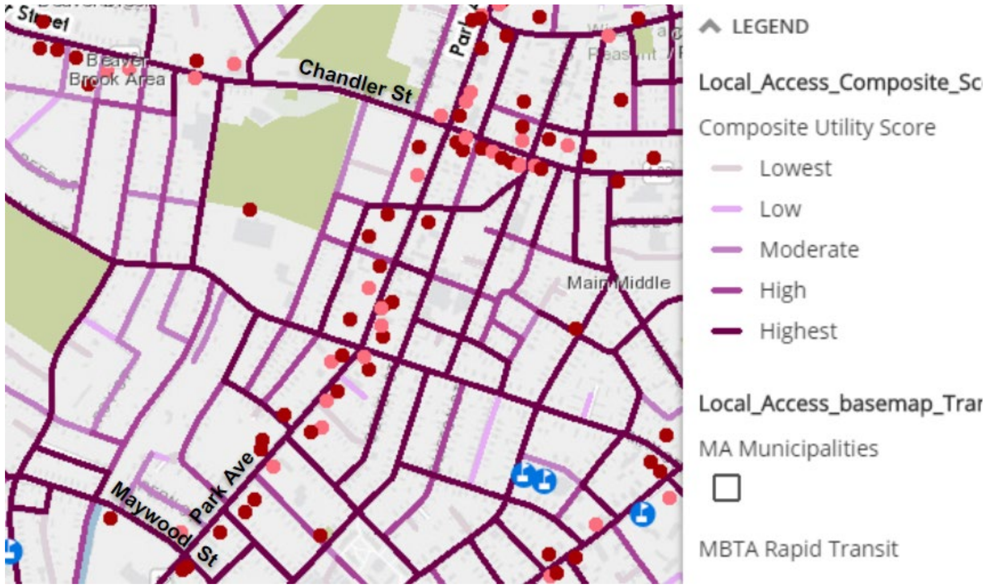

Figure 6: Local Access Score Map

The team also examined the existing stormwater system and requirements along the project section. It is located within the Blackstone River Watershed in Central Massachusetts. The project section was not included in the City of Worcester Card District and therefore does not require further permitting for wetland protection (City of Worcester: Wetlands Protection Ordinance and Wetlands Protection Regulations, 2016). There are multiple deep sump catch basins along Park Avenue that make up the stormwater system. Using OLIVER, the team was able to view the stormwater lines within the project limits, add topography layers to infer the direction of flow, and examine the potential receiving waterbodies (OLIVER: MassGIS's Online Mapping Tool, 2018). Based on this analysis, the team determined that the stormwater from this site would likely flow South along Beaver Brook and into Curtis Ponds before continuing to the Blackstone River. These existing conditions suggest stormwater impact can be minimized by maintaining or reducing impervious surfaces.

4.2.1.2 Intersection of Park Avenue and Maywood Street

The intersection of Park Avenue and Maywood Street was identified as one of the top 200 locations for vehicle collisions in Massachusetts by the MassDOT (Top Crash Locations 2016). The intersection consists of four lanes of two-way traffic on Park Avenue and two lanes of two-way traffic on Maywood Street, depicted in Figure 7. This intersection is managed by a traffic signal.

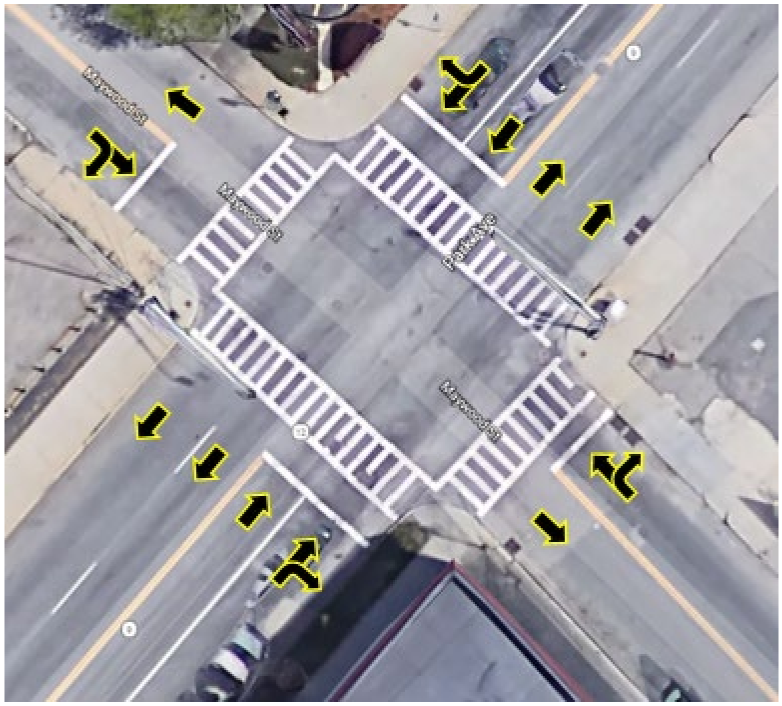

Figure 7: Park Avenue and Maywood Street Intersection (Google Earth)

4.2.1.3 Maywood Street to Downing Street

The segment of Park Avenue from Maywood Street to Downing Street has four lanes of through traffic and lies between two signalized intersections. The lane widths appear to be 10-11 feet according to the measure tool provided on Google Earth. There are three other intersections within this section: Fern Street on the southbound side, Shirley Street on the northbound side, and Fairfield Street on the southbound side.

The majority of this roadway is lined with residential buildings as well as the occasional commercial building. It is for this reason that this section was characterized as within the Residential Zone, see Figure 8. Though few, some significant commercial buildings fall into this Residential Zone and provide large parking lots adjacent to the sidewalk, including a Wendy's, Olsi Auto Sale and Service, and Western Union. In addition to parking lots, on-street parking is permitted for vehicles north of the intersection of Park Avenue and Fern Street. The majority of these vehicles are likely owned by local residents who do not have driveways. A few bus stops are scattered in the northbound and southbound directions. There are no bike lanes present and bicyclists are expected to share the road with motorists.

Figure 8: Photo of Park Avenue north of Maywood Street looking north (Colin Claus 11/7/18)

4.2.1.4 Intersection of Park Avenue and Downing Street

The intersection of Park Avenue and Downing Street consists of four lanes of two-way traffic on Park Avenue and two lanes of two-way traffic on Downing Street, which terminate at the intersection, see Figure 9. This intersection is managed by a traffic signal.

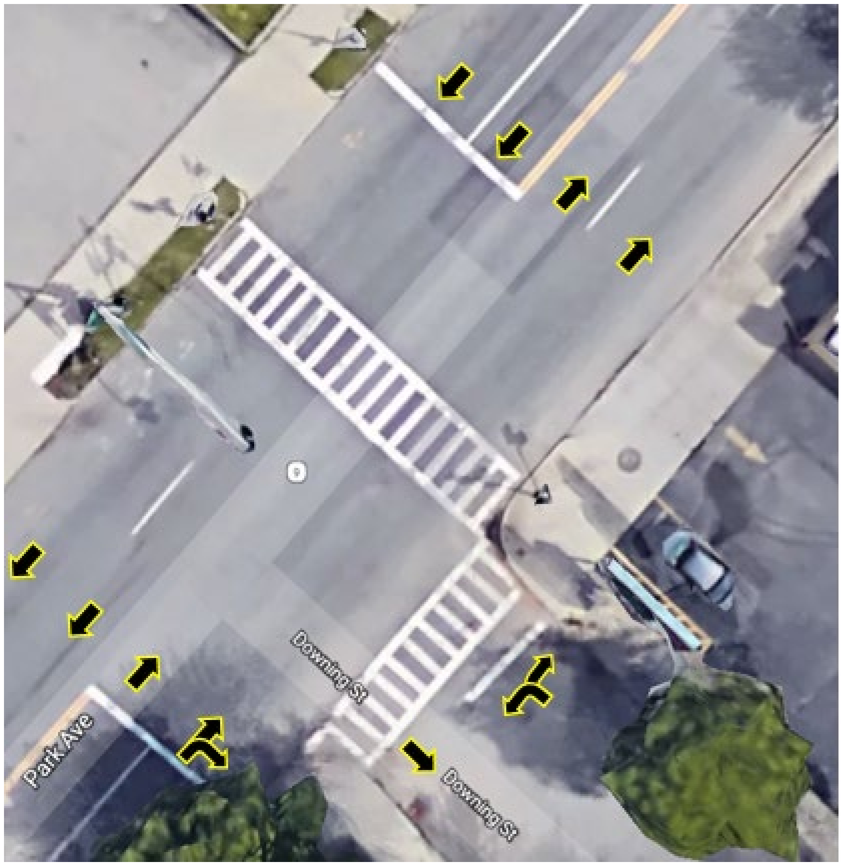

Figure 9: Park Avenue and Downing Street Intersection (Google Earth)

4.2.1.5 Downing Street to May Street

Park Avenue from Downing Street to May Street is bounded by two signalized intersections. There are four lanes of traffic with widths of 10-11 feet according to the measure tool provided on Google Earth. As Park Avenue approaches the intersection with May Street there is no change in lane structure. Park Avenue is intersected by three other streets along this section including Charlotte Street on the northbound side, Enfield Street on the southbound side, and West Oberlin Street on the northbound side.

This section was characterized by the team as within the Commercial and Residential Transition Zone due to the combination of residential and commercial buildings. This section provides a transition from the more residential uses seen south of Downing Street to the more commercial uses north of May Street. There is on-street parking in the northbound and southbound directions throughout this entire section of Park Avenue. Based on this team's observations, on-street parking is seldom used since there are multiple parking lots owned by commercial buildings. On-street parking becomes an issue near the intersection with May Street where vehicles line the northbound side of the street in this area. There are bus stops along this segment in the northbound and southbound directions. There are no bike lanes present and cyclists are expected to share the road with motorists.

4.2.1.6 Intersection of Park Avenue and May Street

The intersection of Park Avenue and May Street was identified as one of the top 200 locations for vehicle collisions in Massachusetts by the MassDOT. The intersection consists of four lanes of two-way traffic on Park Avenue and three lanes of two-way traffic on May Street east of the intersection and four lanes of traffic west of the intersection. On the eastern side of the intersection, May Street has an eastbound lane, a westbound lane, and a combined westbound and right turn lane. On the western side of this intersection, May Street has two westbound lanes, one right turn lane, and one eastbound lane, see Figure 10. This intersection is managed by a traffic signal.

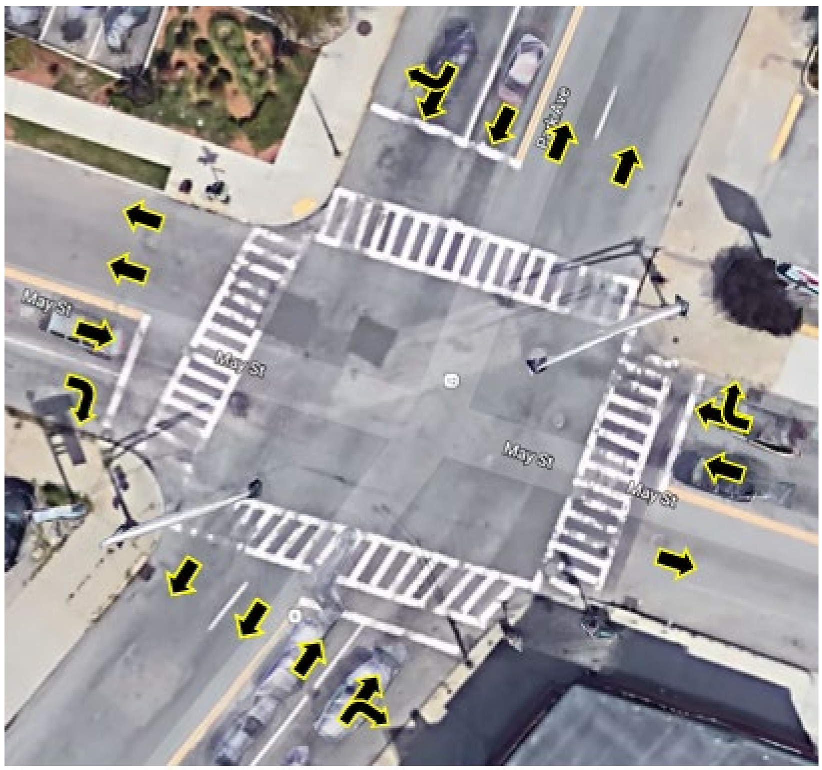

Figure 10: Park Avenue and May Street Intersection (Google Earth)

4.2.1.7 May Street to Chandler Street

Park Avenue from May Street to Chandler Street lies between two signalized intersections and has four lanes of through traffic with widths of 10-11 feet according to the measure tool provided on Google Earth. There is a large area of street pavement in this section, as depicted in Figure 11. As Park Avenue approaches the intersection with Chandler Street, a left-turn only lane is present for northbound traffic. Park Avenue is intersected by two streets in this section: Parker Street in both the southbound and northbound directions and Winfield Street in the northbound direction.

Commercial buildings occupy a large portion of this section of Park Avenue. As such, this section was characterized within the Commercial Zone. On-street parking is available from May Street to Parker Street. After this intersection, minimal on-street parking has been observed by this group. There are no bus stops along this section of Park Avenue. There are no bike lanes present on this section of roadway and bicyclists are expected to share the road with motorists.

Figure 11: Photo of Park Avenue north of May Street looking north (Colin Claus 11/7/18)

4.2.1.8 Intersection of Park Avenue and Chandler Street

The intersection of Park Avenue and Chandler Street was classified by the Highway Safety Improvement Program (HSIP) as a top location where vehicle-vehicle and vehicle-bicycle collisions occur (Top Crash Locations 2016). The intersection consists of five lanes of two-way traffic on Park Avenue, two northbound lanes, two southbound lanes and one left turn lane, and five lanes of two-way traffic on Chandler Street east of the intersection and four lanes of traffic west of the intersection. On the eastern side of the intersection, Chandler Street has two eastbound lanes, a westbound lane, a right turning lane, and a combined westbound and left turn lane. On the western side of this intersection, Chandler Street has two westbound lanes and two eastbound lanes. For clarification, see Figure 12. This intersection is managed by a traffic signal with arrows depicting when turns can occur off of Park Avenue and standard red-yellow-green signals on Chandler Street.

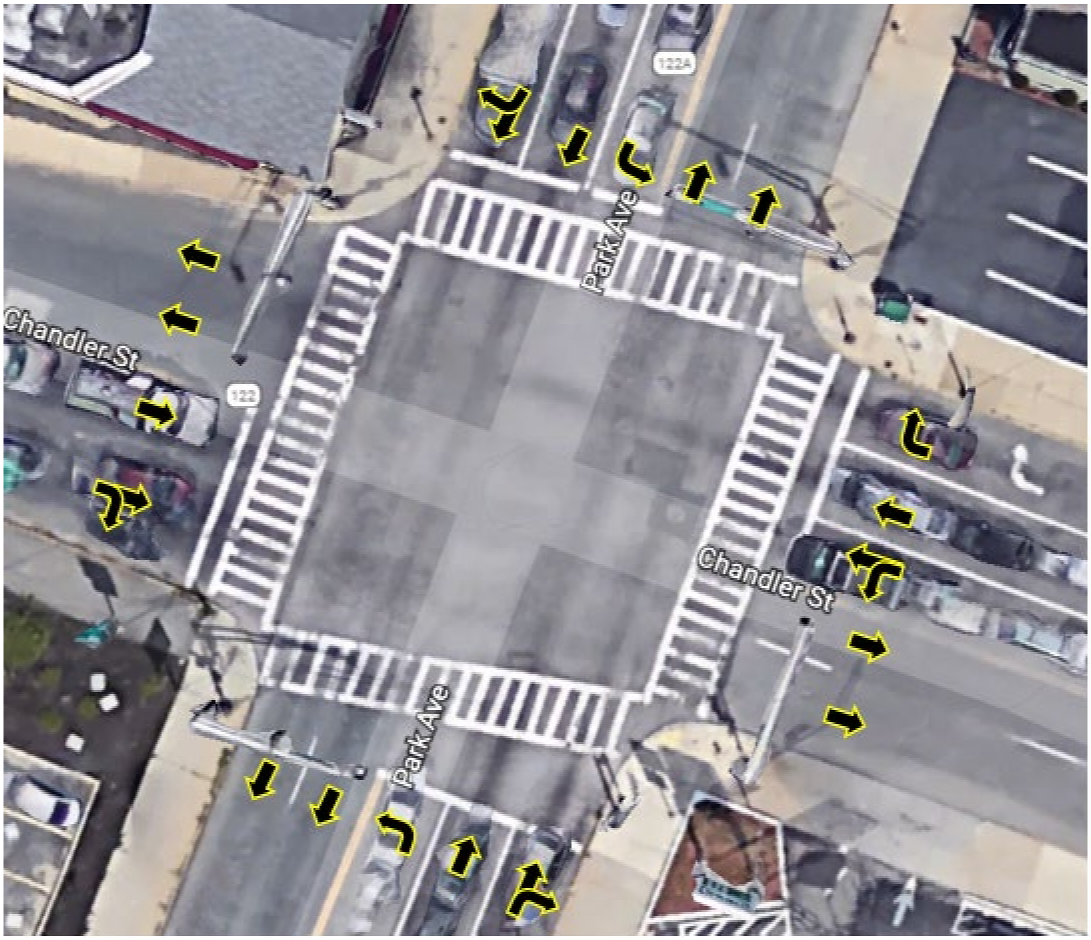

Figure 12: Park Avenue and Chandler Street Intersection (Google Earth)

4.2.2 Existing Traffic Volume Conditions

The team collected traffic count data from the MassDOT Traffic Count Database System (TCDS). Two counts were collected: one count was located just south of the intersection of Park Avenue and Chandler Street and the other was just north of the intersection of Park Avenue and Maywood Street. AADT data was provided with each of the traffic counts and was adjusted with a growth factor of 1% per year.

In order to obtain values for the existing safety conditions in 2016. Table 7 shows the original and adjusted AADT values for each traffic count.

TABLE 7 – Traffic Count Data from TCDS

Location	2004 AADT[1]	2010 AADT[2]	2016 Adjusted AADT[3]
Chandler Street – May Street	25,600	–	28,847
Downing Street – Maywood Street	26,100	25,500	27,069

1. 2004 AADT measured in vehicles per day
2. 2010 AADT measured in vehicles per day
3. 2016 Adjusted AADT measured in vehicles per day

It is important to note that the TCDS did not have any traffic count data for the segment between May Street and Downing Street. For this section, the team decided to use the AADT data for the section of Maywood Street to Downing Street due to a small amount of traffic being gained or lost at the intersection with Downing Street. Therefore these two sections should have similar traffic data.

The TMC data for the signalized intersections provided by Stantec is shown in Appendix C. The TMCs were conducted in September of 2013 and therefore were adjusted for growth, seasonal, and axle factors to calculate the 2016 factored 24-hour count for each intersection. Table 8 displays the data calculated for each intersection. This table provides data that is focused on the calculations for the existing safety conditions in 2016, discussed further in Section 4.2.3.

TABLE 8 – Calculated 2016 AADT for Signalized Intersections

Cross Street	PM Peak Hr. Volume[1]	K Factor	24-Hr. Count (2016)[2]	Axle Factor	Seasonal Factor	AADT[3]
Chandler Street	11,513	0.09	131,798	0.96	0.94	118,935
May Street	10,316	0.09	118,095	0.96	0.94	106,469
Downing Street	7,130	0.09	81,623	0.96	0.94	73,656
Maywood Street	8,099	0.09	89,989	0.96	0.94	83,667

1. PM Peak Hour Entering Volumes measured in vehicles per hour
2. 24-Hour entering vehicles (2016) measured in vehicles per day
3. Factored 24-hour entering vehicles measured in vehicles per day

As discussed in Section 3.2.2, AADT data was not necessary for the analysis of the existing efficiency conditions. However, the AM and PM peak 15-minute volumes were adjusted using the annual growth factor of 1% from 2013 to 2018 for the efficiency analysis. This team utilized the adjusted 15-minute peak period volumes in Section 4.2.4 to conduct the existing efficiency analysis for the project section.

4.2.3 Existing Safety Conditions

Crash data was exported from the MassDOT Crash Portal into Excel spreadsheets. This data was collected for each target location and then sorted by crash year, type, and severity. With the crash data sorted, the team was able to calculate the crash rates for all of the intersections and roadway segments using the previously calculated 2016 factored 24-hour counts and AADT values in Section 4.2.2. The crash data for all of the signalized intersections is displayed in Table 9. This table includes information by year for crash type and severity.

TABLE 9 - Park Avenue Intersections Crash History 2014-2016

Intersection with Park Avenue	Total	Ann. Avg.	Severity				Type of Accident							Crash Rate[1]
			PDO	NFI	FI	NR/U	Head-on	Angle	Rear	Side	Single	Ped/Bike	NR/U	
Chandler Street	51	17	40	5	0	6	0	13	20	9	7	2	0	0.39
May Street	46	15.3	32	12	0	2	1	21	12	9	2	0	1	0.39
Downing Street	15	5	9	5	0	1	0	4	4	3	2	1	1	0.19
Maywood Street	20	6.7	16	3	0	1	3	7	0	8	2	0	0	0.22

PDO: Property Damage Only; NFI: Non-Fatal Injury; NR/U: Not Reported/Unknown
1. Crash Rate measured in crashes per million entering vehicles

Crash data was also collected for all of the roadway segments and is displayed in Table 10.

TABLE 10 - Park Avenue Roadway Sections Crash History 2014-2016

Roadway Sections of Park Avenue	Total	Ann. Avg.	Severity				Type of Accident							Crash Rate[1]
			PDO	NFI	FI	NR/U	Head-on	Angle	Rear	Side	Single	Ped/Bike	NR/U	
Chandler Street to May Street	59	19.7	39	16	0	4	3	18	26	8	1	2	1	5.84
May Street to Downing Street	48	16	35	4	0	7	2	17	4	18	0	5	0	11.57
Downing Street to Maywood Street	8	2.7	6	1	0	1	1	1	3	2	0	1	0	1.23

PDO: Property Damage Only; NFI: Non-Fatal Injury; NR/U: Not Reported/Unknown
1. Crash Rate measured in crashes per million vehicle miles traveled

The team calculated the EPDO and RSI costs for each target location based on the tables displayed in 3.2.3. The results are shown in Table 11.

TABLE 11 – EPDO and RSI Costs for Target Locations

Target Location	EPDO Cost	RSI Cost
Intersection of Park Avenue and Chandler Street	$275,500	$1,100,300
Intersection of Park Avenue and May Street	$413,800	$853,100
Intersection of Park Avenue and Downing Street	$186,700	$362,100
Intersection of Park Avenue and Maywood Street	$66,700	$390,700
Roadway Section between Chandler Street and May Street	$592,100	$1,065,000
Roadway Section between May Street and Downing Street	$363,600	$1,068,700
Roadway Section between Downing Street and Maywood Street	$136,100	$171,000

EPDO: Equivalent Property Damage Only; Relative Severity Index

There is a significant discrepancy between the EPDO and RSI costs in this table. When deciding whether to use EPDO or RSI costs for analysis, this team looked at how each cost was determined. The EPDO cost is based on the severity of crashes at a target location whereas the RSI cost is determined by the types of crashes. The entirety of this site saw no fatal injuries and minimal severe injuries. The EPDO cost is dependent on serious and fatal injuries to adjust the cost. Therefore, it was decided that the RSI costs would be more representative of the section of

Park Avenue discussed in this project. This section has a variety of crashes that result in the cost reflecting the amount of crashes that occurred.

4.2.4 Existing Efficiency Conditions

As discussed in Section 4.2.2, the 2013 TMC data for the AM and PM 15-minute peak volumes provided by Stantec was adjusted to the year 2018 with a 1% annual growth factor for the purpose of the existing efficiency conditions analysis. The efficiency conditions for this section of Park Avenue were output in a series of HCS reports for the signalized intersections and the roadway segments. These reports for the 2018 existing conditions are located in Appendix D for each target location. The team collected data from these reports and created Table 12 to show the existing LOS, delay time, queue length, and volume-to-capacity ratio for each of the signalized intersections during AM and PM peak hours.

TABLE 12 – Existing (2018)[1] Level-of-Service for Signalized Intersections

Intersection with Park Avenue / Movement	AM Peak v/c[2]	AM Peak D[3]	AM Peak LOS	AM Peak Queue[4] 50%	AM Peak Queue[4] 95%	PM Peak v/c	PM Peak D	PM Peak LOS	PM Peak Queue 50%	PM Peak Queue 95%
Chandler Street										
Park Avenue NB L	0.41	63.0	E	2	3	0.76	84.1	F	4	7
Park Avenue NB T	0.86	64.5	E	15	21	0.81	59.2	E	14	20
Park Avenue NB T/R	0.86	65.0	E	15	21	0.81	60.1	E	13	19
Park Avenue SB L	0.81	92.6	F	5	8	1.06	162.8	F	8	13
Park Avenue SB T	0.52	46.4	D	7	12	1.30	200.5	F	36	53
Park Avenue SB T/R	0.53	46.7	D	7	12	1.30	202.6	F	34	50
Chandler Street EB L/T	0.95	81.9	F	19	26	0.72	53.5	D	11	17
Chandler Street EB T/R	0.87	66.2	E	15	22	0.66	50.6	D	10	15
Chandler Street WB L/T	0.67	52.8	D	9	15	1.00	96.0	F	20	28
Chandler Street WB T	0.61	50.3	D	9	13	0.91	74.2	E	17	23
Chandler Street WB R	0.22	43.4	D	2	4	0.17	42.9	D	2	3
OVERALL		**62.5**	**E**				**114.2**	**F**		
May Street										
Park Avenue NB L/T	0.53	11.1	B	4	8	0.56	11.3	B	3	5
Park Avenue NB T/R	0.56	11.6	B	4	7	0.61	12.4	B	5	8
Park Avenue SB L/T	0.31	9.3	A	2	3	0.67	13.6	B	5	9
Park Avenue SB T/R	0.32	9.6	A	2	4	0.71	14.8	B	7	11
May Street EB L/T	0.69	24.4	C	5	9	1.03	85.4	F	10	15
May Street EB R	0.25	17.6	B	1	2	0.35	18.3	B	2	3
May Street WB L/T	0.48	19.2	B	3	5	0.68	25.6	C	4	7
May Street WB T/R	0.51	19.5	B	3	5	0.80	29.8	C	7	11
OVERALL		**14.8**	**B**				**23.8**	**C**		
Downing Street										
Park Avenue NB T	0.44	5.1	A	2	3	0.40	4.9	A	2	3
Park Avenue NB T/R	0.44	5.1	A	1	3	0.40	4.9	A	1	2
Park Avenue SB L/T	0.22	4.3	A	1	1	0.50	5.5	A	2	4
Park Avenue SB T	0.23	4.3	A	1	1	0.53	5.6	A	2	4
Downing Street WB	0.04	14.9	B	0	0	0.30	16.0	B	1	1
OVERALL		**4.9**	**A**				**5.7**	**A**		
Maywood Street										
Park Avenue NB L/T	0.48	11.5	B	4	7	0.47	11.3	B	4	7
Park Avenue NB T/R	0.51	11.6	B	4	7	0.50	11.5	B	4	7
Park Avenue SB L/T	0.29	9.9	A	2	3	0.64	13.4	B	6	9
Park Avenue SB T/R	0.30	10.1	B	2	3	0.67	14.5	B	6	10
Maywood Street EB	0.23	14.2	B	2	3	0.19	14.0	B	1	2
Maywood Street WB	0.23	14.3	B	2	3	0.42	15.8	B	3	6
OVERALL		**11.6**	**B**				**13.2**	**B**		

1. 2018 traffic volumes estimated using 2013 traffic volumes and a 1% annual growth factor
2. v/c = volume-to-capacity ratio
3. D = delay in seconds per vehicle
4. 50th or 95th percentile queue in vehicle per lane

The team also collected data from these reports to create Table 13 to show the existing LOS for each of the roadway sections during AM and PM peak hours.

TABLE 13 – Existing (2018)[1] Level-of-Service for Roadway Sections

	AM Peak					PM Peak				
Roadway Sections of Park Avenue	v/c[2]	S[3]	BFFS[4]	%[5]	LOS	v/c	S	BFFS	%	LOS
Chandler Street to May Street										
Northbound	0.54	26.8	39.4	68.1	B	0.58	26.5	39.4	67.4	B
Southbound	0.53	15.0	39.4	39.2	E	1.30	5.1	39.4	12.9	F
May Street to Downing Street										
Northbound	0.44	24.9	39.4	63.1	C	0.40	25.1	39.4	64.0	C
Southbound	0.31	21.3	39.4	54.0	C	0.69	18.0	39.4	45.6	D
Downing Street to Maywood Street										
Northbound	0.50	23.2	39.4	59.0	C	0.48	23.4	39.4	59.4	C
Southbound	0.22	29.4	39.4	74.7	B	0.51	27.7	39.4	70.4	B
OVERALL										
Northbound		**25.1**	**39.4**	**63.8**	**C**		**25.1**	**39.4**	**63.8**	**C**
Southbound		**19.3**	**39.4**	**49.1**	**D**		**8.8**	**39.4**	**22.4**	**F**

1. 2018 traffic volumes estimated using 2013 traffic volumes and a 1% annual growth factor
2. v/c = through volume-to-capacity ratio
3. S = travel speed in miles per hour
4. BFFS = base free-flow speed in miles per hour
5. % = percent of base free-flow speed

Tables 12 and 13 show that the major problem location is the northernmost signalized intersection of Park Avenue and Chandler Street. This intersection is operating at an “F” for its LOS score. The Southbound approach is the main cause for this LOS since it has control delays over 150 seconds for each of its movements. This is due to the extremely high volumes traveling south on Park Avenue during the PM peak hour.

The other three signalized intersections are operating at acceptable LOS scores. This is likely due to the fact that Park Avenue opens up after the intersection with Chandler Street. There are less signalized intersections and longer roadway sections between the intersections. Passenger vehicles are able to space out and increase their speed to get more vehicles through the intersections and reduce the queue lengths.

4.3 Analysis of Existing Conditions

With the existing conditions documented, the team analyzed safety and efficiency data for the corridor. This section details the analysis conducted by comparing this project’s existing conditions to similar corridors and statewide data.

4.3.1 Safety Conditions Comparison

The team compared crash rate data for signalized intersections with the statewide and District 3 averages, presented in Table 14.

TABLE 14 – Signalized Intersection Crash Rate Comparison

Location	PM Crash Rate[1]
Intersection of Park Avenue and Chandler Street	0.39
Intersection of Park Avenue and May Street	0.39
Intersection of Park Avenue and Downing Street	0.19
Intersection of Park Avenue and Maywood Street	0.22
Signalized Intersection Statewide Average	0.78
Signalized Intersection District 3 Average	0.89

1. Crash Rate measured in crashes per million entering vehicles

Each of the four signalized intersections have crash rates below both the statewide and District 3 averages. Due to large volumes of vehicles traveling through these intersection, there is still a significant amount of crashes that occur yearly.

The team also compared the crash rates for the roadway sections to the statewide and District 3 averages for a principal arterial, presented in Table 15.

TABLE 15 – Roadway Sections (Principal Arterial) Crash Rate Comparison

Location	PM Crash Rate[1]
Roadway Section between Chandler Street and May Street	5.84
Roadway Section between May Street and Downing Street	11.57
Roadway Section between Downing Street and Maywood Street	1.23
Principal Arterial (not freeway or expressway) Statewide Average	2.27
Principal Arterial (not freeway or expressway) District 3 Average	3.49

1. Crash Rate measured in crashes per million vehicle miles traveled

Two of the three roadway sections between Chandler Street and May Street, and May Street and Downing Street have crash rates above the statewide and District 3 averages for principal arterials. The section between Downing Street and Maywood Street has a crash rate below the averages.

The high crash rates associated with the two northern sections are likely a result of the amount of access points and unsignalized intersections. Crashes are prevalent at areas with a larger amount of access points. Also, in the interest of simplicity, the unsignalized intersections were included with the roadway sections since TMC data for the unsignalized intersections was not available. The intersections could be responsible for a significant amount of the crashes for the roadway sections. In the future TMC data should be collected at the unsignalized intersections along Park Avenue to more accurately determine the crash rates.

4.3.2 Efficiency Conditions Comparison

The existing efficiency conditions for Park Avenue were compared with those for Lincoln Street in the Stantec report. The signalized intersections along Lincoln Street were operating at an LOS of “C” or better in 2010 when the study was conducted. These intersections are similar to the intersections of Park Avenue with Downing Street and Maywood Street. Efficiency data for Park Avenue at those intersections shows that they were operating at "C" or better. This leads the team to believe that the analysis of the existing efficiency conditions for Park Avenue is accurate.

As outlined in section 3.3.2, the team conducted an analysis of the no-build conditions for Park Avenue in the year 2030. Also, as previously discussed in Section 4.2.2, 2013 TMC data provided by Stantec was adjusted using a 1% annual growth factor in order to be input into HCS 2010. HCS reports for the 2030 no-build conditions are provided in Appendix D. The data collected from these reports for the signalized intersections and roadway sections is presented in Tables 16 and 17.

TABLE 16 – No-Build (2030)[1] Level of Service for Signalized Intersections

Intersection with Park Avenue	AM Peak					PM Peak				
				Queue[4]					Queue	
Movement	v/c[2]	D[3]	LOS	50%	95%	v/c	D	LOS	50%	95%
Chandler Street										
Park Avenue NB L	0.47	63.5	E	2	4	0.86	103.3	F	5	9
Park Avenue NB T	0.96	84.0	F	20	27	0.91	72.0	E	17	24
Park Avenue NB T/R	0.96	84.6	F	19	26	0.91	73.3	E	16	23
Park Avenue SB L	0.91	114.7	F	6	10	1.17	196.4	F	9	15
Park Avenue SB T	0.59	48.0	D	9	13	1.41	249.6	F	42	63
Park Avenue SB T/R	0.59	48.4	D	8	13	1.42	253.6	F	41	61
Chandler Street EB L/T	1.08	116.0	F	24	34	0.81	60.1	E	14	20
Chandler Street EB T/R	0.98	88.3	F	20	28	0.74	54.7	D	12	17
Chandler Street WB L/T	0.76	57.5	E	11	17	1.12	135.0	F	25	35
Chandler Street WB T	0.69	53.4	D	10	15	1.02	102.0	F	22	30
Chandler Street WB R	0.24	43.8	D	2	4	0.21	43.2	D	2	4
OVERALL		**78.0**	**E**				**142.0**	**F**		
May Street										
Park Avenue NB L/T	0.59	12.1	B	5	9	0.79	44.4	D	2	3
Park Avenue NB T/R	0.63	12.8	B	5	9	1.03	55.4	F	20	28
Park Avenue SB L/T	0.36	9.7	A	2	3	0.97	57.6	E	7	12
Park Avenue SB T/R	0.38	10.0	A	3	5	1.132	90.2	F	30	41
May Street EB L/T	0.91	45.7	D	9	14	1.63	330.2	F	22	37
May Street EB R	0.28	17.8	B	2	3	0.40	18.6	B	2	4
May Street WB L/T	0.55	20.1	C	3	5	0.75	30.6	C	5	8
May Street WB T/R	0.63	21.9	C	4	7	0.92	44.5	D	10	15
OVERALL		**18.9**	**B**				**87.2**	**F**		
Downing Street										
Park Avenue NB T	0.49	5.3	A	2	3	0.44	5.1	A	2	2
Park Avenue NB T/R	0.49	5.3	A	2	3	0.44	5.1	A	1	2
Park Avenue SB L/T	0.25	4.4	A	1	2	0.56	5.9	A	3	5
Park Avenue SB T	0.26	4.4	A	1	1	0.60	6.2	A	3	4
Downing Street WB	0.04	14.9	B	0	0	0.34	16.2	B	1	2
OVERALL		**5.1**	**A**				**6.1**	**A**		
Maywood Street										
Park Avenue NB L/T	0.54	12.2	B	5	8	0.52	11.8	B	5	8
Park Avenue NB T/R	0.57	12.4	B	5	8	0.56	12.2	B	4	8
Park Avenue SB L/T	0.32	10.1	B	2	4	0.75	17.2	B	7	12
Park Avenue SB T/R	0.34	10.3	B	2	4	0.80	19.0	B	8	13
Maywood Street EB	0.26	14.4	B	2	3	0.23	14.2	B	1	2
Maywood Street WB	0.27	14.5	B	2	3	0.48	16.2	B	4	6
OVERALL		**12.1**	**B**				**15.5**	**B**		

1. 2030 traffic volumes estimated using 2013 traffic volumes and a 1% annual growth factor
2. v/c = volume-to-capacity ratio
3. D = delay in seconds per vehicle
4. 50th or 95th percentile queue in vehicle per lane

TABLE 17 – No-Build (2030)[1] Level of Service for Roadway Sections

	AM Peak					PM Peak				
Roadway Sections of Park Avenue	v/c[2]	S[3]	BFFS[4]	%[5]	LOS	v/c	S	BFFS	%	LOS
Chandler Street to May Street										
Northbound	0.61	26.1	39.4	66.4	C	1.02	13.6	39.4	34.4	F
Southbound	0.59	14.7	39.4	37.4	E	1.41	4.2	39.4	10.6	F
May Street to Downing Street										
Northbound	0.49	24.5	39.4	62.4	C	0.44	24.9	39.4	63.2	C
Southbound	0.37	20.9	39.4	53.1	C	1.09	5.9	39.4	14.9	F
Downing Street to Maywood Street										
Northbound	0.55	22.7	39.4	57.7	C	0.54	22.9	39.4	58.3	C
Southbound	0.25	29.3	39.4	74.3	B	0.58	27.1	39.4	68.9	B
OVERALL										
Northbound		**24.6**	**39.4**	**62.5**	**C**		**17.7**	**39.4**	**45.0**	**D**
Southbound		**19.0**	**39.4**	**48.3**	**D**		**6.3**	**39.4**	**16.0**	**F**

1. 2030 traffic volumes estimated using 2013 traffic volumes and a 1% annual growth factor
2. v/c = through volume-to-capacity ratio
3. S = travel speed in miles per hour
4. BFFS = base free-flow speed in miles per hour
5. % = percent of base free-flow speed

From Tables 16 and 17 it is evident that conditions for efficiency will get worse as time proceeds and no changes are made. The intersection of Park Avenue and Chandler Street will experience even worse delays than those existing today. The intersection is already operating at an “F”, and in 2030 the efficiency would drop into the deep “F” category.

An interesting development that occurs in the 2030 no-build conditions is a failure at the eastbound approach for the intersection of Park Avenue and May Street. This failure occurs for the left and through-lane on this approach. This is likely due to an increase in traffic volume without any changes in geometry or signal timing. Currently, the left-through lane is able to accommodate the eastbound traffic. However, with increased volume there will be more vehicles restricting this movement from the westbound approach and more left turning vehicles traveling eastbound to block the vehicles moving through the intersection, as shown in Figure 13.

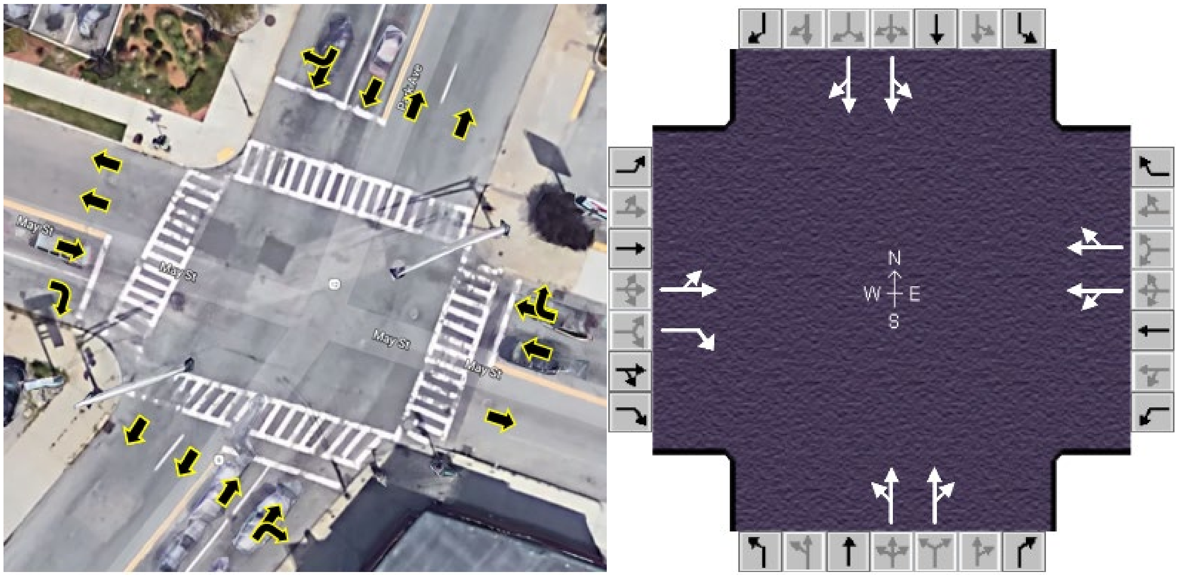

Figure 13: Park Avenue and May Street Intersection (Google Earth & HCS 2010)

The other two intersections remain operating at efficient LOS scores. These intersections do not include heavily trafficked side streets and therefore are less affected by the increase in traffic volume by 2030.

4.4 Countermeasures and Improvements

This section details the countermeasures and improvements considered throughout the course of this project. Each of these countermeasures and improvements were selected based on research and are listed in Table 18 along with a brief description and whether or not the option would impact accessibility, appearance, safety, and efficiency.

TABLE 18 – Considered Countermeasures and Improvements

Category	Countermeasure/Improvement	Impact Area(s)	Description
Bike and Pedestrian Accommodations	Bike Lanes	Accessibility, Safety	Designate a 5' path for bicycles with appropriate striping and signage
	Shared Pedestrian-Bike Path	Accessibility, Safety	Install a shared path at least 10' wide for pedestrians and bicyclists.
	Shared Vehicle-Bike Lane (Sharrow)	Accessibility, Safety	Update signage and striping for shared vehicle and bicycle lanes.
	Rectangular Rapid Flashing Beacon (RRFB)	Accessibility, Safety	Install Rectangular Rapid Flashing Beacon at the intersection of Park Avenue and Parker Street.
Public Transportation Accommodations	Bus Pullouts	Accessibility, Safety, Efficiency	Add designated spaced alongside through lanes at bus stops for buses to pull over.
	Crosswalks at Bus Stops	Accessibility, Safety	Include crosswalks at bus stops, so pedestrians can cross to get to, or depart from, a bus stop.
	New Bus Line/Stops	Accessibility, Efficiency	Add stops on Park Avenue between Chandler Street and May Street where currently none exist.

	Public Transportation Facilities	Accessibility	Add bus shelters at bus stops.
Parking	Remove on-street parking	Accessibility, Safety	Update signage to read "No Parking" along Park Avenue.
	Add on-street parking	Accessibility, Safety	Update parking signage and striping along Park Avenue.
	Purchase land for parking lot	Accessibility	Have the city purchase land for public parking lot.
Vegetation	Trees	Appearance	Add street tress wherever possible.
	Shrubs	Appearance	Add shrubs along Park Avenue.
	Grass	Appearance	Add grass strips along Park Avenue.
	Rain Garden	Appearance	Add rain gardens along Park Avenue.
Roadway Geometry	Pavement Width	Safety, Efficiency	Widen the roadway to accommodate a wider shoulder.
	Road Diet	Safety, Efficiency	Reduce the number of land from four through lanes to two and add a center left turn lane.
	Adjust Geometry	Safety, Efficiency	Modify intersection geometry to increase visibility.
	Widen Lanes	Safety, Efficiency	Increase lane widths.
Signalization and Signage	Signal Timing and Coordination	Safety, Efficiency	Update signal timing to better meet the needs of each intersection and coordinate signals along the corridor.
	Retroflective Backplates	Safety	Add retroreflective backplates to signals and supports where necessary.
	Update Signage	Safety	Add or replace appropriate parking and bus stop signage.
	Systemic Signing and Visibility Improvements	Safety	Carry out a complete overhaul of each intersection.
Two-Way Traffic Buffers	Rumble Strips	Safety	Add rumble strips between northbound and southbound traffic.
	Add Median	Safety	Install a raised center median between northbound and southbound traffic.

4.5 Evaluation

Once necessary research and calculations were completed, each countermeasure and improvement was evaluated to determine the feasibility of implementation. This section details the results of such evaluation through the various methods described in section 3.5.

4.5.1 Eliminate Infeasible

Early in the evaluation process, countermeasures and improvements that would not be feasible to implement on Park Avenue were eliminated. When evaluating options for pedestrian and bicyclist accommodations, the option of creating a shared use pedestrian and bicycle path was eliminated. This improvement was initially considered as it offers protection for both pedestrians and bicyclists from through traffic, but was ultimately deemed infeasible due to space constraints along this section.

In terms of accommodations for public transportation and its users, creating bus pullouts, adding bus stops along the section, and installing bus stop shelters were eliminated from consideration. Bus pullouts can be beneficial as they prevent buses from stopping in through lanes which can result in traffic delays. However, bus pullouts were deemed infeasible due to limited space and the high construction cost associated with removing and resetting curb. Adding bus stops north of May Street was initially considered, but this was also eliminated as an option due to the close proximity of bus stops south of May Street and north of Chandler, as well as the high traffic volumes north of May Street. In addition to this, there is presently only one WRTA bus line that travels along this section of Park Avenue. Line 7 typically passes through Park Avenue once an hour and accommodates approximately ten passengers per day on weekdays (N. Burnham, email communication, January 29, 2019). The option of installing bus stop shelters was also evaluated, but eliminated this option due to space constraints on the sidewalk and maintenance requirements.

Although increasing vegetation along Park Avenue is a primary goal of this project, the options of installing street trees, shrubs, and rain gardens were all eliminated early in the evaluation process. In order to ensure visibility is maintained for drivers, street trees must not be placed within 20-30 feet of an intersection and within 10 feet of driveways (Jahnige 2006). These design standards effectively eliminated the option for adding street trees along the corridor as there are very few locations that are both 20 feet from intersections and 10 feet from driveways. Shrubs and rain gardens were also considered, but each would require frequent maintenance and shrubs would reduce space for snow storage.

A number of options relating to roadway geometry were also eliminated early in the evaluation process due to spatial constraints. These options included, widening roadway shoulders and adjusting intersection geometry. Both of these improvement options have the ability to increase visibility for drivers and prevent sideswipe crashes. However, none of these options would be possible given the spatial limitations along the section. Applying a road diet technique to reduce Park Avenue from four through lanes to two through lanes and a center left turn lane was also eliminated. A center left turn lane offers a buffer between northbound and southbound traffic, potentially reducing the likelihood of sideswipes in the opposite direction. However, this design cannot support large volumes of traffic, and was thereby eliminated from consideration for the segment from Downing Street to Chandler Street. A center left turn lane was further evaluated for the segment of Park Avenue from Maywood Street to Downing Street, where there is slightly lower traffic volumes, but was ultimately eliminated due to the incongruity this geometry would cause along Park Avenue. Park Avenue is approximately three miles of four-lane through traffic, and the addition of a center left turn lane from Maywood Street to Downing Street would alter that congruity for less than a quarter of a mile.

The installation of retroreflective backplates was also considered as it would increase signal visibility for drivers. However, implementing this countermeasure alone was determined to be infeasible as there are currently no backplates on the signals and installing them could require new signal arm and mast supports.

Installing a raised center median and rumble strips between northbound and southbound traffic was also eliminated. These options were initially considered because each provides a buffer between northbound and southbound traffic which could mean a reduction in sideswipe crashes in the opposite direction. The raised center median was eliminated because there are a multitude of driveways and side streets lining Park Avenue, and a raised center median would restrict access to these points. Rumble strips were eliminated from consideration as they are often not used within residential areas due to the sound they produce.

4.5.2 Benefit Cost Analysis

After eliminating infeasible options, potential countermeasures and improvements were narrowed down for the signalized intersections to adding a left turn lane at Park and May and Park and Maywood and, implementing systemic signing and visibility improvements at all signalized intersections. The specific values used for each countermeasure and improvement and the resulting B/C ratio can be seen in Table 19.

TABLE 19 – Benefit-Cost (B/C) of Countermeasures and Improvements at Intersections

Name of Countermeasure/Improvement	Benefit[1]	Construction Cost[2]	B/C Ratio	Y/N ?
Intersection of Park Avenue and May Street				
Add a left-turn lane	$318,900	$287,400	1.11	Y
Implement systemic signing and visibility improvements at signalized intersections	$84,300	$287,400	0.29	N
Intersection of Park Avenue and Downing Street				
Implement systemic signing and visibility improvements at signalized intersections	$35,800	$287,400	0.12	N
Intersection of Park Avenue and Maywood Street				
Implement systemic signing and visibility improvements at signalized intersections	$38,600	$287,400	0.13	N

1. Benefit dollar amount estimated using RSI cost values for associated crash types prevented
2. Construction Cost dollar amounted estimated using MassDOT Construction Cost Estimator

Due to few crashes being prevented by carrying out systemic signing and visibility improvements, as well as the high cost associated with the countermeasure, the B/C ratio for each intersection was less than one. This suggests that this countermeasure would not be a worthwhile investment. This was also true for the option of adding a left turn lane at the intersection of Park Avenue and Maywood Street. The only countermeasure at a signalized intersection to yield a B/C ratio greater than one would be adding a left turn lane at the intersection of Park Avenue and May Street.

For each roadway segment, removing on street parking, updating signage, and adding bike lanes was evaluated. Additionally, adding rectangular rapid flashing beacons on the sections of Park Avenue between May Street and Chandler Street at the intersection of Park Avenue and Parker Street was considered. All of these countermeasures yielded a B/C ratio greater than one and many results much greater than one, see Table 20. This is likely due to a low estimated cost, as many of the construction costs were sourced from large-scale projects which have lower individual item costs. However, due to the high estimated benefit acquired from implementing these countermeasures, it is unlikely the cost would surpass the benefit.

TABLE 20 – Benefit-Cost (B/C) of Countermeasures and Improvements for Roadway Sections

Name of Countermeasure/Improvement	Benefit[1]	Construction Cost[2]	B/C Ratio	Y/N ?
Roadway Section between Chandler Street and May Street				
Remove on-street parking	$301,600	$3,800	79.37	Y
Update signage	$132,700	$3,800	34.92	Y
Install bike lanes	$355,900	$32,600	10.92	Y
Install Rectangular Rapid Flashing Beacon (RRFB)	$571,900	$94,200	6.07	Y
Roadway Section between May Street and Downing Street				
Remove on-street parking	$302,700	$1,800	168.17	Y
Update signage	$133,100	$1,800	73.94	Y
Install bike lanes	$357,100	$22,500	15.87	Y
Roadway Section between Downing Street and Maywood Street				
Remove on-street parking	$48,400	$1,800	26.89	Y
Update signage	$21,300	$1,800	11.83	Y
Install bike lanes	$57,100	$14,400	3.97	Y

1. Benefit dollar amount estimated using RSI cost values for associated crash types prevented
2. Construction Cost dollar amounted estimated using MassDOT Construction Cost Estimator

4.5.3 Scoring Rubric

The final step of evaluating each countermeasure was scoring them in the categories of Appearance, Accessibility, Affordability, Safety, and Efficiency; see Table 15. Based on this rubric, installing bike lanes, installing rectangular rapid flashing beacon at Park Avenue and Parker Street, and updating signage would have the greatest positive impact to Park Avenue. While implementing systemic signing and visibility improvements at signalized intersections, increasing vegetation, and adding a left-turn lane at the intersection of Park Avenue and May Street would have the least positive impact.

TABLE 21 – Scoring Rubric for Countermeasures and Improvements

	Scoring (1 lowest to 5 highest)					
Countermeasure/Improvement	**Accessibility**	**Appearance**	**Affordability**	**Safety**	**Efficiency**	**Total**
Add a left-turn lane (Park Avenue and May Street)	3	3	4	4	2	16
Remove on-street parking	2	4	5	4	3	18
Update signage	4	3	5	4	3	19
Install bike lanes	5	4	5	4	3	21
Implement systemic signing and visibility improvements at signalized intersections	4	3	1	4	3	15
Install Rectangular Rapid Flashing Beacon (RRFB), (Park Avenue and Parker Street)	5	2	5	5	3	20
Increase vegetation	3	5	1	3	3	15
Change lane configuration (Park Avenue and May Street)	3	3	1	3	4	14

4.6 Selection

After thoroughly evaluating each improvement option, six were selected. These improvement options were as follows:

- Install bike lanes
- Install Rectangular Rapid Flashing Beacon (RRFB) at Park Ave and Parker St
- Update signage
- Remove on-street parking
- Increase vegetation
- Modify the lane configuration at the intersection of Park Ave and May St

Installing bike lanes was a high priority as currently there are only shared bicycle-vehicle lanes on this section of Park Avenue. Additionally, based on the scoring rubric, adding bike lanes would improve the section's accessibility, appearance, safety, and be affordable to implement. Installing Rectangular Rapid Flashing Beacon (RRFB) at Park Ave and Parker St also ranked high in the scoring rubric. It was determined that the RRFB would improve the section's accessibility, safety, and be affordable to implement. The final two improvement options selected based on their scores were updating signage and removing on-street parking. Both of these options were determined to be affordable to implement and would increase safety. Further, updating signage would improve accessibility while removing on-street parking would improve the roadway's appearance.

In addition to countermeasures that yielded positive results from the scoring rubric, some countermeasures were selected based on necessity. Increasing vegetation did not yield a high score in the scoring rubric. However, improving the appearance of Park Avenue through the use of vegetation was a primary goal of this project. Additionally, increasing vegetation would ultimately reduce the total area of impervious surfaces, thus minimizing the stormwater impact on the site. Therefore, increasing vegetation was selected as an improvement option. Another improvement option that did not score high in the rubric was changing the lane configuration at the intersection of Park Avenue and May Street. However, using HCS, it was determined that the intersection of Park Avenue and May Street would have a failing level of service during peak PM traffic. After testing various modifications to geometry, it was determined that modifying eastbound lanes on May Street from a through/left lane and a right turn only lane to a left turn only lane and a through/right lane would increase the level of service in 2030 from an "F" to an "E", and was thereby necessary.

HCS analysis was conducted based on the 2030 no-build conditions to examine the impact of the proposed lane adjustment. HCS reports for this analysis are provided in Appendix D. Data collected from these reports for the 2030 build conditions is provided below in Tables 22 and 23.

TABLE 22 – Build (2030)[1] Level of Service for Signalized Intersections

Intersection with Park Avenue / Movement	AM Peak v/c[2]	AM Peak D[3]	AM Peak LOS	AM Peak Queue[4] 50%	AM Peak Queue[4] 95%	PM Peak v/c	PM Peak D	PM Peak LOS	PM Peak Queue 50%	PM Peak Queue 95%
Chandler Street										
Park Avenue NB L	0.47	63.5	E	2	4	0.86	103.3	F	5	9
Park Avenue NB T	0.96	84.0	F	20	27	0.91	72.0	E	17	24
Park Avenue NB T/R	0.96	84.6	F	19	26	0.91	73.3	E	16	23
Park Avenue SB L	0.91	114.7	F	6	10	1.17	194.7	F	9	15
Park Avenue SB T	0.59	48.0	D	9	13	1.41	247.2	F	42	63
Park Avenue SB T/R	0.59	48.4	D	8	13	1.41	251.1	F	40	60
Chandler Street EB L/T	1.08	116.0	F	24	34	0.81	60.1	E	14	20
Chandler Street EB T/R	0.98	88.3	F	20	28	0.74	54.7	D	12	17
Chandler Street WB L/T	0.76	57.5	E	11	17	1.12	135.0	F	25	35
Chandler Street WB T	0.69	53.4	D	10	15	1.02	102.0	F	22	30
Chandler Street WB R	0.24	43.8	D	2	4	0.21	43.2	D	2	4
OVERALL		**78.0**	**E**				**141.0**	**F**		
May Street										
Park Avenue NB L/T	0.59	12.1	B	5	9	0.79	44.4	D	2	3
Park Avenue NB T/R	0.63	12.8	B	5	9	1.03	55.4	F	20	28
Park Avenue SB L/T	0.36	9.7	A	2	3	0.97	57.6	E	7	12
Park Avenue SB T/R	0.38	10.0	A	3	5	1.13	90.2	F	30	41
May Street EB L	0.34	30.5	C	1	2	0.87	79.4	E	3	5
May Street EB T/R	0.87	36.3	D	9	14	0.85	33.6	C	8	13
May Street WB L/T	0.69	39.2	D	2	4	1.06	119.4	F	7	11
May Street WB T/R	0.79	28.9	C	6	10	1.10	93.4	F	17	25
OVERALL		**20.2**	**C**				**71.8**	**E**		
Downing Street										
Park Avenue NB T	0.49	5.3	A	2	3	0.42	4.9	A	2	2
Park Avenue NB T/R	0.49	5.4	A	2	3	0.42	4.9	A	2	2
Park Avenue SB L/T	0.25	4.4	A	1	2	0.60	6.3	A	3	5
Park Avenue SB T	0.26	4.4	A	1	1	0.64	6.2	A	2	4
Downing Street WB	0.04	14.9	B	0	0	0.34	16.2	B	1	2
OVERALL		**5.1**	**A**				**6.2**	**A**		
Maywood Street										
Park Avenue NB L/T	0.54	12.2	B	5	8	0.53	11.8	B	5	8
Park Avenue NB T/R	0.57	12.4	B	5	8	0.56	12.2	B	4	8
Park Avenue SB L/T	0.32	10.1	B	2	4	0.75	17.3	B	7	12
Park Avenue SB T/R	0.34	10.3	B	2	4	0.80	19.0	B	8	13
Maywood Street EB	0.26	14.4	B	2	3	0.23	14.2	B	1	2
Maywood Street WB	0.27	14.5	B	2	3	0.48	16.2	B	4	6
OVERALL		**12.1**	**B**				**15.5**	**B**		

1. 2030 traffic volumes estimated using 2013 traffic volumes and a 1% annual growth factor
2. v/c = volume-to-capacity ratio
3. D = delay in seconds per vehicle
4. 50th or 95th percentile queue in vehicle per lane

TABLE 23 – Build (2030)[1] Level of Service for Roadway Sections

	AM Peak					PM Peak				
Roadway Sections of Park Avenue	v/c[2]	S[3]	BFFS[4]	%[5]	LOS	v/c	S	BFFS	%	LOS
Chandler Street to May Street										
Northbound	0.61	26.1	39.4	66.4	C	1.02	13.6	39.4	34.4	F
Southbound	0.59	14.7	39.4	37.4	E	1.41	4.2	39.4	10.7	F
May Street to Downing Street										
Northbound	0.49	24.6	39.4	62.4	C	0.42	25.0	39.4	63.5	C
Southbound	0.37	20.9	39.4	53.1	C	1.09	5.9	39.4	14.9	F
Downing Street to Maywood Street										
Northbound	0.55	22.7	39.4	57.7	C	0.54	22.9	39.4	58.2	C
Southbound	0.25	29.3	39.4	74.3	B	0.62	27.0	39.4	68.5	B
OVERALL										
Northbound		**24.6**	**39.4**	**62.5**	**C**		**17.7**	**39.4**	**45.0**	**D**
Southbound		**19.0**	**39.4**	**48.3**	**D**		**6.3**	**39.4**	**16.1**	**F**

1. 2030 traffic volumes estimated using 2013 traffic volumes and a 1% annual growth factor
2. v/c = through volume-to-capacity ratio
3. S = travel speed in miles per hour
4. BFFS = base free-flow speed in miles per hour
5. % = percent of base free-flow speed

4.7 Conceptual Design

When applying the selected countermeasures and improvements to Park Avenue, the optimal countermeasures for each character area were considered. This was done to ensure the needs of each specific character area was met, as well as to ensure all recommendations would fit within the limited space of each segment. The first of these segments addressed was the Residential Zone, from Maywood Street to Downing Street. The cross section of this segment is shown in Figure 14. For this segment, parking was maintained on the southbound side of the roadway, as many of the residential buildings along this segment are on the southbound side of the road and do not offer off-street parking. This design also includes a shared bicycle-vehicle path and a five-foot bicycle lane. Further, this design incorporates vegetation within the four feet of sidewalk closest to the roadway. This design also incorporates through lanes at least ten feet wide. The plan view of this design is shown in Figure 15 and offers a to-scale view of the proposed roadway segment.

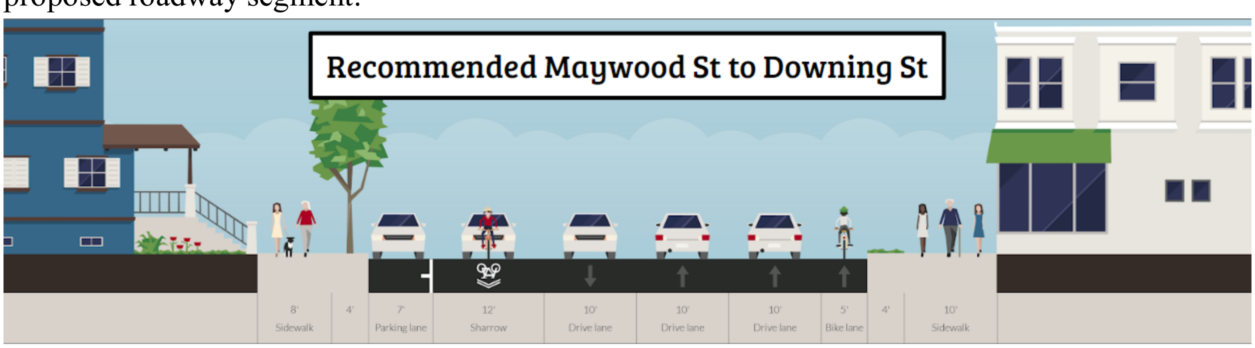

Figure 14: Proposed Maywood Street to Downing Street Cross Section looking north

Figure 15: Proposed Maywood Street to Downing Street Plan

The recommended changes to the segment of Park Avenue from Downing Street to May Street are shown in Figure 16 and 17. Figure 16 displays the roadway cross section, while Figure 17 is a plan view of the segment. Similar to the segment from Maywood St to Downing St, this segment incorporates more vegetation. However, for this segment, lanes were widened to eleven feet, and removing on-street parking provided space for northbound and southbound six-foot bike lanes. Since there are some businesses without off-street parking along this segment, an approach to mitigating the effects of removing on-street parking is discussed in section 5: Recommendations.

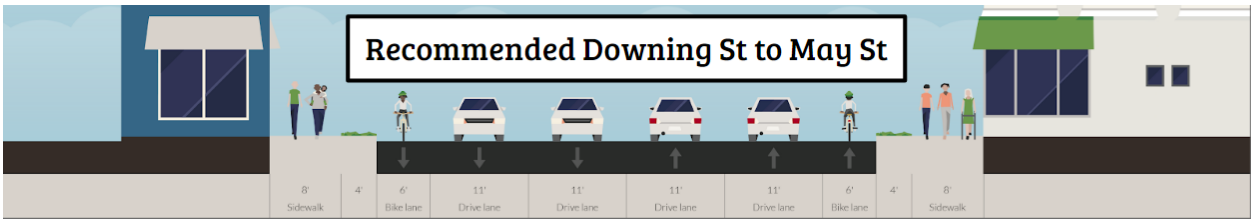

Figure 16: Proposed Downing Street to May Street Cross Section looking north

Figure 17: Proposed Downing Street to May Street Plan

Lastly, a design for the segment of Park Avenue between May Street and Chandler Street was created. The cross section for this segment is shown in Figure 18. This design is the same as that for the segment from Downing Street to May Street due to the similar pavement widths and land uses. A view of this design can also be seen in Figures 19 and 20. The plan view for this design was broken into two sheets due to the length of the segment.

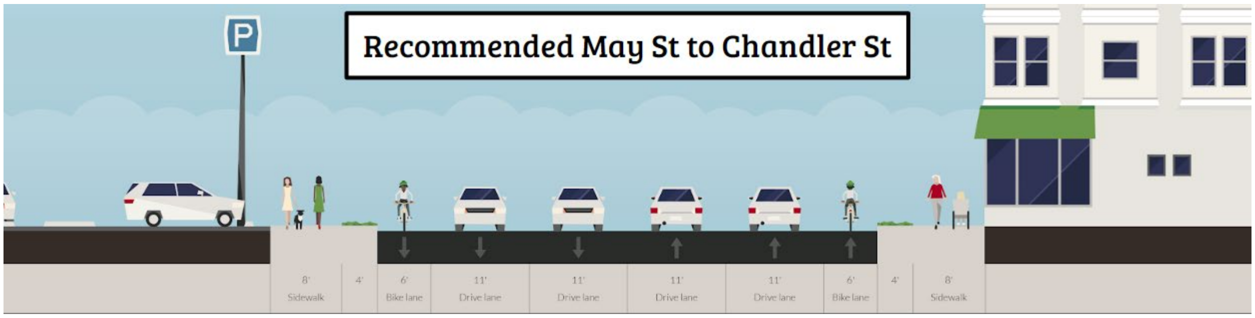

Figure 18: Proposed May Street to Chandler Street Cross Section looking north

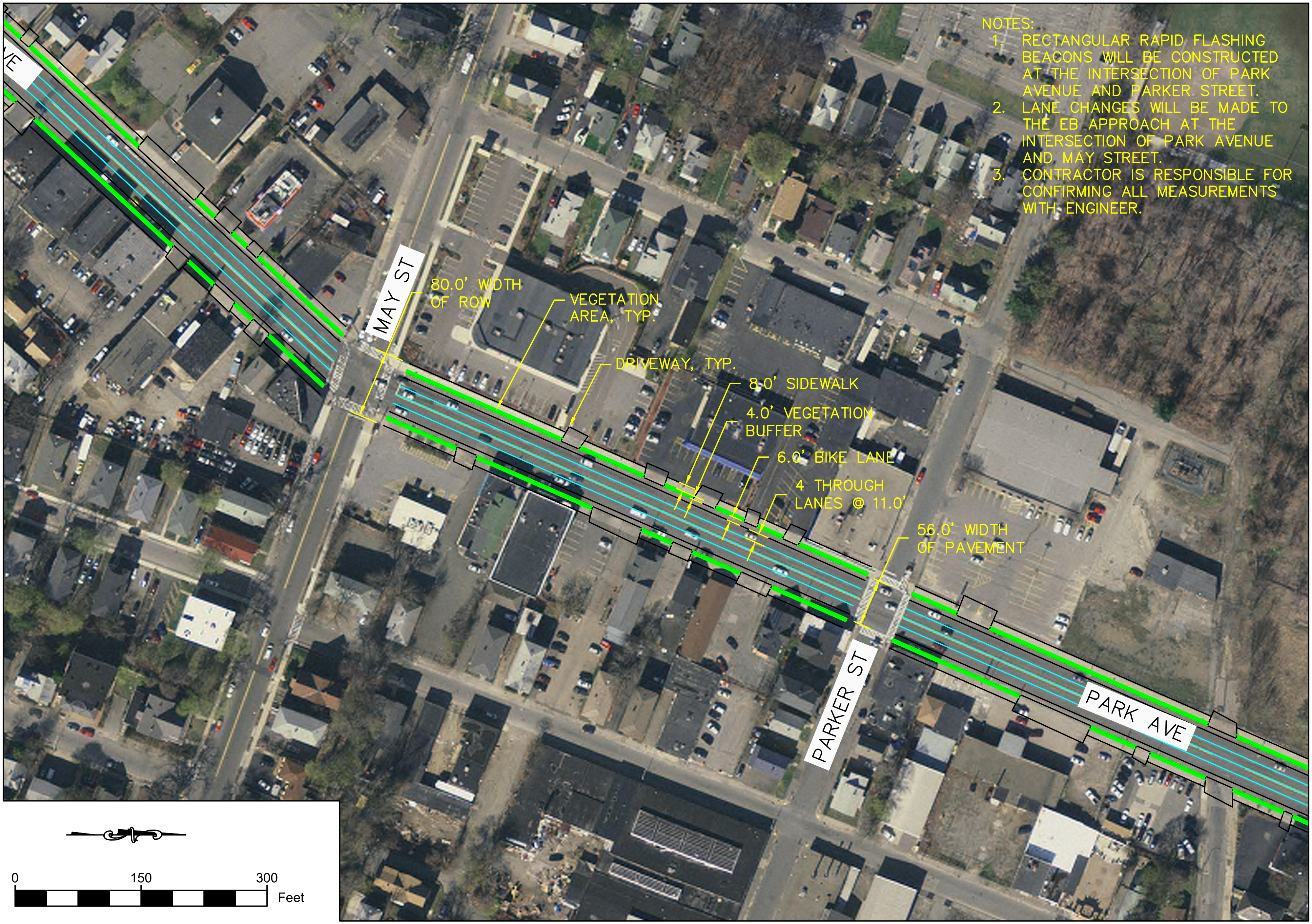

Figure 19: Proposed May Street to Parker Street Plan

Figure 20: Proposed Parker Street to Chandler Street Plan

5. Recommendations

Short-Term Improvements

The following improvements were recommended based on this project's goals of improving accessibility, appearance, safety, and efficiency while remaining affordable:

- Parking - Remove on-street parking along the northbound side for the entire section and along the southbound side from Downing Street to Chandler Street. On-street parking is necessary on the southbound side from Maywood Street to Downing Street due to residential buildings with minimal off-street parking.
- Bicycle Accommodations - Add a designated bicycle lane along the northbound side of the section with widths of six feet from Downing Street to Chandler Street, and five feet from Maywood Street to Downing Street. Add a six-foot bicycle lane along the southbound side of the section from Downing Street to Chandler Street. Add a twelve-foot shared vehicle and bicycle lane along the southbound side of the section from Maywood Street to Downing Street.
- Lane Widths - Widen drive lanes from an existing ten feet to eleven feet from Downing Street to Chandler Street. Widen drive lanes from an existing nine feet to ten feet from Maywood Street to Downing Street.
- Vegetation - Add four-foot vegetation buffers along the Northbound and Southbound sides of the section. These buffers will consist of either grass strips or street trees depending on the space constraints created by access points along the section.
- Pedestrian Accommodations - Add Rectangular Rapid Flashing Beacons at the crosswalk near the intersection of Park Avenue and Parker Street. These beacons will improve pedestrian safety when crossing four lanes of through traffic as well as two bicycle lanes.
- Lane Configuration - Redefine the lane configuration at the intersection of Park Avenue and May Street on the eastbound approach. Convert the right turn only lane to a through and right lane. Convert the through and left lane to a left turn only lane. This will improve the efficiency of the entire intersection especially that of the eastbound approach.
- Signage Improvements - Update and install signage along the section to indicate bicycle lanes, designated on-street parking areas, bus stops, and lane movements. This signage will improve driver awareness in regards to where they belong and what else is occurring on the road.

Future Considerations

Some improvements required more time to evaluate than could be completed within the given duration of this study. Therefore the team recommends that in the future, these considerations be investigated further:

- Data Collection - New Turning Movement Counts should be conducted for all of the signalized and unsignalized intersections. This new TMC data would improve the accuracy of the traffic volume counts as well as the crash rate calculations. Newly released crash data from MassDOT should be included in this study to improve the accuracy of all crash rate calculations. Ultimately more accurate counts and calculations would confirm the conclusions reached in this report. Finally, record plans for Park Avenue or other ROW and pavement width measurements should be collected for the purpose of a final design. This project relied on orthoimagery and Google Earth measurements to complete preliminary conceptual designs for the section.

- Signal Improvements - Signal Warrant Analysis should be conducted for certain signalized (Park Avenue and Downing Street) and unsignalized intersections (Park Avenue and Parker Street) to determine which intersections are in need of signalization. Along with this, coordinated signals should be examined as a potential improvement for the efficiency of the corridor. There is a significant amount of congestion that occurs just north of the intersection of Park Avenue and Chandler Street. This congestion is likely a result of small spacing between signalized intersections that are not coordinated and limit the high traffic volumes from moving. Coordinated signals at these intersections could possibly clear up some of this congestion.
- Public Parking Lot - During this project, it was identified that a parcel of land was for sale in the transition zone between Downing Street and May Street. This parcel has the potential to be purchased by the City of Worcester and converted into a public parking lot to offset the removal of on-street parking along this section.

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Appendix A: Project Proposal

Park Avenue Redesign:
Project Proposal

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December 14, 2018

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Capstone Design Statement

This project focuses on the Park Avenue corridor between Maywood Street and Chandler Street in Worcester, Massachusetts. This section of Park Avenue was flagged by the City of Worcester as in need of improvements. By redesigning this stretch of Park Avenue, this team not only satisfies the needs of the City, but also meets the requirement of students completing a Major Qualify Project (MQP) with a capstone design element prior to graduation. These requirements are set forth by Worcester Polytechnic Institute (WPI) to fulfill the criteria for Accrediting Engineering Programs by the Accreditation Board for Engineering and Technology (ABET). The ABET has provided a series of student outcomes for accredited programs and Outcome C of the 2018-2019 Criteria states that graduates have "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" (ABET, 2017). The following examines the eight constraints related to this project:

- Economic: Most public transportation projects receive funding from multiple levels of government (local, state, and federal). For the City of Worcester and Stantec to implement any of the recommended improvements, this project will research potential funding options. It will also look into the benefits and costs of each improvement option.
- Environmental: This project will consider the environmental impact of all improvement concepts and look to mitigate these impacts. In cases where possible, this project will aim to improve the environmental conditions along this corridor by adding vegetation and reducing impermeable surfaces.
- Social and Political: This team will become familiar with regulation and community objectives at the city and state level. The final recommendations of this team will be in compliance with such regulations and take the needs of stakeholders into consideration. Chiefly, this team will address the needs of Park Avenue users by promoting the safe and efficient utilization of Park Avenue by all modes of transportation and users no matter their socio-economic status.
- Ethical: The projects aims to abide by the ASCE Code of Ethics for all civil engineers so as not to damage the reputation of WPI or Stantec.
- Health and Safety: The project will aim to address safety by focusing on the improvement of dangerous intersections and stretches of roads with high crash rates and poor traffic designs.
- Constructability: The team will determine the most effective improvement options by examining the overall cost of the improvement, the time required to implement it, and the space required for the improvement.
- Sustainability: Long-term improvement concepts will be presented by this project that will aim to improve present and future needs for the corridor. The final design and recommendation will account for future traffic demands and population growth to provide sustainable improvements.

1. Introduction

Park Avenue is a heavily trafficked road that runs through the center of Worcester, MA. Comprised of four lanes of two-way traffic and occasional turning lanes, Park Avenue is designed with preference to through traffic with sidewalks, bus stops, and stretches of on-street parking. Additionally, Park Avenue is lined with businesses and apartments, resulting in traffic from vehicles, bicycles, pedestrians, and transit. Although Park Avenue is utilized by a diverse group of users, the current safety conditions suggest that it is ineffective at serving all of these populations. This is evident due to the fact that four intersections along this stretch of road were identified by the Massachusetts Department of Transportation (MassDOT) as hazardous based on the number of collisions (Top Crash Locations 2016).

This project proposal focuses specifically on the section of Park Avenue from Maywood Street to Chandler Street, presented in Figure 1. This section has been identified by the City of Worcester as an area in need of improvements (F. Moseley, email communication, November 20, 2018). This team has chosen to focus on the issues of safety, efficiency, accessibility, and appearance.

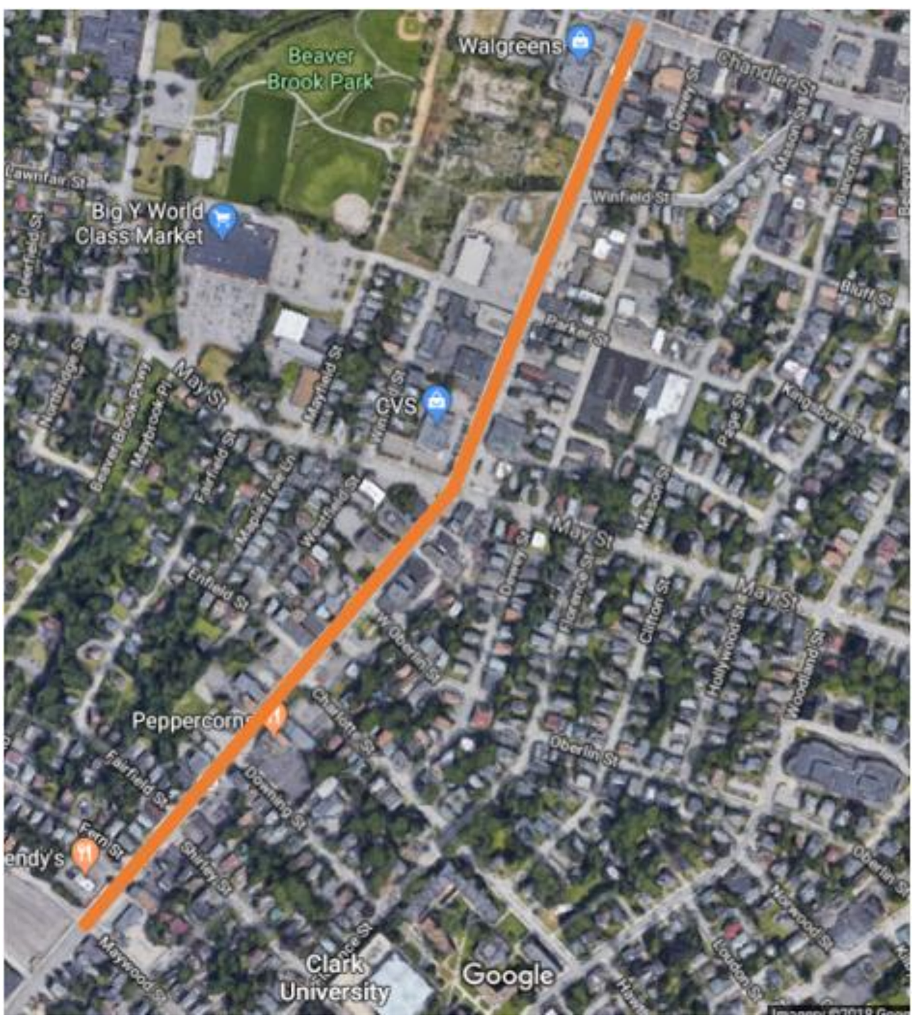

Figure 1: Project Map, Park Avenue from Maywood to Chandler Street (Google Maps)

The stretch from Maywood Street to Chandler Street aims to accommodate pedestrians, parking, bicyclists, and through traffic. This team's observations suggest the current layout of this section of road presents numerous safety concerns for all users. For example, this portion of Park Avenue has little to no parking signage. As a result, cars are often parked over curbs and travel lanes. This lack of clear signage is dangerous to traveling vehicles as well as pedestrians accessing these parked vehicles. Similarly, there is an absence of clearly designated areas for buses to pull over on Park Avenue. This, combined with the dangerous on-street parking, limits mobility for larger vehicles, such as buses, and often results in slowed or stopped traffic. Another example is traffic slow-downs due to left turns at intersections without left turn lanes. The lack of left turn lanes on Park Avenue greatly contributes to the backups and delays during peak travel times. Without such lanes, through traffic is required to merge into the right lane, if it is not hindered by the presence of a bus or illegally parked vehicle.

In addition to safety concerns, the current layout of Park Avenue does not align with the surrounding land use. The section of Park Avenue from Maywood Street to Chandler Street in particular lacks vegetation and pedestrian-vehicle buffers; traits which help a busy street, like Park Avenue, better align with surrounding residential communities. A more welcoming Park Avenue could mean increased business for the companies lining Park Avenue as well as a more engaged community.

Considering these problems, the vision of this project is to develop an improvement concept for Park Avenue between Chandler Street and Maywood Street. The desired outcomes are to achieve eligibility for MassDOT and Massachusetts Complete Street Program funding, improve vehicular and pedestrian safety, improve access to public transportation, improve efficiency of the roadway, and increase vegetation. To achieve the vision of this project, the team has identified a list of objectives that include:

- Research and compile existing conditions, traffic and safety data, MassDOT and City of Worcester regulations for transportation projects, and case studies of similar projects
- Analyze data to identify problems with the corridor
- Determine potential improvement concepts and countermeasures
- Assess the improvement concepts and countermeasures
- Recommend the most efficient improvement concepts and countermeasures based on the previous analyses
- Develop a final design for the corridor that incorporates the recommended improvements
- Finalize a written report and presentation

2. Background

Stantec's involvement in this project began with an evaluation of signal timing at intersections across the City of Worcester. In the past decade, Stantec was tasked with this evaluation in order to determine the potential for signal improvements. During this time, MassDOT requested that Stantec also prepare a cost estimate for upgrades along Park Avenue from Gold Star Boulevard to Stafford/Main Street. Based on Stantec's cost estimate and MassDOT's Transportation Improvement Program (TIP) budget, it was determined that improvements along Park Avenue would need to be broken down into smaller projects. As is stated prior, the focus of this project is updating the portion of Park Avenue from Maywood Street to Chandler Street. However, before one can identify an improvement approach, it is important to acknowledge the history and existing conditions of the area.

2.1 History

Originally named Newton Street, Park Avenue was built between 1861 and 1874, but only traveled as far north as Elm Park. By 1891, Park Avenue stretched through the park to where it intersects with Grove Street as it does today. The road quickly became a busy thoroughfare whose primary users were motorists. According to a local historian, "it likely became even busier after 1933 when it was designated part of the state Route 9, which runs the length of Massachusetts from Boston to the Berkshires" (McKeon, 2018).

In 1878, the section of Park Avenue between May Street and Chandler Street was more developed than the section between Maywood Street and May Street. For example, most lots didn't have any structures built and the entire West side of the southern section had not been divided into lots yet. The few structures that did exist were predominantly residential. By 1919, Park Avenue experienced a high volume of developments with a mix of commercial and residential uses.

Park Avenue from Maywood Street to Chandler Street is under the jurisdiction of the City of Worcester. As such, any modifications to this section of road must be in compliance with the City of Worcester planning goals. Worcester is currently in the process of developing a master plan. Until that document becomes available, Worcester's goals for development can be derived from their Complete Streets Policy (City of Worcester Complete Streets Policy, 2017).

The term, "Complete Street" is a designation given to a street that serves all users no matter age, ability, or mode of transportation. The following factors drive the design of a complete street: number and types of users, available right of way, safety amenities, community needs, parking needs, utilities, public transit, and historic or sensitive land uses (Rabito, n.d.). Complete Streets are a strategy being utilized by urban planners to improve city streets to address issues of safety, congestion, multimodal transportation options, and greenhouse gas emissions (Rabito, n.d.).

2.2 Funding

The majority of transportation projects are funded with a combination of multiple levels of funding, from local, state, and federal sources. According to the Central Massachusetts Regional Planning Commission (CMPRC), Park Avenue is a Federal Aid eligible road (Federal Aid Eligible Road System, 2006). There are several key federal highway programs that provide funding for transportation improvement projects in Massachusetts: the Federal Highway Administration (FHWA), National Highway Performance Program (NHPP), Highway Safety Improvement Program (HSIP), Transportation Alternatives Program (TAP), Transportation Improvements Program (TIP), etc. Most federal funding that is issued through theses programs is matched at the state and local levels (Funding Considerations, n.d.). The State TIP for Massachusetts is a list of projects that will occur within the next four consecutive years of roadway construction. The Office of Transportation Planning prepares this list yearly (State Transportation Improvement Program, n.d.).

For a project to be eligible for funding from MassDOT or the Massachusetts Complete Street Program, it must meet requirements set by the State of Massachusetts. MassDOT requires a series of forms to be completed to receive State and Federal aid. The first form is the Project Need Form (PNF), which collects preliminary information about the proposed project. Next, the Project Initiation Form (PIF) would be completed providing general information, project costs and responsibilities, and the project description. Once these forms are accepted the MassDOT will decide on sources of finding and possible TIP year.

Designs incorporating Complete Streets only have special funding at the state level, since there is no federal legislation regarding Complete Streets. The Massachusetts 2014 Transportation Bond Bill allows MassDOT to allocate $12.5 million for the first two years (2016-2018) of their Complete Streets Funding Program (Complete Streets Funding Program Guidance, 2016). The program requires each municipality to register, undergo training, send a letter of intent, submit a Complete Street policy, and create a priority list of potential projects. The City of Worcester's Complete Street Policy was accepted by MassDOT in February 2018. The city is currently completing a priority list. The project must be in accordance with the City of Worcester's Complete Street Policy in order to receive aid from the Massachusetts Complete Street Program.

2.3 Existing Conditions

The current design of Park Avenue from Maywood Street to Chandler Street seems to serve the through traffic, rather than the entire population that use this section of road. Park Avenue can be accessed by vehicles through one of the numerous crossroads, few of which have traffic signals. Bicyclists and pedestrians also have access to Park Avenue via sidewalks, which line the street on both sides. Bus stops also line the section from Maywood Street to May Street, but are not always accessible due to poorly parked vehicles. In the Fall of 2018, the City of Worcester carried out routine improvements to Park Avenue (Moosey 2018). While these improvements ensure that Park Avenue remains functional, they do not aim to restructure the flow of traffic or alter accessibility for users.

2.3.1 Intersection of Park Avenue and Maywood Street

The intersection of Park Avenue and Maywood Street was identified as one of the top 200 locations for vehicle collisions in Massachusetts by the MassDOT (Top Crash Locations 2016). The intersection consists of four lanes of two-way traffic on Park Avenue and two lanes of two way traffic on Maywood Street, depicted in Figure 2. This intersection is managed by a traffic signal.

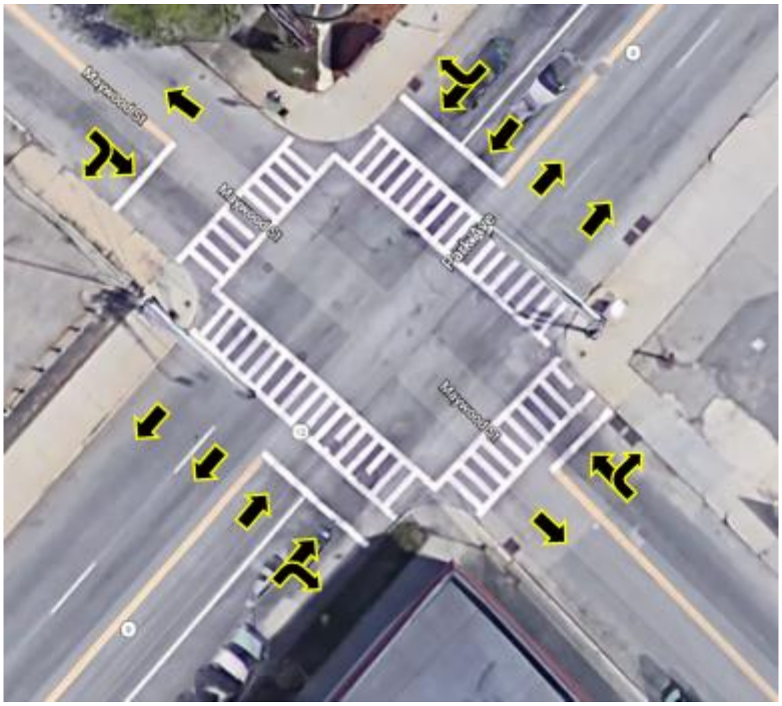

Figure 2: Park Avenue and Maywood Street Intersection (Google Earth)

2.3.2 Maywood Street to Downing Street

The stretch of Park Avenue from Maywood Street to Downing Street has four lanes of through traffic and lies between two signalized intersections. The lane widths appear to be 10-11 feet according to the measure tool provided on Google Earth. There are three other intersections within this section including Fern Street on the southbound side, Shirley Street on the northbound side, and Fairfield Street on the southbound side. The majority of this roadway is lined with residential buildings as well as the occasional commercial building , see Figure 3. Significant commercial buildings that provide large parking lots adjacent to the sidewalk include Wendy’s, Olsi Auto Sale and Service, and Western Union. Along with the parking lots, on-street parking is permitted for vehicles north of the intersection of Park Avenue and Fern Street. The majority of these vehicles are likely owned by local residents who do not have driveways. A few bus stops are scattered in the northbound and southbound directions. There are no bike lanes present and bicyclists are expected to share the road with motorists.

Figure 3: Photo of Park Avenue north of Maywood Street looking north (Colin Claus 11/7/18)

2.3.3 Intersection of Park Avenue and Downing Street

The intersection of Park Avenue and Downing Street consists of four lanes of two-way traffic on Park Avenue and two lanes of two-way traffic on Downing Street, which terminate at the intersection, see Figure 4. This intersection is managed by a traffic signal.

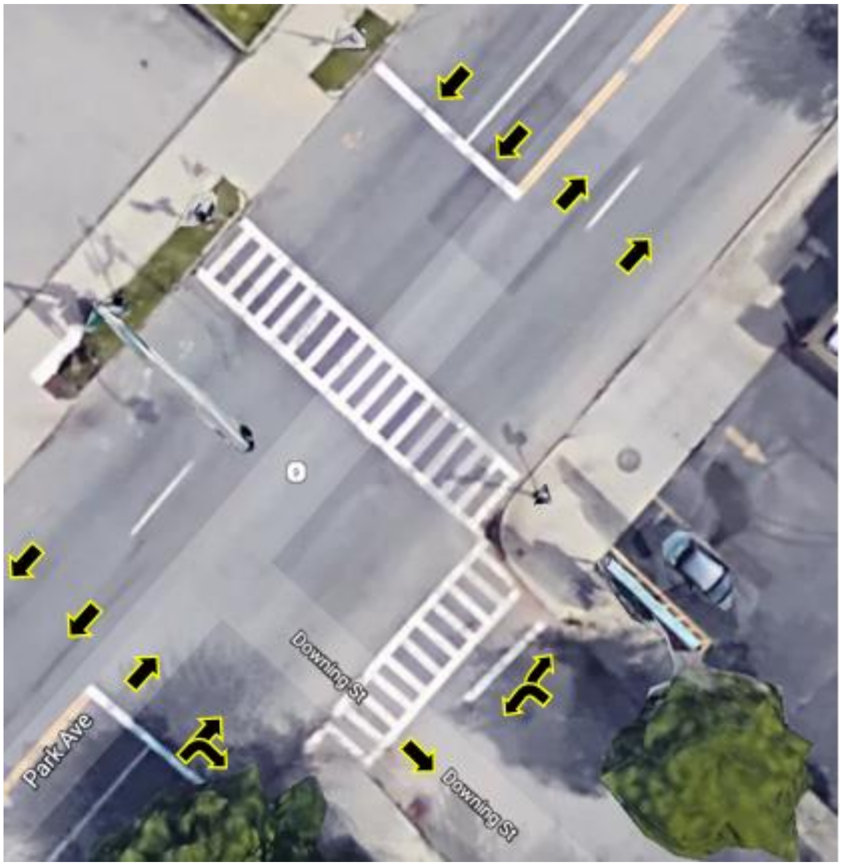

Figure 4: Park Avenue and Downing Street Intersection (Google Earth)

2.3.4 Downing Street to May Street

Park Avenue from Maywood Street to Downing Street is bounded by two signalized intersections. There are four lanes of traffic with widths of 10-11 feet according to the measure tool provided on Google Earth. As Park Avenue approaches the intersection with May Street there is no change in lane structure. Park Avenue is intersected by three other streets along this section including Charlotte Street on the northbound side, Enfield Street on the southbound side, and West Oberlin Street on the northbound side. There is a large amount of commercial buildings on this section of Park Avenue. The amount of residential buildings decrease as the street approaches the intersection with May Street. There is on-street parking in the northbound and southbound directions throughout this entire section of Park Avenue. On-street parking is seldom used since there are multiple parking lots owned by commercial buildings. On-street parking becomes an issue near the intersection with May Street where vehicles line the northbound side of the street in this area. There are bus stops along this stretch in the northbound and southbound directions. There are no bike lanes present and cyclists are expected to share the road with motorists.

2.3.5 Intersection of Park Avenue and May Street

The intersection of Park Avenue and May Street was identified as one of the top 200 locations for vehicle collisions in Massachusetts by the MassDOT. The intersection consists of four lanes of two-way traffic on Park Avenue and three lanes of two way traffic on May Street east of the intersection and four lanes of traffic west of the intersection. On the eastern side of the intersection, May Street has an eastbound lane, a westbound lane, and a combined westbound and right turn lane. On the western side of this intersection, May Street has two westbound lanes, one right turn lane, and one eastbound lane, see Figure 5. This intersection is managed by a traffic signal.

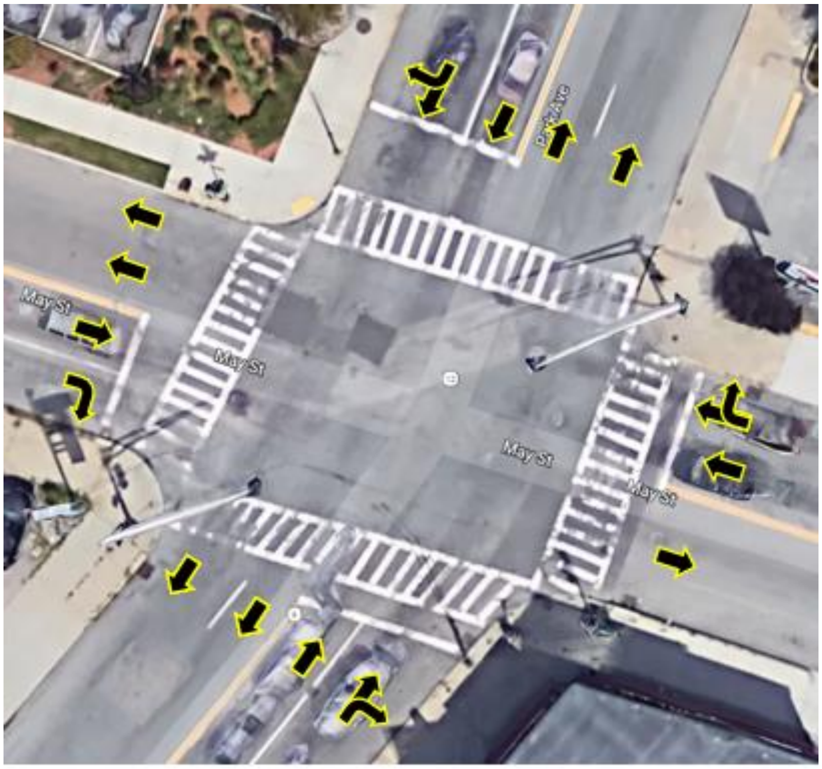

Figure 5: Park Avenue and May Street Intersection (Google Earth)

2.3.6 May Street to Chandler Street

Park Avenue from Maywood Street to Downing Street lies between two signalized intersections and has four lanes of through traffic with widths of 10-11 feet according to the measure tool provided on Google Earth. There is a large area of street pavement in this section, as depicted in Figure 6. As Park Avenue approaches the intersection with Chandler Street, a left-turn only lane is present for northbound traffic. Park Avenue is intersected by two streets in this section including Parker Street in both the southbound and northbound directions and Winfield Street in the northbound direction. Commercial buildings occupy a large portion of this section of Park Avenue. There are a few residential buildings as well. On-street parking is available from May Street to Parker Street. After this intersection, minimal on-street parking has been observed by this group. There are no bus stops along this section of Park Avenue. There are no bike lanes present on this stretch of roadway and bicyclists are expected to share the road with motorists.

Figure 6: Photo of Park Avenue north of May Street looking north (Colin Claus 11/7/18)

2.3.7 Intersection of Park Avenue and Chandler Street

The intersection of Park Avenue and Chandler Street was classified by the Highway Safety Improvement Program (HSIP) as a top location where vehicle-vehicle and vehicle-bicycle collisions occur (Top Crash Locations 2016). The intersection consists of five lanes of two-way traffic on Park Avenue, two northbound lanes, two southbound lanes and one left turn lane, and five lanes of two way traffic on Chandler Street east of the intersection and four lanes of traffic west of the intersection. On the eastern side of the intersection, Chandler Street has two eastbound lanes, a westbound lane, a right turning lane, and a combined westbound and left turn lane. On the western side of this intersection, Chandler street has two westbound lanes and two eastbound lanes. For clarification, see Figure 7. This intersection is managed by a traffic signal with arrows depicting when turns can occur off of Park Avenue and standard red-yellow-green signals on Chandler Street.

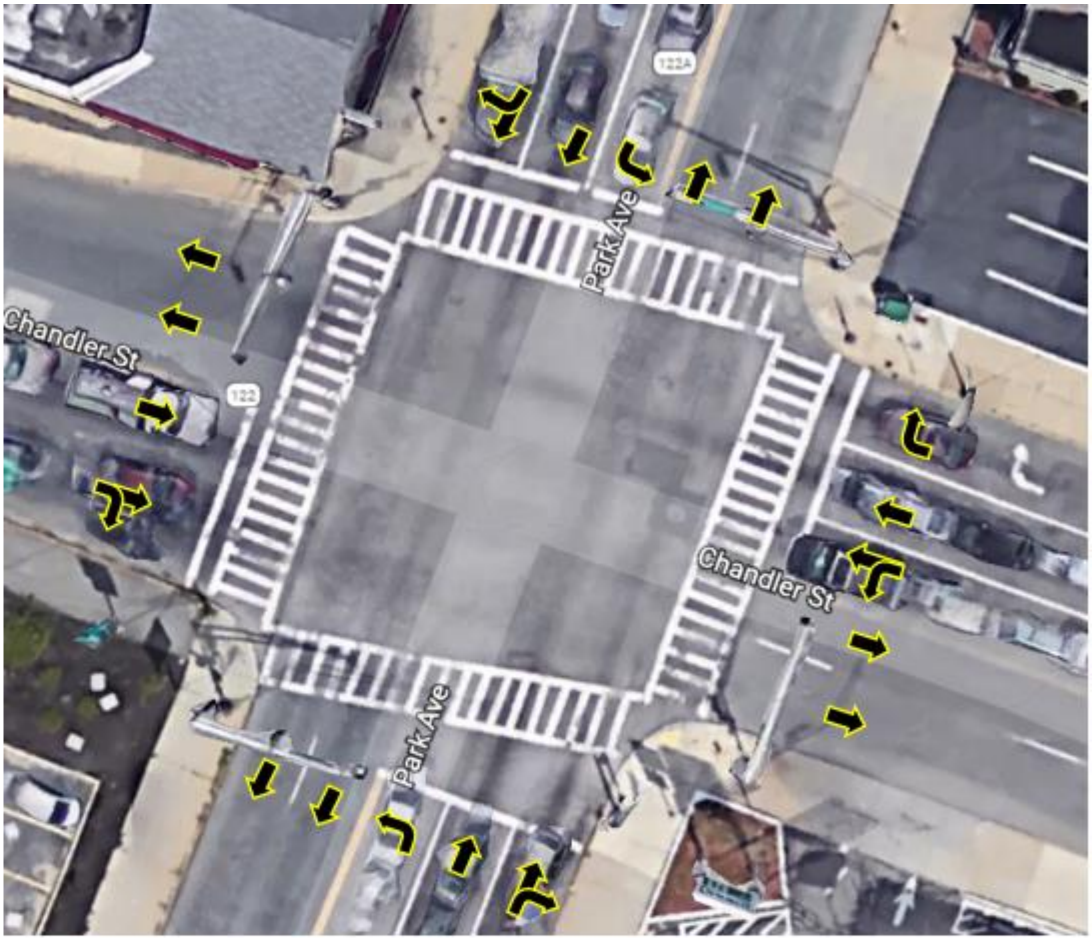

Figure 7: Park Avenue and Chandler Street Intersection (Google Earth)

3. Methodology

The vision of this project is to develop an improvement concept for Park Avenue between Chandler Street and Maywood Street. The desired outcomes are to achieve eligibility for MassDOT and Massachusetts Complete Street Program funding, improve vehicular and pedestrian safety, improve access to public transportation, improve efficiency of the roadway, and increase vegetation.Within this section are methods that aim to achieve these outcomes. These methods primarily consist of evaluating the site's existing conditions, compiling case studies to identify potential improvement concepts, and conducting appropriate analyses to determine a final recommendation. Specific details regarding the methodology of each desired outcome are expanded upon further in this section.

3.1 Safety Improvements

The team will examine crash data for the section of Park Avenue from Chandler Street to Maywood Street. The data will be retrieved from local police, the State Registry of Motor Vehicle, MassDOT, or the National Highway Traffic Safety Authority (NHTSA). It will be important to consider the crash data at intersections as well as for the sections of road between them. The data will be examined and categorized into two tables: one table will depict the severity of crashes while the other will address the amount and type of accidents per year, see Tables 1 and 2.

Table 1: Crash Severity

Year	Fatal	Personal Injury	Property Damage	Total
Average/yr				

Table 2: Crash Types

Year	Rear-end	Head-on	Fixed Object	Etc.	Total
Average/yr					

Data from the turning movement counts conducted in 2013 by Stantec (F. Moseley, email communication, November 27, 2018), along with this information will be used to calculate the average crash rate for each analysis section. The average crash rate will be compared to the statewide average, as well as the average for District 3 where Park Avenue is located. These values are 0.78 and 0.89 respectively for signalized intersections. Average crash rate is measured in number of crashes per million vehicle miles traveled for roadways, and number of crashes per million vehicles for intersections. The average crash rate values for statewide urban roads and urban principal arterials are 2.27 and 3.49, respectively (Intersection and roadway, n.d.).

With this information, countermeasures for the prevalent crash types can be selected. These countermeasures will aim to lower the average crash rate with a Crash Reduction Factor (CRF). The CRF determines the effectiveness of the countermeasures and is used when calculating the amount of money the countermeasure will save when implemented. CRFs for various countermeasures can be searched through a website called the CMF clearinghouse (Crash Modification Factors Clearinghouse, n.d.). The next step will be to calculate the ADT growth from the crash data and turning movement counts for present day and the future. This is an important factor in determining the overall savings for the countermeasures. Also, the amount of money being spent at the intersection or roadway yearly due to the amount of crashes will be determined based on the data provided in the Severity of Crashes table. The amount of crashes of each category that occur yearly will be utilized to calculate the amount of money that each roadway or intersection costs.

Implementing a countermeasure is not free, therefore various cost estimating websites will be consulted for the cost for implementing each countermeasure. A benefit-cost analysis will be conducted with values greater than 1.0 being options that are worth implementing for the roadway or intersection. A do nothing option will be proposed in the case that the benefit-cost ratios are not favorable enough for implementation. Combinations of countermeasures will be analyzed to determine whether they would potentially be more effective than single countermeasures. All of the data will be presented in a table to show each countermeasures' effectiveness, see Table 3.

Table 3: Analysis of Countermeasures

Countermeasure	**Cost of crashes ($)**	**CRF**	**ADT Growth**	**Savings ($) / Benefit**	**Cost of counter-measure**	**B/C Ratio**	**Is counter-measure worth it?**
Do Nothing							

3.2 Efficiency

The Level of Service (LOS) for a roadway or intersection determines the efficiency of the traffic flow. Efficiency for intersections and roadways is determined with different factors and calculations. Initial LOS calculations will be conducted for the existing conditions of Park Avenue in accordance with the *Highway Capacity Manual* (HCM 2010, 2010). LOS will be analyzed for each of the four major intersections as well as for the stretches of road in between them. A grade of A through F is calculated for each analysis section.

3.2.1 Roadways

LOS for a roadway is (an evaluation of the capability of a section to carry traffic). The type of roadway and its geometry play an important role in the methods for calculating the LOS for that roadway. Park Avenue is classified as a Class III Two-Lane Highway for the purposes of LOS calculations (HCM 2010, 2010). The LOS for Park Avenue will be determined based on the Percent of Free Flow Speed (PFFS). LOS also depends on the volume of traffic, travel speed, and entering and exiting traffic.

3.2.2 Intersections

LOS for intersections is determined by the average control delay at the intersection. Control delay is measured in seconds per vehicle. Delay can be examined by approach or incorporating data from the entire intersection. Turning movement counts and signal timing counts are essential for this analysis. Stantec has provided this data for the four major intersections of Park Avenue and Chandler Street, May Street, Downing Street, and Maywood Street.

3.2.3 LOS Software

There are various software used for LOS calculations. This team will use whichever of these software is commonly used for similar projects to calculate the LOS for both intersections and road sections. The software provides different functions for each of these analyses. Hand calculations for certain values will be necessary when utilizing this software. The data for the LOS calculations will be formatted into a table for each intersection and approach, as well as for each section of road between them.

3.2.4 Solutions

The team will use LOS software to evaluate solutions to improve intersection and roadway LOS values. Possible solution categories for intersections would include the geometry of the intersection and signal timing. Solution categories for roadway sections will include speed limit, geometry of the road, and traffic controls. A benefit-cost analysis will be conducted to compare the worth of each solution against one another.

3.3 Public Transportation Access

In order to effectively improve access to public transportation, this team will expand upon their preliminary research on the Worcester Regional Transit Authority's (WRTA) service within the project area. This research will include: evaluating current site conditions and their limitations to buses and bus riders, cases elsewhere in the city with greater access to public transportation, and the costs of potential accessibility improvement methods.

Further, this team will utilize the information gathered to compare the costs and benefits of pursuing different improvement methods. This analysis will serve as this team's method for identifying the most effective improvement option regarding public transportation on Park Avenue.

3.4 Vegetation

Increasing vegetation along Park Avenue is a desired outcome for this project. In order to achieve this goal, and maximize the benefits of increased vegetation, this team will evaluate the site's existing conditions, research cases in which similar updates have been made, and compile cost estimates for this type of improvement.

An initial evaluation of the section of Park Avenue from Maywood Street to Chandler Street was carried out by this team. This evaluation provided valuable insight into the existing vegetation along this stretch of road. Moving forward, this team will utilize their preliminary assessment to critically evaluate spatial constraints and their impact on reaching this goal.

In addition to the information gained from the site itself, it is also important to research like projects and their results. As such, this team will investigate case studies on projects that similarly identified increasing vegetation as a goal. Further, cost estimates for this type of work will be sought from either these studies or other available sources such as the MassDOT or Stantec. Potential benefits of adding vegetation, such as increasing pedestrian-vehicle buffers and creating a more welcoming environment for users, will also be explored. Provided this information, the team will execute a benefit-cost analysis in order to determine the most effective approach to increasing vegetation on Park Avenue.

3.5 Conceptual Design

In order to communicate our recommended improvement concept, this team will utilize AutoDesk Civil 3D. Since this is a preliminary design concept, aerial images and available Massachusetts GIS data will be used to establish street layouts. This concept will be presented as part of this team's recommendation along with a complete explanation of the suggested improvements for Park Avenue.

3.6 Project Schedule

This team utilized a Gantt chart template in Microsoft Excel to create a schedule for the upcoming tasks (See the Project Schedule in Figure 8). The schedule is broken up into four categories: Research and Development, Analysis and Preliminary Design, Final Design and

Recommendation, and Finalization of Deliverables. Under each of these categories is a series of tasks that this team has identified using this project's methods and expected deliverables. The duration of each task was estimated based on this team's current understanding. This team believes that the Project Schedule is a realistic, but is also flexible for any unforeseen problems.

Park Avenue Redesign

Stantec

Project Start: 1/9/2019

Display Week: 1

TASK		PROGRESS	START	END
Research and Development				
Task 1	Document existing conditions		1/9/19	1/18/19
Task 2	Compile case studies		1/9/19	1/18/19
Task 3	Calculate average crash rate for roadways and intersections		1/14/19	1/22/19
Task 4	Calculate level of service for roads and intersections		1/14/19	1/22/19
Analysis and Preliminary Design				
Task 1	Compare Average Crash Rate with statewide and District 3 and identify countermeasures		1/22/19	1/29/19
Task 2	Compare LOS calculations with statewide average and identify improvements		1/22/19	1/29/19
Task 3	Conduct benefit cost analysis		1/29/19	2/6/19
Task 4	Assess options for improving access to public transportation		2/6/19	2/13/19
Task 5	Assess options for increasing vegetation		2/6/19	2/13/19
Final Design and Recommendations				
Task 1	Create conceptual design		2/13/19	2/20/19
Task 2	Formulate reccommendations		2/13/19	2/20/19
Finalization of Deliverables				
Task 2	Create presentation to Stantec		2/20/19	3/1/19
Task 3	Write MQP Report		1/28/19	3/1/19

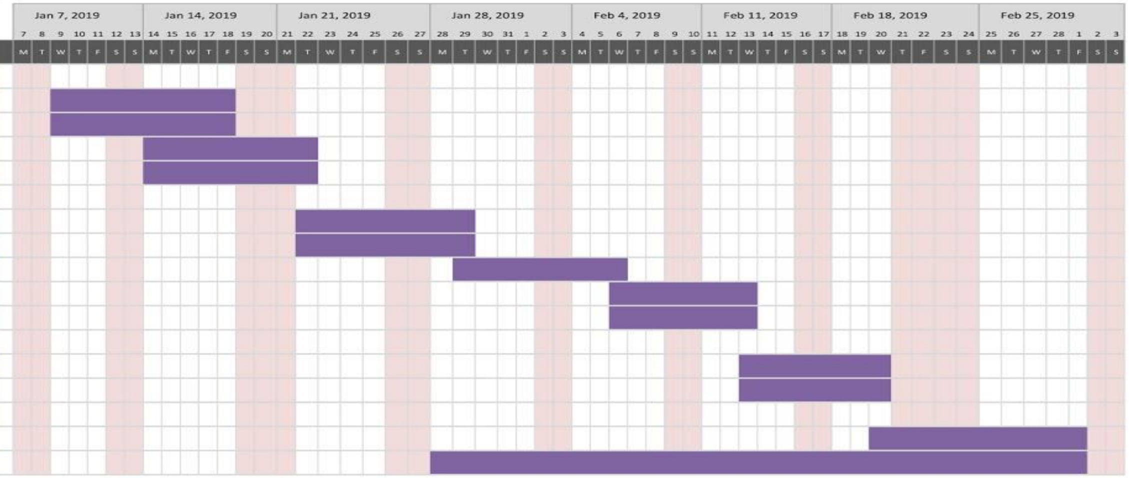

Figure 8: Gantt Chart of Project Schedule

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Appendix B: Crash Areas

Maywood Street to Chandler Street, Project Section

Intersection of Park Avenue and Chandler Street

Chandler Street to May Street

ParkXMay:

May_Downing:
Segment length = 0.22 mi

ParkXDowning:

Downing_Maywood:
Segment length = 0.14 mi

ParkXMaywood:

Appendix C: Turning Movement Counts

File Name: C:\Users\Steve\Documents\2013\PETRA\Worcester, MA\FST\QW-027\QW027006.ppd
Start Date: 9/25/2013
Start Time: 7:00:00 AM
Site Code: QW027006
Comment 1: N/S Street : Park Avenue
Comment 2: E/W Street: Chandler Street
Comment 3: City/State : Worcester, MA
Comment 4: Weather : Clear

	Park Ave From North				Chandler St From East				Park Ave From South				Chandler St From West				
Start Time	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Total
07:00 AM	88	327	68		89	309	61		34	648	57		172	567	25		2445
07:15 AM	88	330	68		111	381	66		47	641	55		147	565	27		2526
07:30 AM	94	334	82		110	393	78		49	588	51		148	543	28		2498
07:45 AM	117	337	82		116	394	78		62	569	59		148	526	27		2515
08:00 AM	111	381	93		112	348	72		79	540	73		145	514	32		2500
PHF	0.69	0.88	0.71		0.86	0.76	0.72		0.68	0.88	0.64		0.93	0.86	0.70		
Heavy	0%	4%	2%		3%	5%	6%		6%	2%	14%		2%	1%	4%		
Adj. parking			N				N				N				N		
04:00 PM	116	662	83		206	492	83		80	518	104		111	367	62		2884
04:15 PM	105	653	91		200	514	76		79	511	115		133	390	50		2917
04:30 PM	93	653	77		200	545	67		83	512	108		142	386	47		2913
04:45 PM	86	659	86		210	522	57		85	553	95		150	361	45		2909
05:00 PM	75	658	97		202	501	58		76	528	95		140	358	49		2837
PHF	0.74	0.98	0.69		0.89	0.89	0.75		0.97	0.86	0.82		0.77	0.82	0.70		
Heavy	1%	1%	1%		0%	1%	0%		0%	1%	1%		1%	1%	0%		
Adj. parking			N				N				N				N		

File Name: C:\Users\Steve\Documents\2013\PETRA\Worcester, MA\FST\QW-027\QW027007.ppd
Start Date: 9/25/2013
Start Time: 7:00:00 AM
Site Code: QW027007
Comment 1: N/S Street : Park Avenue
Comment 2: E/W Street: May Street
Comment 3: City/State : Worcester, MA
Comment 4: Weather : Clear

	Park Ave From North				May St From East				Park Ave From South				May St From West				
Start Time	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Total
07:00 AM	34	299	52		44	200	69		60	805	106		54	244	85		2052
07:15 AM	36	314	59		68	238	75		69	854	115		55	258	99		2240
07:30 AM	36	342	59		76	249	81		69	819	136		56	268	108		2299
07:45 AM	48	360	53		78	246	80		61	791	130		58	271	109		2285
08:00 AM	55	391	56		84	210	76		47	714	116		57	257	104		2167
PHF	0.75	0.86	0.87		0.70	0.78	0.88		0.72	0.92	0.89		0.70	0.88	0.87		
Heavy	0%	4%	0%		7%	1%	2%		4%	2%	2%		9%	1%	3%		
Adj. parking			N				N				N				N		
04:00 PM	52	747	51		149	289	77		55	571	112		86	206	106		2501
04:15 PM	54	752	55		145	310	86		61	579	112		85	213	128		2580
04:30 PM	53	732	62		135	324	99		57	590	112		82	222	145		2613
04:45 PM	46	720	63		130	342	96		54	584	106		78	215	143		2577
05:00 PM	44	742	71		132	346	93		52	584	123		74	204	149		2614
PHF	0.88	0.93	0.83		0.86	0.89	0.77		0.79	0.91	0.95		0.85	0.87	0.83		
Heavy	0%	0%	0%		2%	0%	0%		0%	1%	2%		1%	0%	2%		
Adj. parking			N				N				N				N		

File Name: C:\Users\Steve\Documents\2013\PETRA\Worcester, MA\FST\QW-027\qw027008.ppd
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Start Time: 7:00:00 AM
Site Code: QW027008
Comment 1: N/S Street : Park Avenue
Comment 2: E/W Street: Downing Street
Comment 3: City/State : Worcester, MA
Comment 4: Weather : Clear

	Park Ave From North			Downing St From East			Park Ave From South			
Start Time	Left	Thru	Peds	Left	Right	Peds	Thru	Right	Peds	Total
07:00 AM	13	391		3	5		1013	9		1434
07:15 AM	15	435		5	5		1091	11		1562
07:30 AM	15	462		4	6		1070	12		1569
07:45 AM	23	462		3	7		1006	11		1512
08:00 AM	30	479		5	8		921	9		1452
PHF	0.75	0.99		0.50	0.75		0.88	0.60		
Heavy	0%	3%		0%	0%		1%	0%		
Adj. parking		Y			N			N		
04:00 PM	20	939		33	32		706	17		1747
04:15 PM	18	964		36	35		720	16		1789
04:30 PM	21	952		36	32		731	17		1789
04:45 PM	20	925		39	34		738	19		1775
05:00 PM	22	950		41	35		744	22		1814
PHF	0.71	0.92		0.70	0.71		0.95	0.68		
Heavy	0%	1%		0%	0%		1%	0%		
Adj. parking		Y			N			N		

File Name: C:\Users\Steve\Documents\2013\PETRA\Worcester, MA\FST\QW-027\QW027009.ppd
Start Date: 9/25/2013
Start Time: 7:00:00 AM
Site Code: QW027009
Comment 1: N/S Street : Park Avenue
Comment 2: E/W Street: Maywood Street
Comment 3: City/State : Worcester, MA
Comment 4: Weather : Clear

	Park Ave From North				Maywood St From East				Park Ave From South				Maywood St From West				
Start Time	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Total
07:00 AM	23	311	47		25	52	37		14	838	22		63	54	17		1503
07:15 AM	23	355	48		33	51	36		14	915	19		59	61	19		1633
07:30 AM	24	382	39		42	52	48		11	956	20		66	57	16		1713
07:45 AM	23	397	28		45	48	44		6	964	20		49	55	13		1692
08:00 AM	24	436	22		49	35	51		5	909	25		43	40	12		1651
PHF	0.86	0.88	0.51		0.75	0.65	0.63		0.39	0.97	0.63		0.69	0.59	0.80		
Heavy	4%	2%	10%		0%	0%	6%		18%	1%	0%		9%	2%	0%		
Adj. parking			N				N				Y				N		
04:00 PM	46	839	43		102	78	71		11	587	18		53	37	16		1901
04:15 PM	46	859	50		109	80	78		12	611	18		48	35	15		1961
04:30 PM	45	869	51		104	83	74		12	636	34		53	39	15		2015
04:45 PM	50	898	48		91	82	78		12	699	36		50	37	19		2100
05:00 PM	43	878	48		83	88	75		12	700	35		46	42	16		2066
PHF	0.78	0.96	0.86		0.84	0.89	0.89		0.60	0.87	0.47		0.83	0.71	0.68		
Heavy	0%	0%	4%		0%	0%	0%		0%	0%	0%		4%	0%	0%		
Adj. parking			N				N				Y				N		

Appendix D: Compressed (Zipped) Folder Attachment

Park Avenue Redesign Appendix D:
"Compressed (Zipped) Folder Attachment"
This folder contains the following files:

- -All HCS 2010 Files
- -All HCS 2010 Reports
- -AutoCAD Civil 3D File