Worcester Polytechnic Institute
Digital WPI

Major Qualifying Projects (All Years) | Major Qualifying Projects

December 2020

Northern Strand Community Trail On-Road Extension

Sarah Kwatinetz
Worcester Polytechnic Institute

Maggie Ostwald
Worcester Polytechnic Institute

Lily Spicer
Worcester Polytechnic Institute

Follow this and additional works at: https://digitalcommons.wpi.edu/mqp-all

Repository Citation

Kwatinetz, S., Ostwald, M., & Spicer, L. (2020). *Northern Strand Community Trail On-Road Extension*. Retrieved from https://digitalcommons.wpi.edu/mqp-all/

This Unrestricted is brought to you for free and open access by the Major Qualifying Projects at Digital WPI. It has been accepted for inclusion in Major Qualifying Projects (All Years) by an authorized administrator of Digital WPI. For more information, please contact digitalwpi@wpi.edu

Northern Strand Community Trail
On-Road Extension

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

By:
Sarah Kwatinetz (CE)
Maggie Ostwald (CE)
Lily Spicer (CE)

December 11th, 2020

Advisors:
Leonard Albano
Suzanne LePage

This report represents work of WPI undergraduate students submitted to the faculty as evidence of a degree requirement. WPI routinely publishes these reports on its web site without editorial or peer review. For more information about the projects program at WPI, see http://www.wpi.edu/Academics/Projects.

Abstract

This project aimed to improve bicycle and pedestrian accessibility in Lynn, Massachusetts by completing the on-road extension of the Northern Strand Community Trail. The existing conditions of the roadway were analyzed and examined to identify areas in need of improvements. Initial designs were evaluated based on various criteria and the best solution was selected. The final design was thoroughly detailed and presented to advisors from WPI and Stantec. The recommended designs include separated bike lanes, sidewalk improvements, and signage and signal revisions.

Executive Summary

The Northern Strand Community Trail is an 11.5-mile bicycle path and walking trail. It is located in Northeastern Massachusetts, and is part of the Bike to the Sea Trail (*Northern Strand*, n.d.). The Northern Strand currently connects the cities of Everett, Malden, Revere, and Saugus. The on-road extension will continue the trail through Lynn and end at Nahant Beach. The entirety of the on-road extension spans from Western Avenue to Nahant Beach; however, this MQP project provided designs for the second half, from the Market Street train station to Nahant Beach.

The Lynn downtown and waterfront areas are disconnected because the area between them is automobile-oriented and there are improper and insufficient pedestrian and bicycle accommodations between the two areas ("Priority Corridors", 2016). This MQP project provided our sponsor, Stantec, with a series of design suggestions for the on-road extension of the Northern Strand Community Trail to improve bicycle and pedestrian accommodations. This was achieved through the following objectives.

Objectives:

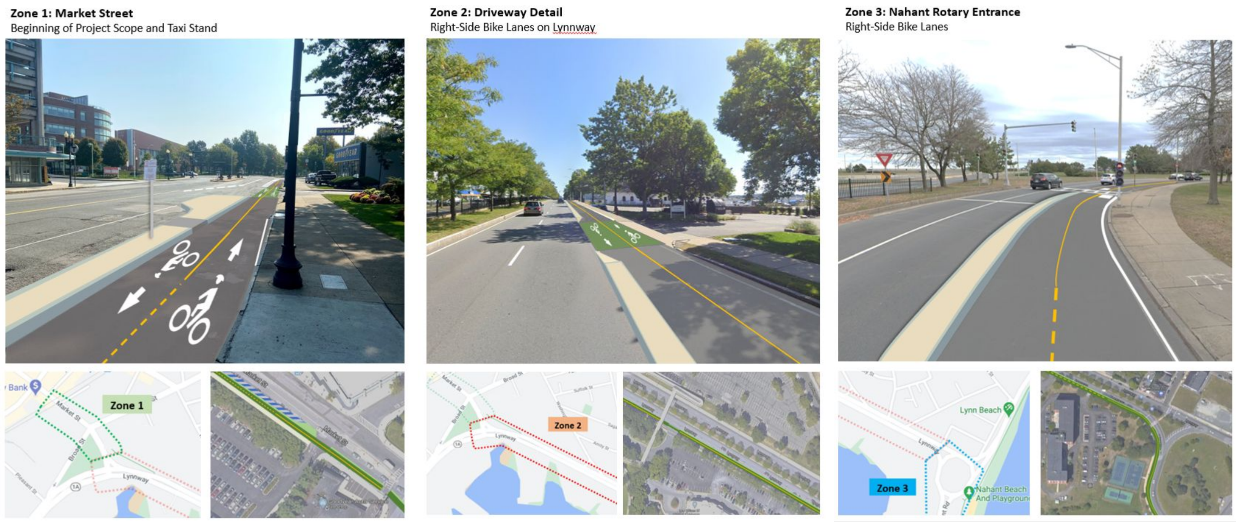
1. Identify and analyze the design constraints for the existing trails and the proposed on-road bike path.
2. Understand the existing operational conditions for the signalized intersections of Market Street and Broad Street, Market Street and the Lynnway, and the rotary.
3. Develop multiple design options for the new on-road bike path.
4. Select the best design of bicycle accommodations based on design constraints.

This process began by identifying the existing physical and environmental constraints. Prior reports of the area from the Central Transportation Planning Staff (CTPS), the City of Lynn, and the Economic Development & Industry Corp. (EDIC), Fay, Spofford, & Thorndike, and BETA Group all helped in evaluating the design constraints. The team also analyzed the intersections of Market Street and Broad Street, Market Street and the Lynnway, and the Nahant Rotary to determine the levels of service and crash rates. To account for the effects of COVID-19, the team collected turning movement count data at Market Street and Broad Street during the peak AM and PM hours. It was found that both peaks were significantly lower than projected 2020 volumes. This intersection was chosen for analysis because the other intersection was not experiencing its expected traffic volumes due to an adjacent construction project, and the rotary traffic volumes are seasonal.

Overarching design goals were identified before preliminary designs were created. These goals included:

- Improving safety and accessibility
- Encouraging alternative transportation
- Connecting the downtown and waterfront areas
- Ensuring adequate flow for existing and future traffic volumes

Each of the three identified project zones within the scope also had specific goals that were considered in the design process. With guidance from MassDOT's *Separated Bike Lane Planning & Design Guide*, AASHTO's *Guide for Development of Bike Facilities*, and the National Association of City Transportation Officials' (NACTO) *Urban Bikeway Design Guide,* aerial and perspective drawings of all design options were completed.



Example design mock-ups

Our preliminary designs were evaluated using a two-step decision matrix. The criteria of primary focus were safety, accessibility, impact on traffic, cost, need for easements, constructability, and environmental impact/sustainability. The design that was ultimately recommended was **Alternative A: 2-Way Separated Bike Lane** which includes a 2-way separated bike lane in the existing right lanes of Market Street and the Lynnway, as seen in the mock-ups above. Final design drawings and AutoCAD files of the bike lane cross sections and lane widths can be found in Appendices F and G.

Acknowledgements
This project would not have been possible without constant support from WPI and Stantec. Specifically, we would like to acknowledge our advisors at WPI, Professor Suzanne LePage and Professor Leonard Albano, and mentors at Stantec, including Rachel Santarsiero, Frederick Moseley, Walt Woo, and Erica Lotz.

Authorship

This Major Qualifying Project was completed by undergraduate students Sarah Kwatinetz, Maggie Ostwald, and Lily Spicer of the Civil Engineering department at Worcester Polytechnic Institute. All three team members participated in the writing and revising of this report, as well as the research and data collection supporting it. Sarah Kwatinetz focused on the historical background and AutoCAD designs, Maggie Ostwald focused on the traffic studies and mock-up designs, and Lily Spicer focused on the cost estimates and utility analysis.

Capstone Design Statement

This project entails designing a portion of the on-road extension of the Northern Strand Community Trail in Lynn, MA. The team must supply improved on-road bicycle accommodations, evaluate different types of on-road facilities, and perform signalized intersection analysis while preserving on-street parking and minimizing the impact on traffic, the environment, pedestrians, and cyclists. To best provide Stantec with a comprehensive design and to fulfill the Worcester Polytechnic Institute (WPI) capstone criteria for Accrediting Engineering Programs by the Accreditation Board for Engineering and Technology (ABET), the following eight constraints were considered:

Economic:

Cost analysis is an important factor in choosing a design, as it must fit within the proposed budget for the project. The team fulfilled this real-life constraint by evaluating the costs for each design and subsequently using these as a factor in the decision process of design selection.

Environmental:

It is crucial to ensure in any project that there are limited or no consequences on the environment. Ensuring the limited environmental impact of a project can also affect project funding. Environmental analysis of the project area was performed using ArcMap GIS to ensure minimal environmental impact could be considered in the comparison of design alternatives.

Social and Political:

The team worked closely with our sponsor, Stantec, to familiarize ourselves with the needs of the residents of Lynn. In doing so, the project team addressed residents' and trail users' concerns regarding the project and to propose a design solution which fits those needs, and to create a design that is accessible to all.

Ethical:

This project abided by the American Society of Civil Engineers (ASCE) Code of Ethics for all civil engineers to ensure the safety and welfare of the public, protect the reputation of WPI and Stantec, and to maintain professionalism, honesty, and virtue.

Health and Safety:

This project sought to improve safety for bicyclists by designing dedicated accommodations for bicyclists of all levels of expertise. The team referenced bike accommodation best practices presented in the AASHTO *Guide for Development of Bike Facilities,* MassDOT's *Separated Bike Lane Planning & Design Guide,* and MassDOT's *Complete Streets Funding Program Guidance.* These references allowed us to create designs that are consistent with the traffic industry and to adhere to safety recommendations.

Constructability:

Constructability is an important design constraint in selecting a final design proposal. Design alternatives must be feasible and practical for implementation with limited construction time. Constructability is also a significant consideration in planning for economic constraints.

The amount of resources, such as time, money, laborers, and equipment, required to implement a design was considered while selecting a final design.

Sustainability:

The team aimed to produce designs for bicycle accommodations that will benefit the City of Lynn and will serve the needs of the trail users for many years. The team designed with maintenance implications in mind and considered factors such as sea-level rise in decision making. The implementation of bike paths is also a sustainable alternative to personal vehicle travel, and greater accessibility may lead more individuals to choose this form of transportation.

COVID-19:

The team accounted for the inconsistencies of the new traffic count data due to the effects of the pandemic. We used old traffic count data and adjusted accordingly to represent typical data.

Professional Licensure Statement

The National Council of Examiners for Engineering and Surveying (NCEES) requires that engineers in practice are held to a standard of experience and knowledge by providing professional licensing to qualified engineers. This ensures quality work, entrusts a standard of best practices in the workplace, and encourages confidence in the industry.

There are several steps involved in obtaining professional licensure which require time, experience, and formal education. First, one must earn a bachelor's degree in a program certified by the Accreditation Board for Engineering and Technology (ABET). The next step, passing the Fundamentals of Engineering (FE) exam, can begin as soon as one semester before graduating with a bachelor's degree. Once a candidate passes this exam, they are certified as an Engineer in Training (EIT). The final step to becoming a professional engineer is to pass the Professional Engineering (PE) exam. The PE cannot be taken until the candidate has at least four years of experience in the industry. The PE exam and resulting licenses when it is passed are administered at the state level.

Becoming a certified PE is an extensive and challenging process of professional development but creates opportunities for engineers to advance in their field. There are several responsibilities in the industry that can only be completed by certified Professional Engineers, such as reviewing and approving designs and other documents. PEs are encouraged to hold a standard of professionalism in the workplace by the National Society of Professional Engineers (NSPE) Code of Ethics and are required to participate in continuous professional and educational growth and development in their field.

Throughout this project, we worked alongside licensed engineers, both EITs and PEs, and noted their experience and skills in engineering. Our exposure to professional licensure during this project displayed the growth we are capable of in our upcoming careers.

Table of Contents

List of Tables

List of Figures

1.0 - Introduction

The Northern Strand Community Trail, also known as the Bike to the Sea Trail, is an 11.5-mile bicycle path and walking trail located in Northeastern Massachusetts. After connecting the towns of Everett, Malden, Revere, Saugus, and Lynn, the trail will transition to an on-road design to reach Nahant Beach. This extension will incorporate dedicated bicycle accommodations to improve accessibility and safety without compromising other roadway facilities. For decades, the City of Lynn, Bike to the Sea, Inc., and the Solomon Foundation have actively worked towards this on-road extension of the trail. Now, Stantec has stepped in as the resident engineer and construction manager to implement the idea.

This MQP aimed to provide our sponsor, Stantec, with a series of design options for the on-road extension of the Northern Strand Community Trail between Market Street and Nahant Beach, to ultimately complete the trail. To achieve this, our MQP team met the following objectives:

1. Identify and analyze the design constraints for the existing trails and the proposed on-road bike path.
2. Understand the existing operational conditions for the signalized intersections of Market Street and Broad Street, Market Street and the Lynnway, and the rotary.
3. Provide multiple design options for the new on-road bike path.
4. Select the best design of bicycle accommodations based on design constraints.

2.0 - Background

The Northern Strand Community Trail, also known as the Bike to the Sea Trail, is an 11.5-mile bicycle path and walking trail, connecting Everett, Malden, Revere, and Saugus, and eventually Lynn, Massachusetts (*Northern Strand*, n.d.). The trail follows the former Saugus Branch Railroad and is designed to extend onto complete streets, incorporating pedestrian and bike-friendly roadside facilities, to reach Nahant Beach.

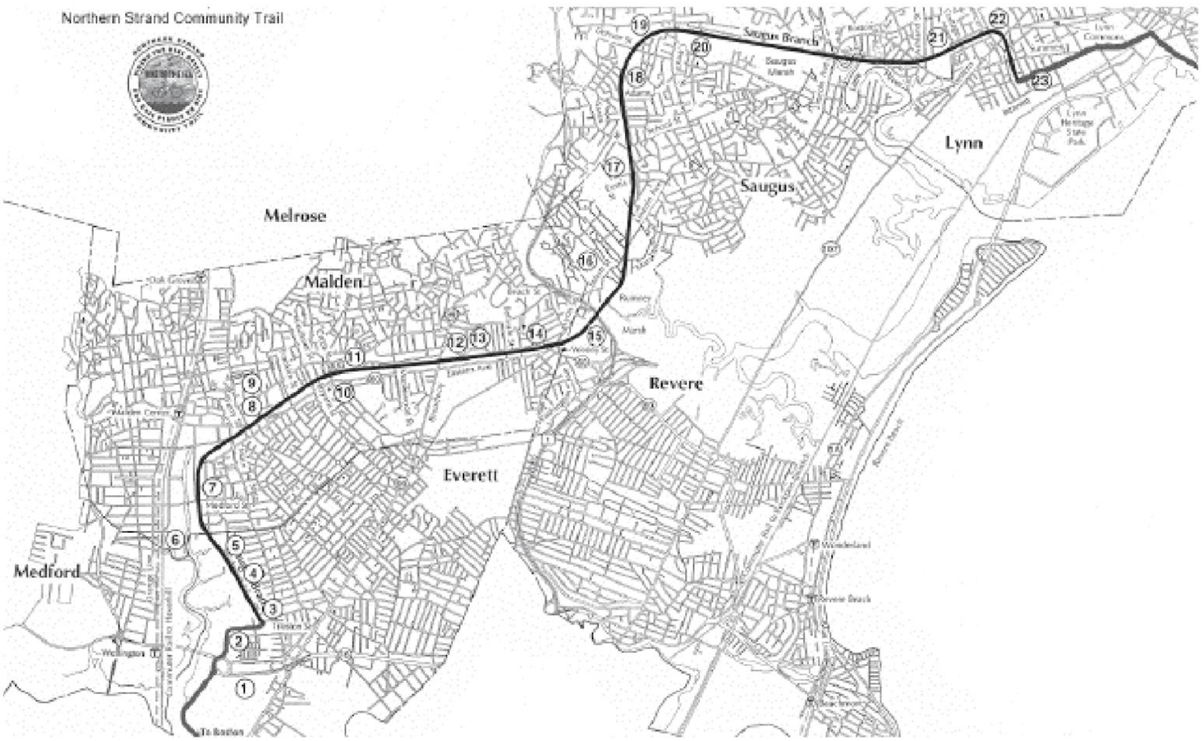


Figure 1: Map of the Northern Strand Community Trail (City of Malden Master Plan, n.d.)

2.1 - History of the Trail

Figure 2: Timeline of events (Northern Strand, n.d.)

Founded in 1993, Bike to the Sea, Inc. (B2C) was the first organization to advocate for the Northern Strand Community Trail. This non-profit historically pushes to "[connect] communities by building and improving shared-use paths and promoting safe and happy trail use for all ages and abilities" (*About Us*, n.d.). Shortly after, the trail was adopted into the Metropolitan Area Planning Council (MAPC) regional bicycle trail plans, the DEM statewide trails plan (now DCR/EOEEA), and was included into the route between Boston and Maine in the East Coast Greenway, a 3000-mile trail spanning from Maine to Florida (*Northern Strand*).

After nearly a decade of lease negotiations with the MBTA, Everett, Malden, Saugus, and Revere entered 99-year leases in 2005 (*Northern Strand*). Things looked promising for B2C, but progress was halted as state policy required communities to front the costs for planning and design. Over the next few years, with help from Rails to Trails, Recreational Equipment, Inc. (REI), local donors, B2C, and a non-profit from Nevada called Iron Horse Preservation, rough trails were completed out of recycled asphalt (*Northern Strand*). The new trails were popular with residents; however, it was clear a paved pathway was needed. Everett and Malden eventually paved their local portions using Gateway Parks funds, meals tax, and general revenue bonds.

The Iron Horse Preservation had difficulty finishing the Revere section of the trail and garnering support from residents of Lynn, so in 2016, the Solomon Foundation began involvement to assist with grants and technical aspects of the project (*Northern Strand*). By 2018, the Solomon Foundation had partnered with the City of Lynn to work on the design for the extension to Nahant Beach.

The extension into Lynn was initially met with resistance from its residents, as more pressing issues like crime and sewage backups took priority. Without support from the City of Lynn and its residents, B2C had trouble obtaining funds for the project and its design. By 2019, however, with more success in Everett, Malden, Saugus, and Revere, and persistent advocacy, the Executive Office of Energy and Environmental Affairs (EOEEA) of Massachusetts was able to commit to funding the whole project through the Gateway Cities Program. This greatly improved the overall project's efficiency, as instead of multiple municipalities working together, it was now one cohesive trail project. This was largely in part due to the Governor's and MassDOT's shift in how they handle state, municipal, and non-profit-joint projects, and because of the Solomon Foundation and the Deputy Chief of Staff's vision of the trail as a state-level project. (*Northern Strand*).

2.2 - Project and Funding

Most of the project funding comes from the Gateway Cities Program, a Massachusetts grant funding program that helps provide social and economic opportunities in cities where manufacturing jobs have disappeared. This grant has provided $1.5M for design, $11M for construction of the Northern Strand Trail, and $8M for construction of the projected on-street extension in Lynn. The Solomon and Barr Foundations, as a part of the ‘A Greener Greater Boston’ program, have contributed $102,500. The City of Lynn also contributed $37,500 to the budget (*Northern Strand*).

Major stakeholders in this project are Bike to the Sea, Inc., The Solomon Foundation, The Barr Foundation, MA Executive Office of Energy and Environmental Affairs (EOEEA), the cities the trail passes through, and their residents. Stantec is providing construction management services and acting as the resident engineer, and Brown, Richardson, and Rowe, Inc. is providing construction administration services. For the on-road section, funding from MassDOT has been secured in a contract through the EOEEA.

2.3 - Existing Conditions

The 11.5-mile trail runs through Everett, Malden, Revere, Saugus, and Lynn, Massachusetts. The rail-trail portion of the trail is under construction for route improvements, while the on-road extension, shown in Figure 3, is still in the design phase. Stantec has been working on the design for the rail-trail portion as well as the entirety of the on-road extension; however, this MQP focuses on only a portion of the Lynn on-road extension that is approximately 4,270 feet in length (0.8 miles). This spans from the T Station on Market Street to Nahant Beach. Within the MQP scope, we have identified three major project areas – Market Street, the Lynnway, and the Nahant Beach area. The project area includes two high volume intersections and one rotary.

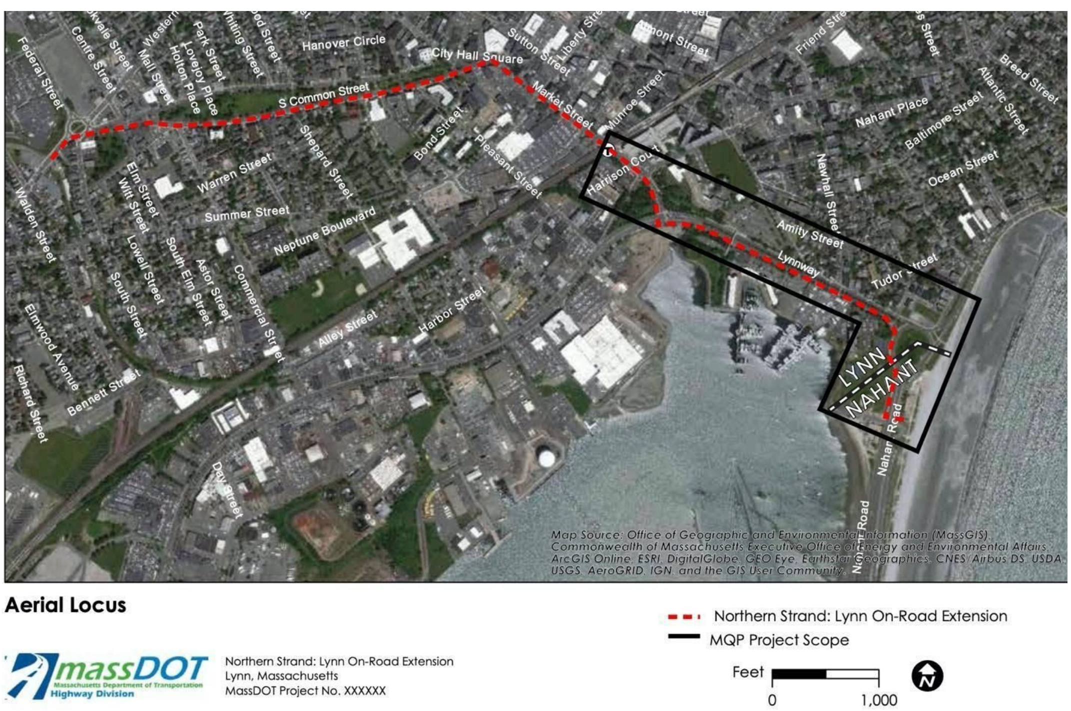


Figure 3: On-Road extension with MQP project scope, boxed (Stantec, 2020)

The trail outside of the MQP project scope, shown in Figure 4, includes the existing rail-trail along the old Saugus railroad and the on-road extension down South Common Street to the T-Station on Market Street in Lynn.

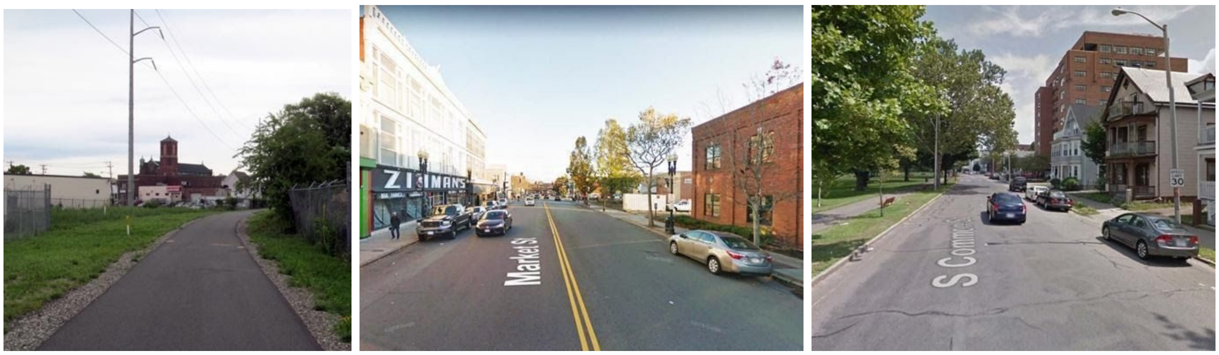


Figure 4: Trail in Malden and proposed on-road extension via Market Street and S. Common Street (Google User PI.1415926535)

In the extension design, many considerations such as the traffic loads, intersection design, environmental restraints, cost, constructability, the preservation of on-street parking, biker safety, and more were evaluated to guide Stantec's final design. This design will eventually tie-in to our designs which begin at the T Station on Market Street.

2.4 - Analyzing Need

The extension of the Northern Strand will provide economic opportunities and facilitate connectivity between the downtown, waterfront, and surrounding neighborhoods. The Lynn Waterfront Master Plan identified the "waterfront property [as an] exceptional site made up of contiguous parcels of land that are severely underutilized" and noted, "land of this magnitude in a strategic location along a beautiful waterfront is rare, particularly when it is located within 10 miles of downtown Boston" (*Lynn Waterfront*, 2007). Additionally, "[consultants] estimate that a fully implemented plan and built-out waterfront would provide almost 10,000 construction jobs, 5,000 permanent jobs, and approximately $18 million in annual property tax revenue" ("Priority Corridors", 2016). The Lynnway, however, has been identified in the Lynn Waterfront Master Plan as acting as a barrier between downtown Lynn and its under-utilized waterfront, hindering economic growth. The team believes increasing connectivity through improved bicycle and pedestrian facilities will allow this area to develop.

In addition to the economic opportunities the Northern Strand extension presents, many necessary infrastructural improvements have been identified to make the area within the MQP project scope more accessible and resilient. The roadways within the project scope, stretching from the intersection of Market Street and Broad Street to the Nahant Rotary, are intimidating to bicyclists and pedestrians alike. Specifically noteworthy is the Lynnway's "swooping curve as it transitions to Carroll Parkway [carrying high] volumes of thru traffic at maximum speeds [as well as the current Route 1 configuration, which forces] eastbound drivers to turn left onto the eastern end of Market Street and then immediately to turn right to return to Broad Street/ Route 1A" (*Lynn Waterfront*). Not only does this series of intersections take up a lot of space, it "renders the waterfront practically inaccessible [to pedestrians and bicyclists]" (*Lynn Waterfront*).

The auto-oriented design of these intersections and roadways makes the area dangerous to non-vehicles. High speed and heavy volumes of vehicles, paired with sidewalks riddled with obstructions and cracks, non-ADA-compliant ramps, and without a shoulder or tree barrier, makes these sidewalks uncomfortable and unsafe, especially for those with disabilities. Many of the unsignalized intersections along the Lynnway lack stop signs or pedestrian signals. Also, lack of pavement markings and defined shoulders put bicyclists at risk, forcing them to use sidewalks. In addition to this, the locations and lack of these sidewalks and crossings make the area less pedestrian-friendly. Most notably, there is no sidewalk along the green space on the southbound side of Market Street between Broad Street and the Lynnway, where a desire-path is found instead.

3.0 - Methodology

The goal of this project was to provide our sponsor, Stantec, with a series of design options for the on-road bike extension of the Northern Strand Community Trail to improve bicycle accommodations near Nahant Beach, resulting in the completion of the trail. This MQP project achieved this by completing the following objectives.

Objectives:
1. Identify and analyze the design constraints for the existing trails and the proposed on-road bike path.
2. Understand the existing operational conditions for the signalized intersections of Market Street and Broad Street, Market Street and the Lynnway, and the rotary.
3. Develop multiple design options for the new on-road bike path.
4. Select the best design of bicycle accommodations based on design constraints.

3.1 - Objective 1: Identify Physical and Environmental Constraints
Identify and analyze the design constraints for the existing trails and the proposed on-road bike path.

3.1.1 - Project Zones
The area within the project scope spans three different roads, each presenting new uses, traffic volumes, and design options. To clarify the varying designs in each segment, the total project scope was divided into three zones (Figure 5).

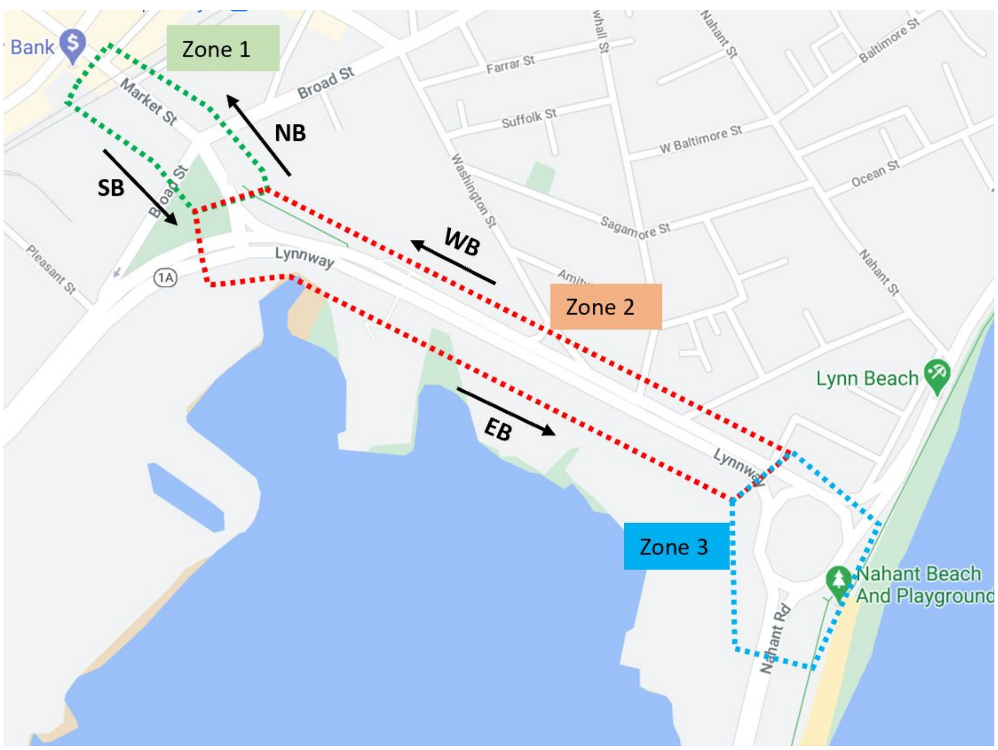


Figure 5: Project zones (Google Maps, 2020)

Project Zone 1: Market Street

The first zone stretches from the MBTA commuter rail overpass to just before where Market Street reaches the Lynnway (Figure 6). This is where the Northern Strand Community trail on-road extension ties in with Stantec's design outside of our project scope. This zone includes the intersection of Market Street and Broad Street.

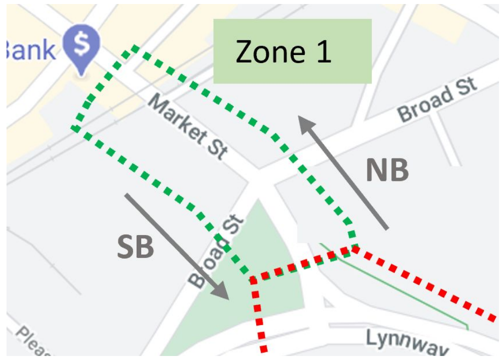


Figure 6: Project zone 1 (Google Maps, 2020)

Project Zone 2: The Lynnway

The second zone of the on-road extension is the 0.7 mile stretch from the intersection of Market Street and the Lynnway to the trail's ending just before the Nahant Rotary.

Figure 7: Project zone 2 (Google Maps, 2020)

Project Zone 3: Nahant Rotary

The third zone of the on-road bike path begins at the rotary and extends into Nahant to the beach entrance.

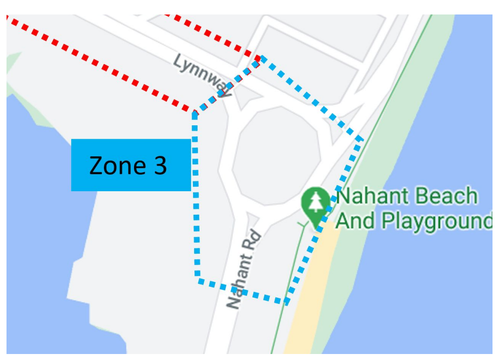


Figure 8: Project zone 3 (Google Maps, 2020)

3.1.2 - Physical Constraints

Our team obtained project scope AutoCAD survey files from the Executive Office of Energy and Environmental Affairs (EOEEA) and also used street view maps and in-person observation to evaluate the existing conditions along the route and determine whether the sidewalk, lane, and shoulder widths are optimized for the current level of service. There is a sidewalk along at least one side of the roadway and there is little to no shoulder throughout the project site, but there are multiple lanes of traffic along the whole length of the route. From this, we identified the best placement and arrangement for implementing a bike path. The intersections were evaluated in terms of biker safety and vehicle traffic impacts. The project area was divided into three defined zones due to their unique layout and attribute.

<u>Project Zone 1</u>

At the intersection of Market Street and Broad Street, we looked for places where higher pedestrian traffic was anticipated. We also evaluated the number of lanes and the traffic volumes to determine where a bike lane could best be implemented.

<u>Project Zone 2</u>

A new development was under construction during our study period at the intersection of Market Street and the Lynnway. Because of this, this intersection has already been redesigned to accommodate the anticipated changes. We took this into consideration and maintained the existing conditions at the intersection while installing bicycle accommodations. The eastbound and westbound directions of the Lynnway were often analyzed separately because they are separated by a large median and operate quite differently. The eastbound side has incoming traffic from several parking lots for the marina and some DCR-owned greenspaces. The westbound side has some on-street parking in front of many businesses, incoming traffic from four streets, outgoing traffic from two streets, and potential foot traffic from the North Shore Community College campus. We evaluated how the differences along the Lynnway would dictate our design proposal on either side of the roadway.

<u>Project Zone 3</u>

The third zone is the Nahant Rotary, where three streets intersect. One exit goes south toward the Town of Nahant, one goes north along the coast, and the third directs drivers west, back onto the Lynnway. We evaluated the existing signalized pedestrian crossings and how they could be adapted to allow cyclists to safely reach the ocean as intended.

3.1.3 - Environmental Constraints

Because the project site is next to the ocean, the environmental conditions were taken into consideration. We used the survey files in combination with GIS map layers of the project area. The GIS layers were also used to evaluate whether there is proper drainage out of the project site and ensure that the future implementations will withstand the conditions. The GIS layers provided by the Massachusetts Office of Coastal Zone Management, the Department of Conservation and Recreation (DCR), and the Sea Level Affecting Marshes Model (SLAMM) were key in visualizing our limits.

3.1.4 - Synthesis of Existing Information

The team utilized the following data to evaluate existing conditions:

- 2016 Route 1A/Lynnway/Carroll Parkway Study in Lynn by the Boston Region Metropolitan Planning Organization (MPO)/Central Transportation Planning Staff (CTPS)
- 2007 Lynn Waterfront Master Plan by the City of Lynn and the Economic Development & Industrial Corp. (EDIC)
- 2006 Traffic Volume and Turning Movement Counts by Fay, Spofford, & Thorndike, LLC.
- 2005 City of Lynn Downtown Traffic Study conducted by BETA Group, Inc.

The CTPS report from 2016 provided crash data analysis from 2010-2012 as well as LOS analysis, turning movement counts, spot speed data, and bicycle and pedestrian traffic volumes collected in May of 2015. This report was commissioned as a part of the Boston MPO's Long-Range Transportation Plan (LRTP) to address the region's current mobility needs, focusing on maintaining and modernizing roadways with high levels of congestion and safety problems; expanding the quantity and quality of walking and bicycling; and making transit service more efficient and modern. Raw counting data for all infographics in the 2016 report were available in the report's appendix. This data was annualized by the team in order to compare it to previous data and turning movements collected in this MQP using MassDOT seasonal and axle correction values for Essex county.

The Downtown Traffic Study published in 2005 by the City of Lynn addressed "issues of congestion within the downtown area and mitigation through improved intersection operations, design and safety [and develops] recommendations associated with pedestrians" ("Downtown Traffic", 2005). BETA Group, Inc. conducted manual turning movement counts in June of 2004, and this data was annualized by using a 1% growth rate to reach a 2005 existing conditions baseline and organized into a LOS analysis ("Downtown Traffic). In addition to this, BETA Group measured continuous traffic volumes, provided a summary of crash data between 2001 and 2003, and outlined any intersection geometry, design, or timing issues the group encountered.

The Lynn Waterfront Master Plan was beneficial in gaining a contextual understanding of how existing roadways in Lynn function and how they should be improved. The Master Plan notably identified the impracticalities of the Lynnway as it currently stands and also the potential benefits of improving bicyclist and pedestrian access to the Lynn waterfront.

Lastly, the team also used data provided to us by our sponsor, Stantec, collected by Fay, Spoffard, & Thorndike, LLC in March of 2006. Within these documents were turning movement counts for each of the intersections in this project as well as 24-hour traffic volume data for the Lynnway.

3.2 - Objective 2: Evaluate Existing Conditions

Understand the existing operational conditions for the signalized intersections of Market Street and Broad Street, Market Street and the Lynnway, and the rotary.

3.2.1 - Intersection Analysis

Understanding the existing conditions of the site involved the analysis of three intersections and consideration of the roadways between them. Historical data and counts were used to understand the existing conditions at each intersection and the roadways between them. Data was collected by our team to better understand the impact of COVID-19; see Section 3.2.3 for more details. The findings presented in Section 4.0 are a combination of data obtained from our own traffic counts and data from preexisting and adaptable counts. Gaining an understanding of the existing conditions in this area aided in identifying how the intersections could be altered without significantly decreasing their levels of service.

Market Street and Broad Street

The intersection of Market Street and Broad Street is a signalized four-way intersection with Broad Street being one-way in the westbound direction (Figure 6). We conducted a manual traffic count of this intersection during the weekday AM and PM peak hours. We also recorded current signal timings while at the site. Then, we used Highway Capacity Software to determine the current level of service of this intersection. Similar counts at this intersection dated 2015 and 2006 were also analyzed using HCS to compile comparable data over fourteen years.

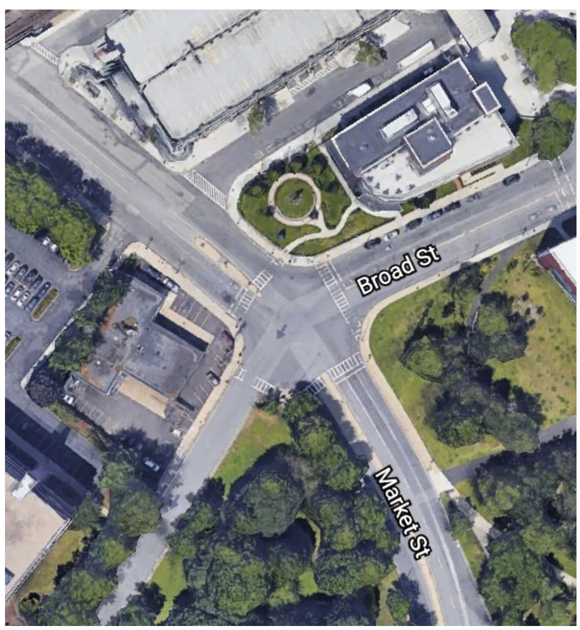


Figure 9: Intersection of Market Street and Broad Street (Google Earth, 2020)

Market Street and the Lynnway

The intersection of Market Street and the Lynnway, a state highway, is a signalized three-way intersection (Figure 10). A fourth direction was recently added to provide access to a new development located south of the intersection, where construction is still ongoing. We studied reports of data collected at this intersection in both 2006 and 2015, but our team did not perform a traffic count at this intersection. We felt our own counts, if conducted, would not be comparable to the historical data because a new traffic pattern had been introduced so recently. Additionally, the building the new road leads to was not open yet, so our numbers would not accurately represent actual volumes in this intersection once the construction on this building was completed.

Figure 10: Intersection of Market Street and the Lynnway (Google Earth, 2020)

<u>Nahant Rotary</u>
The rotary in Figure 11 connects the Lynnway with Lynn Shore Drive and Nahant Road, but for this project, it is used to safely direct bicyclists to and from Nahant Beach. The traffic volumes and use of individual lanes in this rotary were important in deciding where bike accommodations could be included. Turning movement counts from 2006 and 2015 were studied at this intersection. The team did not conduct a count here. Our primary aim in conducting new studies was to see the impact of the pandemic, but worried our control would be obscured by varying seasonal volumes to and from the beach.

Figure 11: Rotary intersection of the Lynnway and Nahant Rd. (Google Earth, 2020)

3.2.2 - Crash Reports

We gathered existing crash report data relevant to the project scope to ensure areas of particular interest were acknowledged. This data was obtained from the 2016 CTPS report. It provided insight into the instances of crashes involving vehicles, pedestrians, and bicycles, which informed our decision-making regarding bicycle infrastructure. The data were averaged over the 2010-2012 collection period and expanded to estimate the number of crashes per five years, so the numbers could be more easily compared.

3.2.3 - Effect of COVID-19 on Traffic Volumes

The ongoing pandemic proved to be a significant challenge in collecting traffic data that is representative of the pre- and post-pandemic era. New traffic counts alone cannot represent the true data, as travel had been lessened by remote work and school and adjusted business operations. A creative and calculated combination of existing counts, new counts, and appropriate adjustment factors allowed us to develop a more complete picture of the local traffic. New counts were conducted with the understanding that volumes would be lower and were conducted with the primary intent of measuring the impact of the pandemic on traffic volumes. The intersection of Market Street and Broad Street was used for the collection of data because the other intersections within the scope had additional variables that prevented us from holding COVID-19 as the single control variable.

Historical peak hour data, taken from 2006 and 2015, was first annualized using the MassDOT seasonal correction multipliers for Essex county and the appropriate year. This annualized data was then used to calculate the actual annual growth rates between the years of 2006 and 2015. The calculated growth rate was then applied to make 2020 peak hour projections. A second projection was also created using a 1% estimated growth rate, which was identified and used by BETA Group, Inc. in the 2005 Lynn Downtown Traffic Study.

The group observed the AM and PM peak hours of Market and Broad Street and then followed the same steps of annualizing to obtain the 2020 observed baseline values. These values were then compared to the two 2020 projections to draw conclusions about the effect of the pandemic on traffic volumes.

3.3 - Objective 3: Develop Potential Solutions

Develop multiple design options for the new on-road bike path.

3.3.1 - Define the Design Goals

In order to make informed design choices, we defined project goals. This process involved revisiting the initial eight capstone design constraints as well as diving deeper into the goals of the local municipalities and the users for this project. Further examination into the project zones also revealed that they each contain unique design challenges, so our project goals were also separated by project zones.

The initial eight constraints - economics, environmental, social/political, ethics, health and safety, constructability, and sustainability of the project - each provided different objectives in the designs, but also had a lot of overlap. For example, economics and constructability were both considered through examining the grant opportunities at the federal and state levels the project is eligible for. However, many of these grants were aimed at addressing environmental concerns such as air quality, or social, political, safety, and ethical aspects such as accessibility, so even more constraints were met. Additionally, as the project progressed and design options needed to be compared against one another, these constraints were given point values by which we ranked each design's effectiveness in each of the categories. More detail on this process is discussed in Section 3.4.2.

The objectives of the Lynn government and those who participated in public meetings also tied in well with these design constraints. The goals of the local municipalities were obtained by reading through the Lynn Waterfront Master Plan, and public opinion was derived from the series of public meetings and workshops conducted previously about the trail. The first set of public meetings was held for the towns (Everett, Revere, Malden, Saugus, and Lynn) through which the trail runs. Many of these meetings discussed the future of the off-road portion of the trail; however, there were some points identified relevant to the on-road portion that were incorporated into our design process. Additionally, the Solomon Foundation did a series of community workshops which identified regional and local goals for the design. These goals were also considered in our final design choices.

3.3.2 - Preliminary Designs

The findings from Objectives 1 and 2 and our outlined project goals dictated the proposed design options. Consideration was taken at each intersection to allow for proper functionality and biker safety. Once the existing operational conditions were evaluated, the team drafted preliminary designs based on the constraints identified. Some constraints could not be compromised, some had overlap, and others had more flexibility, so numerous design options were produced.

To ensure our design options were adhering to safety regulations and were intuitive to riders and drivers, we utilized MassDOT's *Separated Bike Lane Planning & Design Guide* and AASHTO's *Guide for Development of Bike Facilities* and the National Association of City Transportation Officials' (NACTO) *Urban Bikeway Design Guide* as a starting point for our designs. The Massachusetts *Complete Streets Funding Program Guidance* document was also a great reference regarding best practices, prioritization of constraints, and safety auditing. In an effort to make these streetscapes accessible to all users, we looked to the *Americans with Disabilities Act Accessibility Guidelines* and the *Massachusetts Architectural Access Board Rules and Regulations* for guidance. After our own data collection and observations, we better adapted current best practices to our project.

3.4 - Objective 4: Select the Final Design

Select the best design of bicycle accommodations based on design constraints.

3.4.1 - Evaluate Feasibility of Design Options

<u>Decision Matrix Discussion</u>

To ensure the inclusion of all eight design constraints, a decision matrix was used to rank alternatives. Due to the multi-faceted nature of the design alternatives, two decision matrices were used in sequence to determine the optimal designs. First, general options were considered including a shared bike lane, one-way separated bike lanes, and two-way separated lanes. Then, specific options for the design of a two-way separated bike lane were explored for each portion of the project scope. A blank decision matrix for the 2-Way Separated Bike Lane Options is shown in Table 1 for reference. Key criteria required of the final designs were drawn from the eight design constraints. Impact on traffic, such as the resulting LOS of adjusted intersection designs, was also one of the considered criteria in the matrix. Based on their perceived importance, the constraints were assigned different point scales, with a maximum of 5. For example, accessibility and safety have the maximum weight because they structure the backbone and determine the ultimate success of this project. Criteria with less significant weights are still important considerations and could be cause for alarm if several of them are not met. The design alternatives were compared by identifying how thoroughly they achieve each of the criteria. This led us to a quantitative assessment of the designs we worked with.

Table 1: Example decision matrix

Factors Considered (and related maximum point value)		Market Street Alternative 1	Market Street Alternative 2	Lynnway Alternative 1	Lynnway Alternative 2
Accessibility	**5**				
Safety	**5**				
Traffic Impact	**4**				
Cost	**4**				
Easements	**3**				
Constructability	**3**				
Environment/ Sustainability	**3**				
Long-Term Maintenance	**2**				
Adaptability into other bike networks	**2**				
Aesthetics	**1**				

3.4.2 - Deliverable for Stantec

The team's final design plans were presented to Stantec in the form of concept designs and technical drawings alongside explanations of the design choice. These plans will be considered by Stantec in combination with existing plans they have developed to finalize the development of the on-road extension of the trail.

The deliverable includes specifications regarding pavement design and signage, elevation cross sections, utility designs, and a preliminary cost estimate. Mock-up designs were originally designed in powerpoint using photos from Google Earth and our site visit, and were edited to reflect the final design choices. More detailed designs were created using AutoCAD, beginning with a base file provided by the EOEEA.

Preliminary cost estimates were determined using the *2018 MassTrails Cost Estimating Tool* and MassDOT's *Construction Project Estimator and Standard Item List*. These tools also aided in the quantitative comparison of one option against another based on their estimated implementation costs.

The deliverable also outlines the implications of the design. Implications were considered based on the previously discussed capstone design constraints, with the addition of the impact of the new design on local traffic flow, which was analyzed using HCS. Data collected at the intersection of Market and Broad Street from 2006, 2015, and 2020 were compiled and modified to reflect the new lane configuration following the addition of bicycle lanes. The 2020 data, which we recently collected ourselves, was modified to reflect the changes to the intersection recommended by the bicycle lane design. The signal timing was optimized in HCS for both models, making them more comparable on the assumption that the intersection would be reoptimized once the changes are made and the bicycle lanes are opened.

4.0 - Findings

This section outlines the results of data collection and research conducted throughout the project as well as the design process that led the team to final recommendations.

4.1 - Objective 1: Identify Physical and Environmental Constraints

Identify and analyze the design constraints for the existing trails and the proposed on-road bike path.

4.1.1 - Project Zones

Physical and environmental constraints were identified and grouped according to project zone. These zones were described in detail in Section 3.1.1. Figure 12 is a map of the project area and the respective zones.

Figure 12: Project zones (Google Maps, 2020)

4.1.2 - Physical Constraints

Before examining the physical constraints within each project zone, the team evaluated the existing infrastructure to better understand the area as a whole. Appendix B features a map markup of the project scope in its entirety with the existing ramps, on-street parking, and driveways from the intersection of Market Street and Broad Street to the Nahant Rotary. Figure 13 shows a few sections of this map markup for reference.

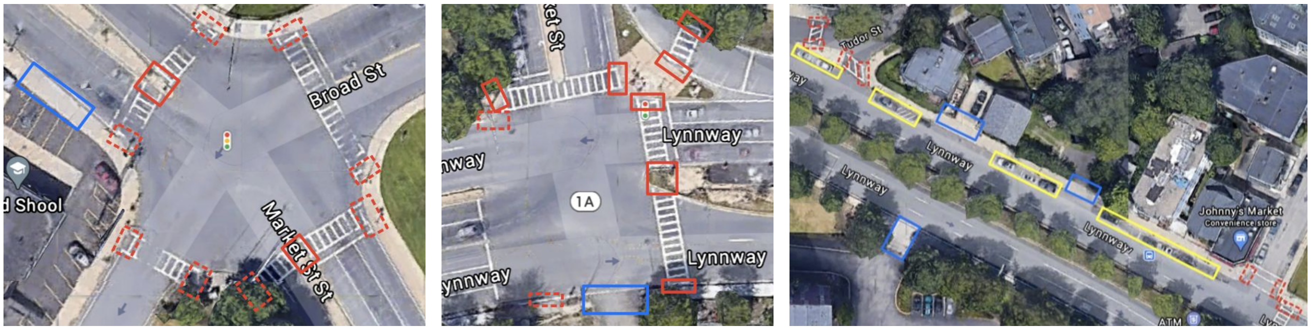


Figure 13: Ramp, driveway, and on-street parking markup (Google Earth, 2020)

Of the 47 ramps within the project scope, 32 are not ADA-compliant. The intersection of Market Street and the Lynnway in Zone 2 was most recently reconstructed; therefore, the ramps here made up nearly half of the ADA-compliant ramps. When "curb cuts and ramps lack detection-warning plates and are not compliant with Americans with Disabilities Act (ADA), [this] poses problems for people with disabilities" and is extremely dangerous, especially among high-speed traffic like the Lynnway ("Priority Corridors"). In Figure 14 are a few examples of ramps in Zones 1 and 2 that lack detection-warning plates.

Figure 14: Non-compliant wheelchair ramps at intersection of Market Street and Broad Street (left) and along the Lynnway (mid) and at the rotary (right) (Google Earth, 2020)

The crosswalks at the intersections of both Tudor Street and Washington Street with the Lynnway in Zone 2 do not have ramps at one of their sides (Figure 15). These crossings force the pedestrians and bicyclists who need the ramp to leave the crosswalk and use the private driveway to get up to sidewalk level. This violates ADA standard 406.5: Location, which states that the ramp must be fully contained within the crosswalk (*2010 ADA Standards*, 2010).

Figure 15: Crossing at Tudor Street and Lynnway (Google Earth, 2020)

There are also some spaces along the sidewalk which are unsafe for those with disabilities. Sidewalk obstructions, uneven slopes, cracks, and curb edging are some issues identified along the stretch of the Lynnway. This is shown in Figure 16 below.

Figure 16: Dangerous sidewalk at a driveway at 150-154 Lynnway (Google Earth, 2020

In Appendix C, the AutoCAD survey files are marked up to indicate above ground utilities, traffic signal cabinets, trees, etc., and their corresponding quantities along the project corridor. Being able to better visualize the existing infrastructure aided in evaluating design recommendations in terms of construction feasibility. The *MassDOT Standard Items* list was used to properly breakdown and estimate the cost associated with the later design recommendations (*Standard Items,* 2020). This is outlined in greater detail in Section 4.4 - Selection of Final Design.

<u>Project Zone 1</u>

This 0.1-mile stretch features a T Station and the intersection of Broad Street and Market Street. Because of this, there is anticipated pedestrian traffic in this area. Market Street, in between Broad Street and State Street, features two lanes in each direction as well as short-term parking and a taxi area (Figure 17). On the southbound leg of Market Street between Broad Street and the Lynnway, there are also two lanes. Traffic may flow normally with just one lane here, but there is also an option to keep both lanes for vehicles and utilize the greenspace along the road. On Broad Street, there is 15-minute parking outside of the All Care VNA Hospice. Otherwise, there are no other designated parking spaces, and the shoulders of the roadways are too narrow to park without blocking a travel lane. Finally, this area currently has no bike infrastructure in place.

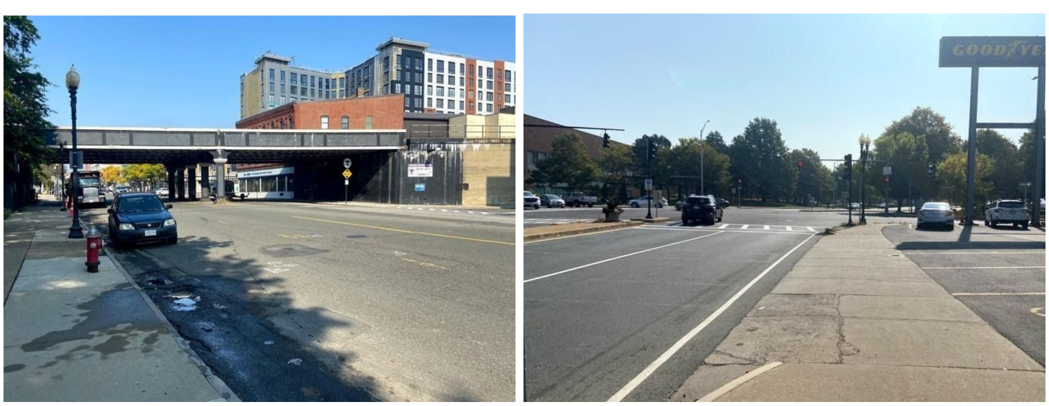


Figure 17: Market Street near the intersection of Market Street and Broad Street (Google Earth, 2020)

It is clear that Market Street would benefit from the addition of bike infrastructure because "the [current] expanse of pavement and lack of any markings makes crossing the street or biking along it unsafe" and the wide lanes encourage speeding (*Northern Strand*).

<u>Project Zone 2</u>

The intersection of Market Street and the Lynnway is currently a three-way signalized intersection, but a new development was under construction at the time of this study. There was a recent reconstruction of the intersection to account for an added direction of traffic. After the intersection and on the Lynnway in the westbound direction, there are only two lanes, offering little to no flexibility in replacing one of those lanes with bike accommodations (Figure 18). On the eastbound section of the Lynnway, we find three lanes where two lanes would likely suffice (Figure 18). These constraints within the existing layout of the roadways indicate where there is flexibility for bike lanes, and where there is not. Average vehicle speeds are also impacted by changes in traffic volumes and patterns. For example, if an eastbound lane on the Lynnway was replaced with bike lanes, it would be encouraged to also reduce the speed limit. This would make the roadway more welcoming and safe for vehicles and cyclists alike.

Figure 18: Lynnway eastbound (left) and westbound (right), Sept. 2020

As far as available on-street parking, there are sixteen spaces along the Lynnway in the westbound direction between the Nahant Rotary and the community college. The majority of these spaces are short-term parking, ranging from 15 to 30 minutes; however, there are six spaces with no sign to indicate a time limit. Additionally, the small island at the intersection of Tudor Street and the Lynnway has a sign that states "no parking on either side"; however, the face of the sign is not visible from the Lynnway side of the island and vehicles have been parked along the island edge on multiple occasions (Figure 19).

Figure 19: No parking sign at Tudor Street and Lynnway (Google Earth, 2020)

We must also consider access to businesses in the project area. There are nine commercial driveways of concern along the eastbound direction of the Lynnway. Depending on where the bike lane is implemented, the traffic turning in and out of these driveways poses a potential threat to bikers. There are also five intersecting side road access points and four residential driveways on the westbound direction of the Lynnway that could interfere with the implementation of a bike lane. The bikers' safety is the highest priority, but business loading and unloading spaces were considered as well.

<u>Project Zone 3</u>

The rotary currently has two to three lanes and has crosswalks on two of its three exits. There is already a sidewalk along the rotary between the Lynnway and Nahant Road. Figure 20 shows the lanes of the rotary. The entrance to Nahant Beach is located just south of the rotary on Nahant Road. There is no parking within the rotary but there is a beach parking lot shortly after the rotary on Nahant Road. It is important to note that this zone is located on land owned by the Department of Conservation and Recreation (DCR), as this indicated special requirements for development here.

Figure 20: Entering Nahant Rotary from the Lynnway (Google Earth, 2020)

4.1.3 - Environmental Constraints

The project site lies within the range of baseline flooding that is expected with the 1% annual chance flood inundation (Figure 21). This is generally concerning, considering the area of currently impermeable surfaces, though, our designs aim to modify this existing area rather than adding to the total impervious surfaces, wherever possible.

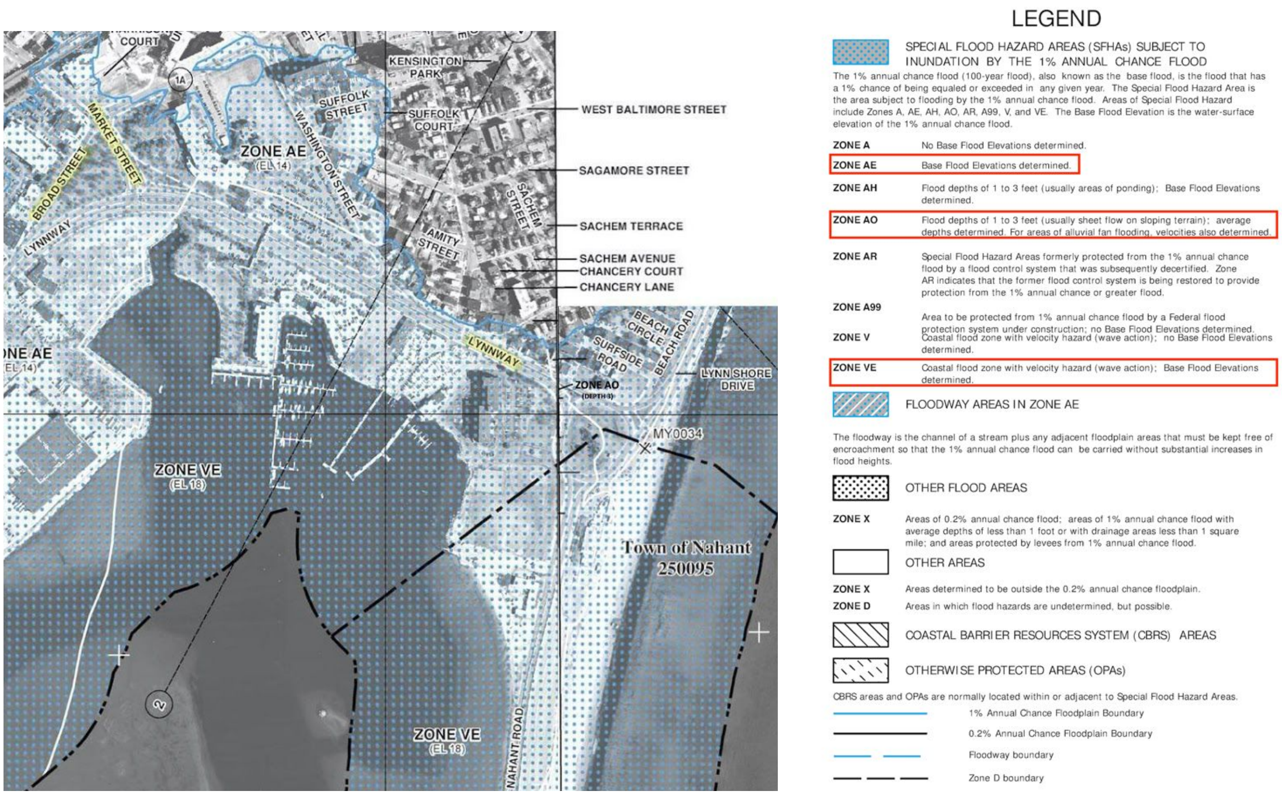


Figure 21: Flood map and legend of the project site and surrounding area (City of Lynn, 2019)

Other notable constraints also include those associated with the nearby ocean. Priority habitats of rare species are found along Nahant beach, where this trail ends. In Figure 22, priority habitats are indicated by the green polygon. Coastal bank loss, currently minimal, may not immediately affect the bike path but could have a long term effect in Lynn. Coastal bank loss was compared in 1990 and 2014; yellow lines indicated low loss within the margin of error, while orange lines represent moderate loss. The Sea Level Affecting Marshes Model (SLAMM) estimates minimal changes in local waterways and wetlands over the next five decades. While updated bicycle and pedestrian routes do not pose an imminent threat to any of these concerns in the surrounding environment, it is important to keep any potential for harm in mind during any development project.

Figure 22: Priority habitats of rare species and coastal bank loss near project site (GIS, 2020)

Of the several greenspaces along the project route, some are owned by the Department of Conservation and Recreation (DCR). Note that the colors of the parks in the map below (Figure 23) simply indicated whether they were open or closed due to the pandemic. Lynn Heritage State Park, being near but not encompassing the site, may be avoided in our designs, but the Lynn Shore and Nahant Beach Reservation are unavoidable in the scope of this project.

Figure 23: DCR parks located within project scope (Policy Guide, 2011)

Finally, the whole of our project scope is within Massachusetts's Coastal Zone (Figure 24). The Coastal Zone Management Program, passed by U.S. Congress in 1972 to "preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone" ("Policy Guide", 2011). The states are responsible for developing their own coastal management programs; in Massachusetts, the members of the EOEEA, the agency primarily funding this project, are involved in coordinating the program.

Figure 24: The inland limit of the coastal zone, indicated by the red line (GIS, 2020)

4.2 - Objective 2: Evaluate Existing Conditions

Understand the existing operational conditions for the signalized intersections of Market Street and Broad Street, Market Street and the Lynnway, and the rotary.

4.2.1 - Intersection Analysis

The level of service (LOS) of an intersection indicates the average number of seconds each vehicle must wait before proceeding through the intersection. A LOS of A indicates free flow, where the delay is less than ten seconds, while F indicates forced flow, with a delay of greater than eighty seconds (*Highway Capacity*, 2010). Generally, if a new development causes a functional intersection to fail, the developer must perform traffic studies and make adjustments to the traffic pattern to improve flow. The levels of service of various intersections within our project scope are indicated in Figure 25, as determined by the Boston MPO.

Figure 25: Level of service (Google Earth, 2020)

4.2.2 - Crash Reports

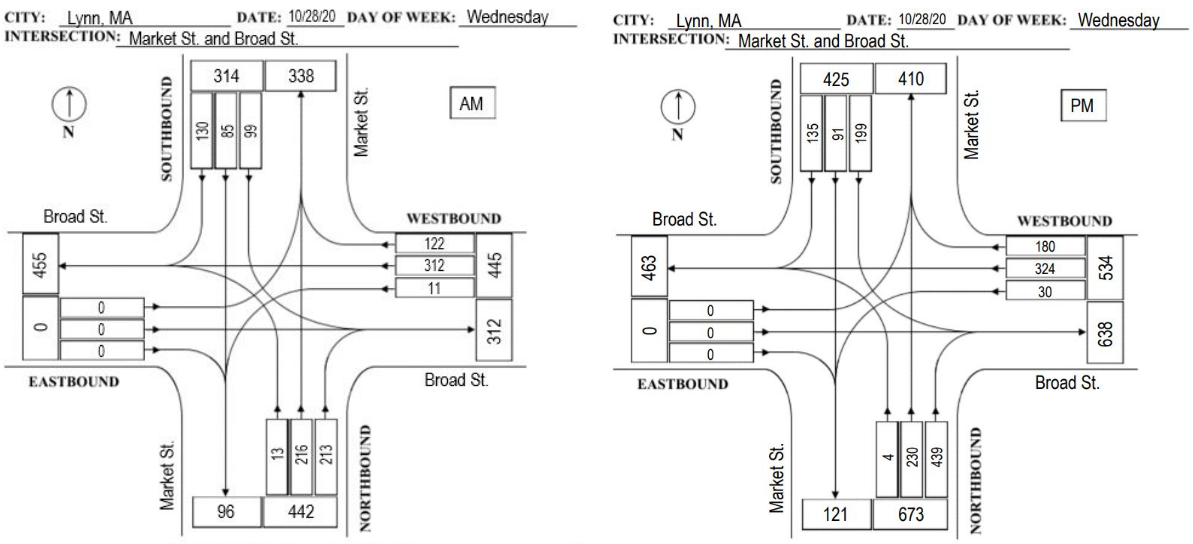
Crash report data, collected by Boston MPO, was used to calculate estimated crashes per five years and is presented below (Figure 26). When making changes to the traffic pattern, it is important to note where crashes commonly occur. Our designs should not increase the likelihood of crashes and should, wherever possible, work to decrease the crash rate.

Figure 26: Crash reports (Google Earth, 2020)

4.2.3 - Effect of COVID-19 on Traffic Volumes

Data Collected

The group collected turning movement counts at the intersection of Market Street and Broad Street from 7:00-9:00 am and 4:00-6:00 pm on Wednesday, October 28th, 2020. Turning movement diagrams for the peak hours are shown in Figure 27. Historical turning movement count data and diagrams for the intersection of Market Street and Broad Street and the rest of the data we collected can be found in Appendix D.



STREET	ENTERING VOLUMES	PERCENT OF FLOW	TIME OF COUNT
Market St. NB	442	36.80%	7:15 – 8:15 AM
Market St. SB	314	26.15%	
Broad St. EB	0	0%	PHF = .95
Broad St. WB	445	37.05%	
			VEHICLES COUNTED
			ALL VEHICLES: 1201
TOTAL	1201	100.0%	TRUCKS: 107
			PERCENT TRUCKS: 8.91%

STREET	ENTERING VOLUMES	PERCENT OF FLOW	TIME OF COUNT
Market St. NB	673	41.24%	4:15 – 5:15 PM
Market St. SB	425	26.04%	
Broad St. EB	0	0%	PHF = .99
Broad St. WB	534	32.72%	
			VEHICLES COUNTED
			ALL VEHICLES: 1632
TOTAL	1632	100.0%	TRUCKS: 64
			PERCENT TRUCKS: 3.92%

Figure 27: Peak hour turning movement diagrams for Market Street and Broad Street

Based on our findings, the AM peak hour was between 7:15-8:15 am with a total of 1201 vehicles, and the PM peak hour was 4:15-5:15 pm with a total of 1632 vehicles. Overall, heavy vehicles were more prevalent in the morning peak hour at 107 total, or 8.91%, compared to the evening peak hour with 64 heavy vehicles or 3.92%. The AM and PM peak hours had peak hour factors (PHF) of 0.95 and 0.99, respectively. PHF is used to "convert the hourly traffic volume into the flow rate that represents the busiest 15 minutes of the rush hour" (Tarko and Perez, 2005). Our values are consistent with expected PHF values because, generally, an intersection's PHF is lower in the morning than the afternoon/evening, the PHF will be higher in busier/more urban areas, and are within the range of 0.80-0.98 (Tarko and Perez). Our PHF values are also closer to 1.0, which indicates the traffic flow over the peak hour is more uniform.

COVID Analysis

To compare the group's observed values of COVID-19 data to the existing data from the Market Street and Broad Street intersection, as displayed in the table below, all data was first annualized using the MassDOT seasonal correction factors from the appropriate years. Additionally, traffic volumes typically change over time, so in order to draw conclusions about the effect of

COVID-19 on traffic volumes, annual growth rates must also be used to project non-COVID volumes for 2020. To do this, the group created both a high and low projection of expected non-COVID 2020 traffic volumes.

Table 2: 2020 peak hour volumes affected by COVID-19

	Type of 2020 data	Peak Hour Volume (veh/hr)*	Estimated % Change due to COVID-19
AM	Observed	1201	
	Low Projection	1524	-26.87%
	High Projection	1797	-49.64%
PM	Observed	1632	
	Low Projection	1930	-18.26%
	High Projection	2167	-32.76%

*volumes annualized using MassDOT seasonal axle correction factors.

The low estimate was calculated using the data from 2006 and 2015 of the same intersection. The data from 2006 had peak hour volumes of 2064 and 2275 for AM and PM, respectively, and 2015 had peak hour volumes of 1800 and 2170, respectively. Using the peak hour data from these years, an annual growth rate of -2.28% for the AM and -1.31% for the PM was calculated. This was then applied to the annualized 2015 data to make the 2020 projections. Compared to the observed values, it was found that COVID-19 had decreased the expected volume by 26.87% in the AM peak and 18.26% in the PM peak.

Another 2020 estimate was generated using a 1% annual growth rate from the 2015 data. This represents our high projection for 2020. This growth rate was used by BETA Group, Inc. in their 2005 Lynn Downtown Traffic Study, and claims to be representative of the annual traffic growth of this area. Using this growth rate, it was found that the intersection of Market Street and Broad Street experienced a 49.64% and 32.76% decrease in traffic volumes in the AM and PM peaks respectively.

In both scenarios, the intersection experienced a significant decrease in traffic volumes for both the AM and PM peak hours. This is consistent with our expectations that COVID-19 would decrease the number of vehicles during rush hours due to the increases in remote work and unemployment as a result of the pandemic.

4.3 - Objective 3: Develop Potential Solutions

The team used the above synthesis of the existing and collected data above to identify major design goals and requirements.

4.3.1 - Defining the Design Goals
A redesign of the waterfront is not a new topic of discussion for the City of Lynn. There are greenspaces in the surrounding areas that are not being utilized and the downtown area is cut off from waterfront businesses and recreation. Studies have been done and small projects have been implemented over the past five years, all with the focus on beautification and connectivity of the waterfront with Lynn's downtown to promote economic growth ("Priority Corridors"). One of the remaining propositions for the waterfront is this bike infrastructure. Additionally, in workshops and public meetings, the community members also expressed interest in making biking more accessible and safe for all. These goals were directly translated into our overall goals for the project designs.

Overarching Goals Identified

- Promote safety and accessibility
- Encourage alternative transportation (walking & biking)
- Connect the downtown and waterfront
- Ensure design can handle existing and future traffic volumes

To accomplish these, some safety features we identified were to focus on improving bicyclist visibility and awareness through lines of sight, signage, and pavement markings, and to increase accessibility through improved and updated pedestrian infrastructure. Another overarching goal for the project was to encourage use of the bike path by making it easy to navigate. Lastly, the integrity of the intersections and roadways must be maintained at the very least, and be able to accommodate future traffic volumes.

Additional design goals were identified for each project zone:

Project Zone 1
Since the team only designed the second half of the on-road bike trail, there is a designated tie-in spot on Market Street. This tie-in spot is a two-way bike lane located under the commuter rail overpass. One primary objective for our design was to maintain the vehicle traffic flow despite the implementation of new bike lanes along Market Street. One way to do that would be to put the new bike path and sidewalk in the greenspace adjacent to Project Zone 1 instead of taking a lane of traffic from that portion of Market Street. There is also potential conflict between southbound drivers taking a right turn onto Broad Street and the bikers continuing straight through the intersection. This issue can be minimized with signal timing, signage, and pavement markings. The team also considered the ability of the design to merge with other trail networks in Lynn and connect with a proposed bike path on Broad Street.

Project Zone 2
Project Zone 2 includes the intersection of Market Street and the Lynnway. The on-road bike trail will allow for a safe transition from Market Street to the Lynnway. Since this intersection was recently updated to accommodate the new development at 254 Lynnway, the team avoided making any drastic changes while implementing our design.

The bike path along the Lynnway could be on either the left or right side of eastbound traffic. If on the left, the bikers would ride along the median with greatly reduced accessibility to the businesses on the route. This could potentially force the bikers to exit the protected bike lane at an unsafe or unmarked area. There are two existing signalized crosswalks on the Lynnway that could be modified to allow bike traffic to cross, but more of those similar structures would have to be implemented as well. If the bike trail is on the right side of the Lynnway, the accessibility issue would be improved; however, there is now more vehicle interference at the driveway access points that intersect with the bike lane.

In general, Project Zone 2 has mostly automobile-oriented infrastructure. The designs considered this and made it more pedestrian and biker friendly by incorporating infrastructure that slows down vehicle traffic and protects those not in automobiles.

<u>Project Zone 3</u>
Project Zone 3 includes the rotary by Nahant beach. The bikers have an easy and safe way of merging with the vehicles yielding to enter and the vehicles exiting the rotary. The bike lane would be best when it avoids crossing traffic. If the bike lane must cross traffic, signalized crosswalks would be implemented to protect the bikers and pedestrians from points of interference. Lastly, the bike lane would conclude at the entrance of Nahant Beach to successfully connect the Northern Strand Community Trail to the ocean.

4.3.2 - Preliminary Designs
<u>Points of Interference</u>
After goals were established, the initial step of the design phase was to identify points of interference at each intersection, as shown in Figure 28 and 29, where the bike lane would be passing through the path of a vehicle. This informed our design choices, as minimizing points of interference would increase the safety of our designs.

Figure 28: Example of points of interference analysis for Market Street and Broad Street intersection (adapted from Google Earth, 2020)

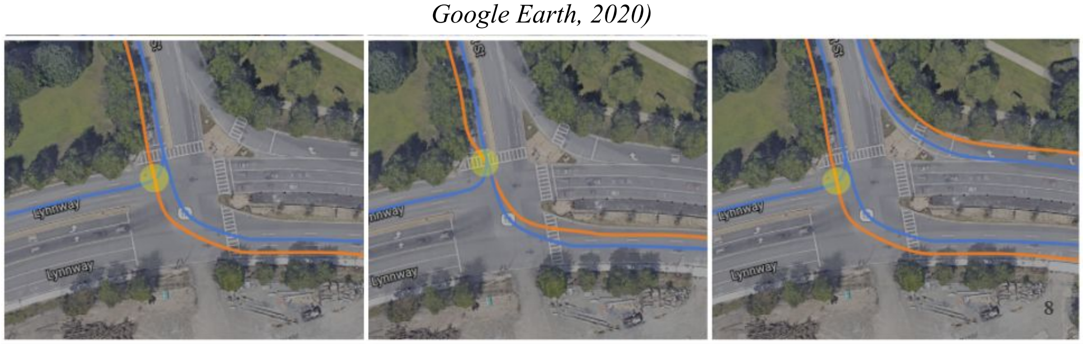


Figure 29: Example of points of interference analysis for Market Street and the Lynnway intersection (adapted from Google Earth, 2020)

Aerial and Perspective Drafting

After the main pathways were identified, the group examined the reference materials provided through MassDOT, AASHTO, and NACTO bike lane design guides. These guides informed us of the specific requirements such as the minimum lane widths, pavement markings, intersection crossings, driveway detailing, etc.. We used these details to draft aerial and perspective drawings of the design options to visualize each design option (Figure 29). This also allowed us to pick out any design aspects that could be visually confusing to drivers or bikers. Copies of all of the mock-ups can be found in Appendix E.

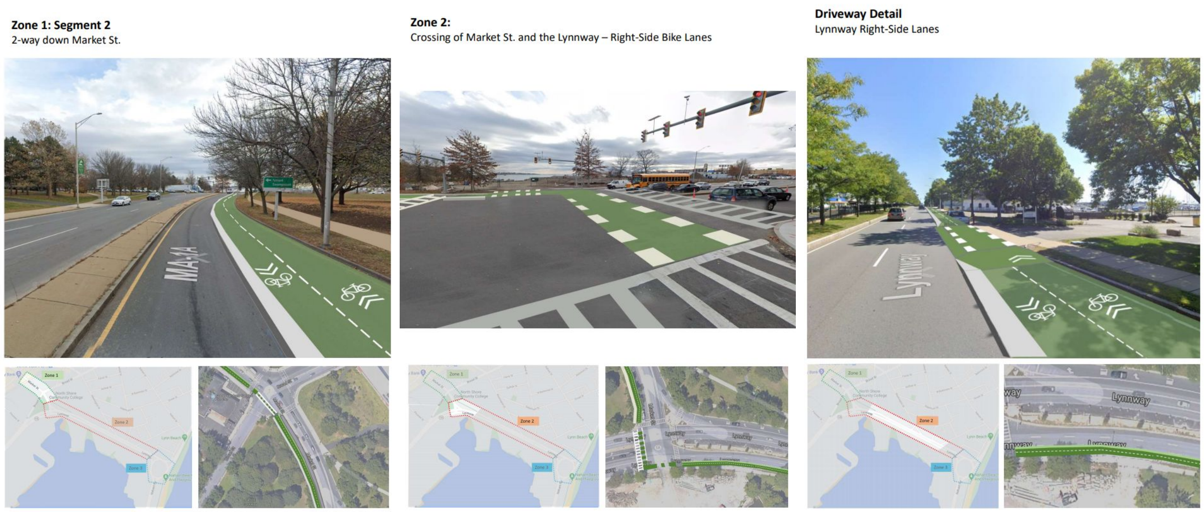


Figure 30: Example preliminary design mock-ups

Secondary details, such as curb heights and bike lane elevations, were decided upon after the final design choice as the preliminary design phase focused more on general layout and design.

Design Choice and Funding

Another important constraint the group considered during the design phase was the funding as different federal, state, and private grants have different project requirements that need to be met to be eligible to apply. Many projects utilize multiple sources of funding, which allows more flexibility. (“How Communities”, 2014). Although the on-street extension of the Northern Strand has obtained a contract through the Gateway Cities Program and the EOEEA, the team dove deeper into other potential sources of funding for the project on both federal and state levels.

Federally, there are a lot of programs that prioritize projects involving transportation updates, especially those which make the area more accessible and provide alternative modes of transportation. One notable example of this is the Congestion Mitigation and Air Quality Improvement Program (CMAQ). By making walking and biking to the Lynn waterfront more accessible, residents and visitors will not have to rely on vehicle traffic. Another example of federal funds would be the Highway Safety Improvement Program (HSIP). CTPS has identified that both the Lynnway and the Nahant Rotary would be eligible for federal funding through HSIP because of their classification as “urban principal [arterials]” and the HSIP “crash-cluster status” of the rotary (“Priority Corridors”). Lastly, designers could also look into other programs like the Surface Transportation Program (STP) and the Transportation Alternatives Program, which also incentivize projects which reduce the reliance on automobiles (*Funding for Community Transportation*).

There is also money available on the state level. MassDOT's Bicycle Network and Pedestrian Connections contains the Complete Streets Program which funds projects that prioritize the improvement of "walking, biking, transit and vehicles – for people of all ages and abilities" ("Complete Streets", 2016). The Complete Streets Program has already funded pedestrian crossings, sidewalks, and bike lanes in Lynn. Additionally, there are other grants such as the Massachusetts Community Health and Healthy Aging Funds which fund projects that address housing, transportation, and accessibility (*Mass Community Health*).

4.4 - Objective 4: Select the Final Design

Our preliminary designs were evaluated using a decision matrix in two steps. The criteria listed in the tables below stem from the eight design constraints listed in the Capstone Design Statement, as they have guided our work thus far. After each factor is assigned a proper point scale and assessed fairly, the option with the highest total score, out of 32, is noted as the optimal design in that matrix.

There were three alternative design schemes in consideration. The decision matrix in Table 3 displays the comparison of these alternatives.

Alternative A: 2-Way Separated Bike Lane on One Side of Roadway

Alternative B: 1-Way Separated Bike Lane on Each Side of Roadway

Alternative C: Shared Lane on Each Side of Roadway

Table 3: Design Scheme Decision Matrix

Factors Considered (and related maximum point value)		Alternative A	Alternative B	Alternative C
Accessibility	**5**	5	5	2
Safety	**5**	4	4	1
Traffic Impact	**4**	3	3	3
Cost	**4**	3	2	4
Easements	**3**	3	3	3
Constructability	**3**	2	1	3
Environment/ Sustainability	**3**	3	3	3
Long-Term Maintenance	**2**	2	1	2
Adaptability into other bike networks	**2**	2	2	2
Aesthetics	**1**	0.5	0.5	1
Total	**32**	**27.5**	**24.5**	**24**

Based on the results in Table 3, the optimal design is Alternative A, a two-way separated bike lane. Alternative A could be designed in a number of ways. We outlined two options for Market Street and two options for the Lynnway. Designs on the two roads could all function independently of each other, creating a total of four possibilities when these options are mixed and arranged. The decision matrix in Table 4 was used to determine the optimal combination of two-way separated bike lanes on Market Street and the Lynnway.

Market Street Alternative 1: Bike Lanes in Existing Green Space next to Market Street

Market Street Alternative 2: Bike Lanes in Existing Right Lane of Market Street

Lynnway Alternative 1: Bike Lanes in Existing Left Lane of Lynnway

Lynnway Alternative 2: Bike Lanes in Existing Right Lane of Lynnway

Table 4: Alternative A Decision Matrix

2-Way Separated Bike Lane Options		**Market St**		**Lynnway**	
Factors Considered (and related maximum point value)		Alternative 1	Alternative 2	Alternative 1	Alternative 2
Accessibility	**5**	5	5	3	5
Safety	**5**	5	4	4	3
Traffic Impact	**4**	4	3	3	3
Cost	**4**	2	3	3	3
Easements	**3**	2	3	3	3
Constructability	**3**	2	2	2	2
Environment/ Sustainability	**3**	1.5	2	3	3
Long-Term Maintenance	**2**	2	2	2	2
Adaptability into other bike networks	**2**	2	2	1	2
Aesthetics	**1**	0	1	1	0.5
Total	**32**	**25.5**	**27**	**25**	**26.5**

Based on the results in Table 4, the optimal design for Alternative A is the combination of Market Street Alternative 2 and Lynnway Alternative 2.

5.0 - Conclusions

The following section provides an overview of our final design layout as well as its associated design specifications, cost analysis, and design implications. Design choices are justified using associated industry standards, and areas with variability in acceptable options were given explanations of how we made those design choices.

5.1 - Design Recommendation

Our analysis of the various design options of bike and pedestrian accommodations in Lynn led us to recommend the complete design and construction of a two-way separated bike lane in the existing right lanes of Market Street and the Lynnway to Nahant Beach.

The key criteria that proved this design better than Alternative B, one-way separated lanes on each side, were cost, constructability, and long-term maintenance. Alternative B would likely require a larger budget due to more complicated design specifications and the construction costs of installing bike lanes on both sides of the road instead of just one. Additionally, a one-way lane would not be wide enough for a plow to drive through, rendering the path useless during the winter months.

The right lane path on Market Street was preferred over a path in the greenspace primarily due to the complications of land easements. The greenspace along Market Street is owned by the City of Lynn and could involve a more complicated process to gain rights to develop. The right lane design is also advantageous in that the trees in the greenspace will not need to be cleared to make way for the bike lane.

The right lane design on the Lynnway was chosen over the left lane path due to the limited accessibility to a trail that runs along the median. The safety of users at driveway intersections is a concern in the chosen design; however, we believe additional pavement markings, signs, and elevation differentiation will ensure safety of both cyclists and drivers.

5.1.1 - Design Mock-Ups

AutoCAD was utilized to create more detailed drafts of the designs for the whole project scope (See Figure 31). Using existing conditions from survey files provided by the EOEEA, the MQP final design was drawn using AutoCAD. This includes the general layout of the bike path and its median; the infrastructure to be removed, protected, retained, or added; various pavement markings on and off the bike path; the signage to be added; as well as typical pavement cross sections. The full set of AutoCAD sheets can be found in Appendix F.

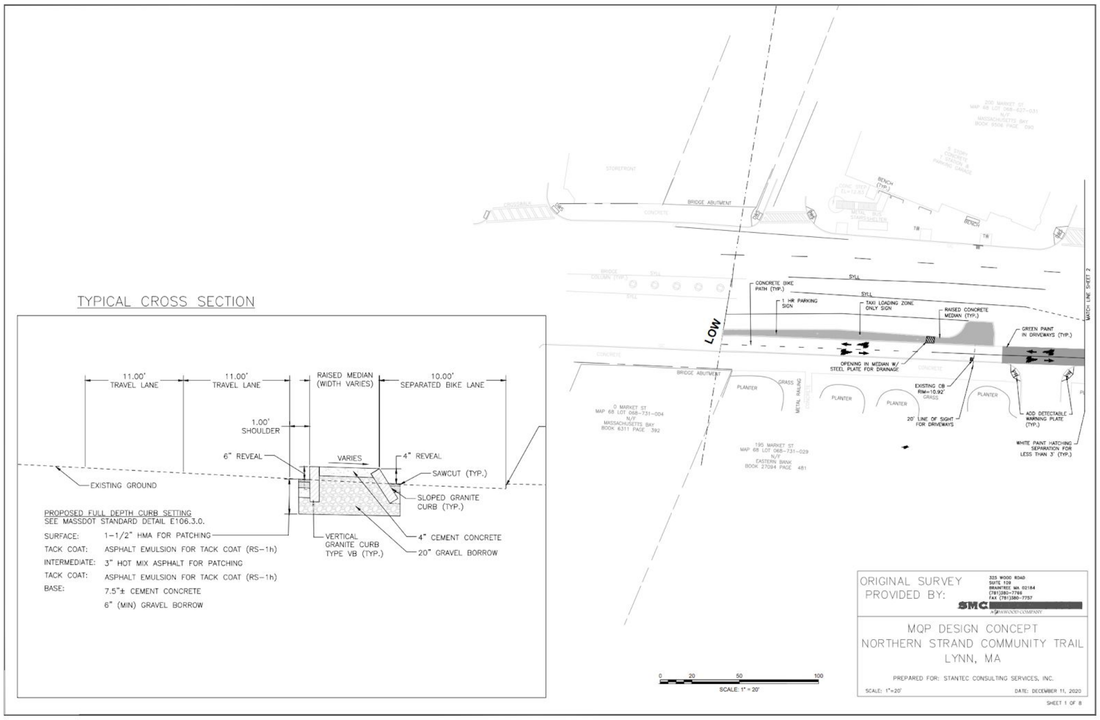


Figure 31: AutoCAD design

Additionally, the perspective and aerial mock-up graphics previously presented were updated to better reflect final design specifications. Full versions of these mock-ups can be found in Appendix G.

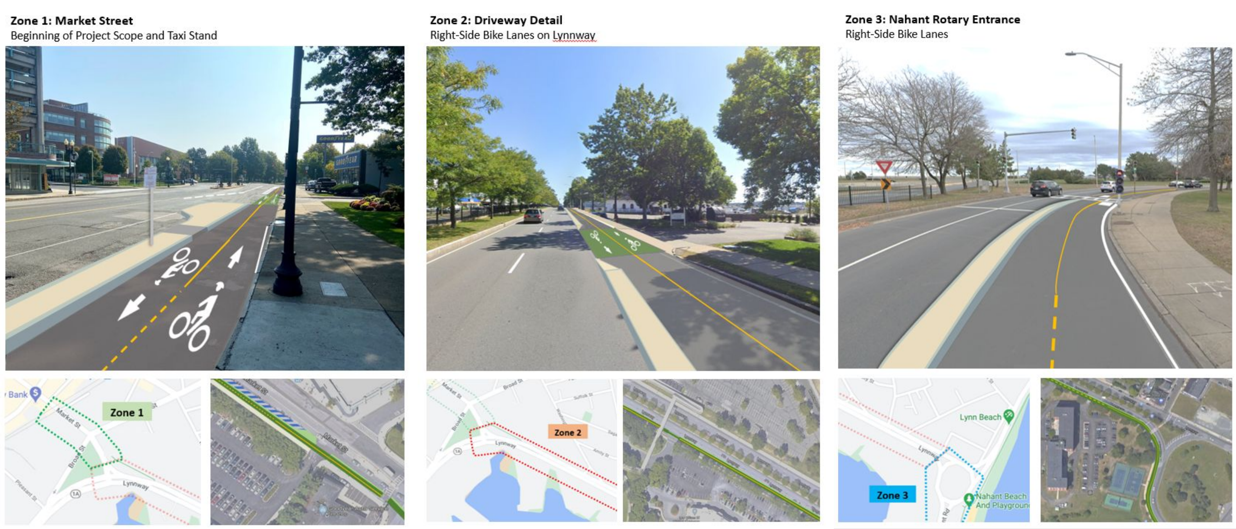


Figure 32: Final design mock-ups

5.1.2 - Details and Specifications

Upon the selection of the final design layout, key design choices regarding pavement treatments, markings, signage, crossings, signaling, and the handling of utilities were made by the group. These decisions were informed by the *MUTCD,* the *NACTO Urban Bikeway Design Guide,* *ADA regulations, AASHTO Guide for the Development of Bike Facilities,* and the *MassDOT Separated Bike Lane Design Guide* to ensure our final design follows industry standards. Details are as follows:

Complete Streets and Roadway Layout

Designing complete streets was a priority throughout the scope of the project. This is the method of designing for all users of the space: the drivers, pedestrians, and bicyclists. For our design, as we were retrofitting a bike lane into an existing roadway, our priority was to make the space safer for bicyclists without lowering the roadways' functionality for the vehicles as well as considering the future traffic levels.

One design issue we encountered was at the beginning of the scope on Market Street. In order to accommodate a 10ft bicycle lane with separation, we had to reconfigure the island in order to maintain an acceptable travel lane width and shoulder (Figure 33). The original lane configuration here featured lanes ~15ft in width, which is very wide for urban areas and can contribute to speeding. Lane narrowing is an effective method at reducing speeding, and our design's narrowing of the lanes to 11ft plus a 1ft shoulder is still wide enough to ensure driver comfort.

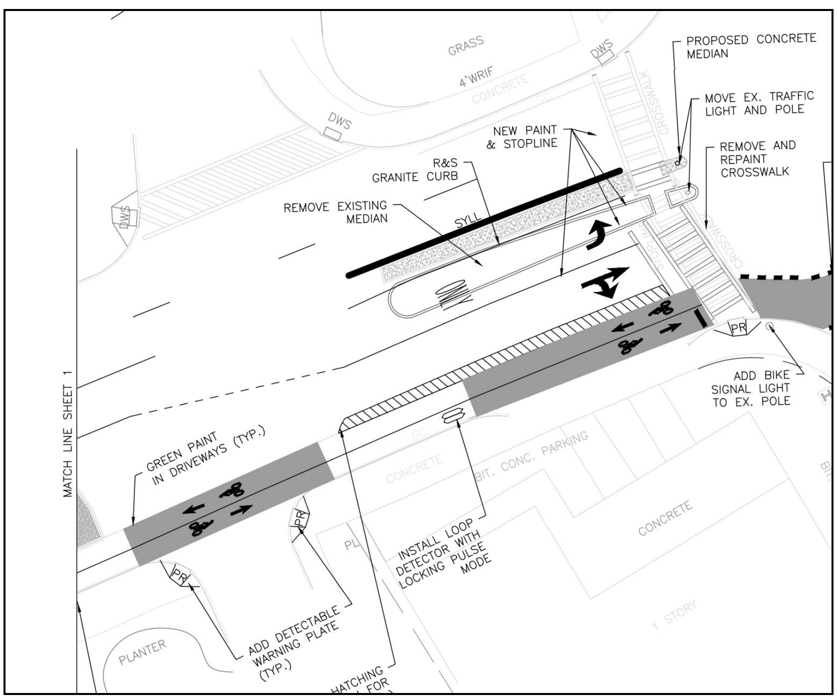


Figure 33: Median and lane reconfiguration at Market Street and Broad Street intersection

Also along this portion of Market Street is a taxi-loading zone. As a major goal of the project and the city is to maintain existing on-street parking, the team incorporated a taxi-loading zone area toward the tie-in with the out of scope design that ensures the spaces will be maintained. If the city wanted to convert these loading zones into parking, this could easily be achieved by a change of signage.

The intersection of Market Street and the Lynnway has recently undergone intersection reconfiguration due to a new residential development being constructed. Because of this, we were advised against making any major intersection design changes. Therefore, the only changes we designed at this intersection were the paint for the bike crossing and adding bicycle traffic signals and signage.

Lastly, we had the opportunity to make improvements to the space for pedestrians. We identified a total of 7 ramps that lacked detectable warning plates as well as two areas along the Lynnway where the sidewalk was in poor condition. As construction of our design would require the right lane to be closed to traffic, it is a good opportunity to make these updates to the sidewalks in congruence with the bike lane construction.

Pavement Treatment and Medians

Another major design factor considered was whether the surface of the bike lane would be milled and resurfaced or whether the bike infrastructure would utilize the existing pavement surface. The team considered the option of resurfacing the entirety of the bike lane; however, cost estimates, outlined in Table 5 below, revealed that resurfacing would add an additional $150,000, increasing the overall estimate by around 15%. Given that upon visiting the site, the team witnessed that the pavement surface was in great condition outside of a couple potholes near the tie-in point. Thus, the cost was not justified, and the team opted to just repair the small amount of damaged pavement and leave the rest as is.

Table 5: Cost estimation for the resurfacing

ITEM	Unit	Amount	Unit Price	Total Price
MILLING	sq yd	4,275	$7.00	**$29,925**
REMOVE&RESET GAS/WATER GATES	each	3	$667.33	**$2,002**
REMOVE&RESET GUTTER INLET	each	12	$2,250.00	**$27,000**
REMOVE&RESET HANDHOLES	each	2	$365.59	**$731**
REMOVE&RESET MANHOLES	each	11	$365.59	**$4,021**
SURFACE COURSE	tons	350	$150.00	**$52,500**
TACK COAT	gal	428	$8.25	**$3,531**
			Base Total:	$119,711
			With Contingency	$150,000

Medians were designed with the safety and comfort of bicyclists in mind as well as the aesthetics of the roadway. For medians, asphalt berms, concrete curbs, and granite curbs are all acceptable, but the group chose to use granite curbs (see Figure 34 below) to match the look of existing structures throughout the project.

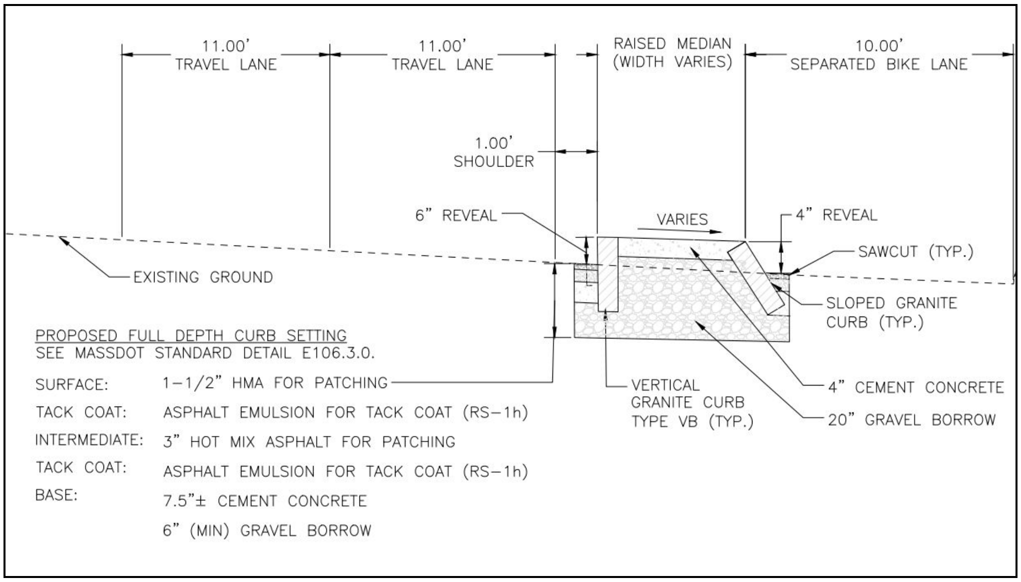


Figure 34: Typical cross section

The side of the median along the bike lane has sloped granite curb with a 4" reveal. The sloped curb is more biker-friendly than a vertical curb as it reduces the risk of wheel strikes. For the other edge, which abuts the vehicle driving lane, the group chose to use vertical granite curbs with a 6" reveal to discourage vehicle encroachment. In places near existing fire hydrants, such as in Figure 35, we changed the curb to mountable granite curbs to allow emergency vehicles access.

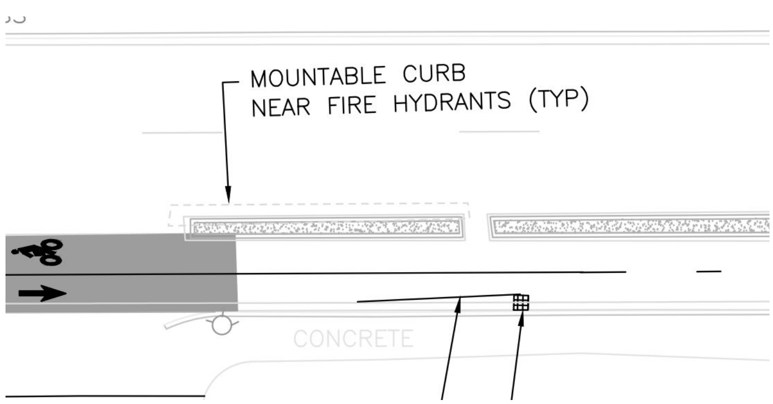


Figure 35: Mountable curb at fire hydrant

Pavement Marking, Wayfinding, and Signage

The MUTCD provides guidelines for signage and markings on and along bicycle lanes. General marking guidelines include color and size of various symbols. In accordance with Section 9C.03, a yellow line indicates travel in opposite directions in our design. This yellow line is dashed, except within approximately 40 feet of driveways and intersections, in which case the yellow line is solid to discourage passing. The size of the dashes adheres to the 1-to-3 segment-to-gap ratio, with 3-foot dashes spaced 9-feet apart (Figure 36)

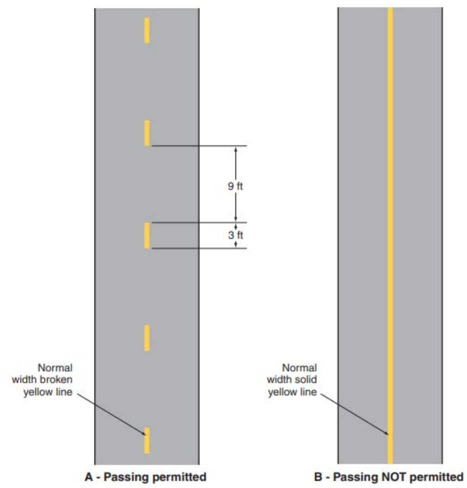


Figure 36: Bike lane centerline markings (MassDOT, 2015)

The bicycle lanes are identified by bicyclist symbols and arrows located at lane beginnings and periodically throughout the project scope. As defined by MUTCD Section 9C.04, bicycle lanes can be defined by a bike, a bicyclist, or the words “bike lane” (Figure 37).

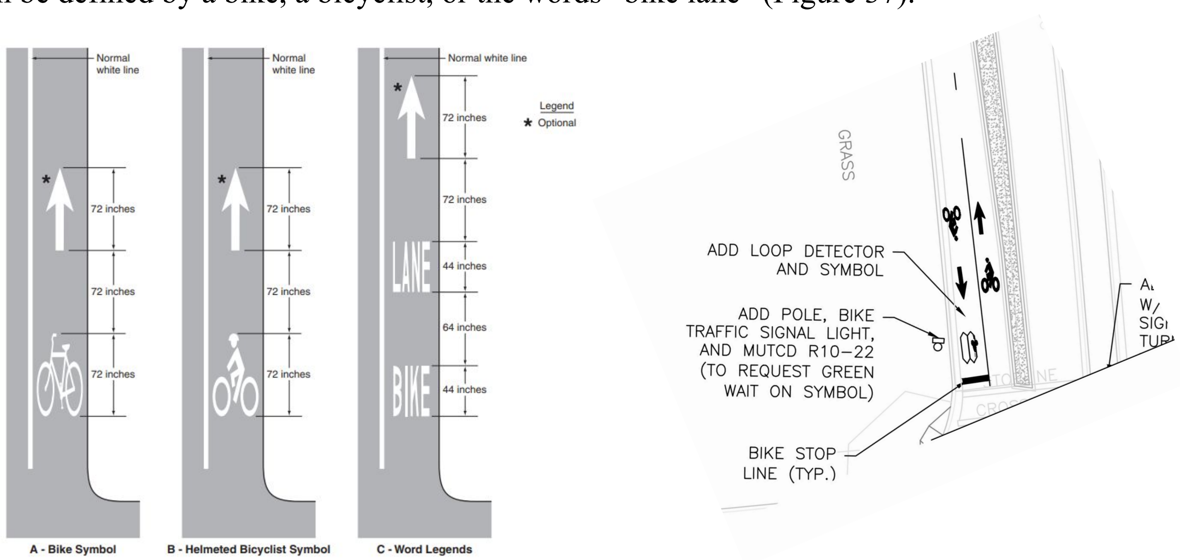


Figure 37: Bike lane indication markings (MUTCD, 2009)

MassDOT regulations require street-level painted medians to be painted with diagonal cross hatching when they are less than 3 feet wide (Figure 38). Our designs include street-level medians instead of elevated medians in three places: one to avoid moving a manhole cover, one where the median is very short in length between two driveways, and a third on Market Street to maintain vehicle access to the Goodyear Tire driveway.

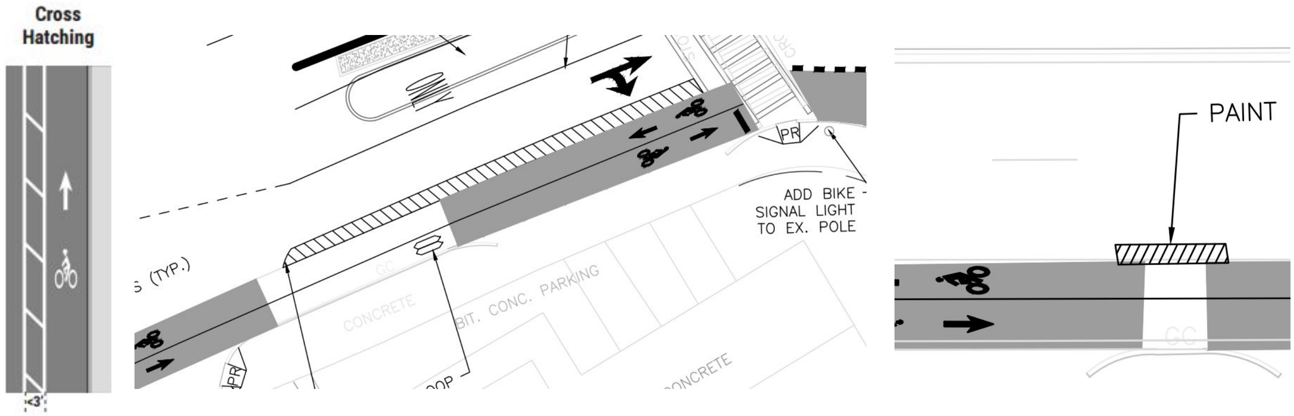


Figure 38: Cross hatching in place of the raised bike median

At both intersections within our project scope, loop sensors should be installed to call for a signal change to allow cyclists to cross. At the intersection of Market and Broad Streets, cyclists will travel at the same time as vehicle traffic, so the loop detector is placed further back from the stop line (NACTO, 2013) . Because of the turn required at the intersection of Market Street and the Lynnway, bicycles will travel during the pedestrian signal. To call for the signal for waiting bikes at this intersection, the loop detector at this intersection is located immediately behind the stop line. The MUTCD Bicycle Detector Symbol in Figure 39 is marked on the pavement at the location of the loop sensor to indicate the ideal location to activate the signal. In addition, MUTCD Sign R10-22 should be placed near the bike signal at the intersection of Market Street and the Lynnway to encourage cyclists to wait on the marking, where the sensor is located.

Figure 39: Bicycle detector symbol and sign (MUTCD, 2009)

In accordance with MassDOT Separated Bike Lane Guidelines, green markings in the bike lane are used only at points of interference, such as driveways and intersections. Stop lines are appropriately placed ahead of all crosswalks, and dotted white lines outline the bike lane within intersections. To improve driver awareness at bike and pedestrian crossings, MUTCD warning signs are also used. If the arrow is most appropriate by engineering judgement, it is placed approximately 10 feet ahead of the crosswalk and where the "trail x-ing" sign is more appropriate, it is placed approximately 75 feet ahead of the crosswalk. (Figure 40).

Figure 40: Warning signs W11-15, W11-15P, and W15-7P (MUTCD, 2009)

Finally, wayfinding signs are included in several locations where the path turns (Figure 41). A sign at the intersection of Market Street and the Lynnway instructs cyclists to turn left or right, depending on their direction of travel, and again at the turn towards the beach entrance. Another sign located at the beach entrance indicates the end of the Northern Strand Community Trail.

Figure 41: Wayfinding signs D11-1, M6-1, and M4-6 (MUTCD, 2009)

Utilities

To properly implement a separated bike path onto an existing roadway, certain utilities in the path of construction were assessed. The gutter inlets are currently in the existing far right lane of the corridor, and our proposed design does not move them. Since the final design will only require a sawcut and trench to construct the median and no resurfacing will be done, the swale will remain along the sidewalk curb. Water will now be temporarily obstructed by the new bike median and travel along that curb. There will be cuts with a minimum width of 2-feet along the bike median (Figure 42) to allow the water to flow across the bike lanes and into a nearby catch basin (*Separated Bike Lane,* 2015). To meet AASHTO HS20 loading conditions, a steel plate will be placed in the median opening when adjacent to parking (Figure 42). According to MassDOT's *Separated Bike Lane Planning & Design Guide*, Type B-1 Hook Lock Cascade Grates are preferred in bike lanes with flow entering from the left; however, the existing inlet grates do not have any opening large enough to catch a bike wheel so the existing inlets will remain. There will also be a 20-foot solid white line that precedes the gutter inlets to alert bikers.

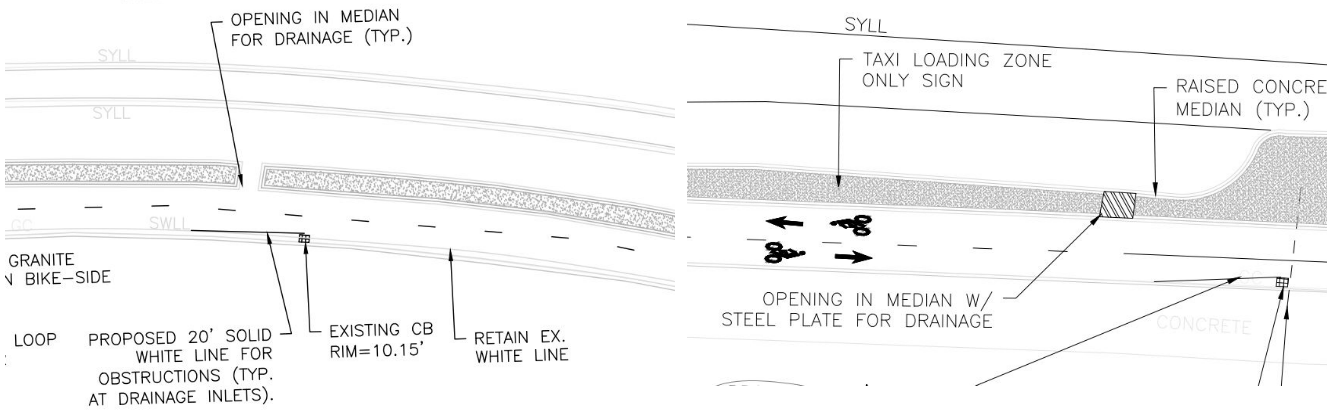


Figure 42: Median cuts for drainage

For the manholes that are partially within the bike median, the existing manhole will remain and the median will be cut on either side (Figure 43). For manholes that are entirely within the bounds of the median, risers will be used to raise the manhole cover to the same elevation as the median (Figure 43).

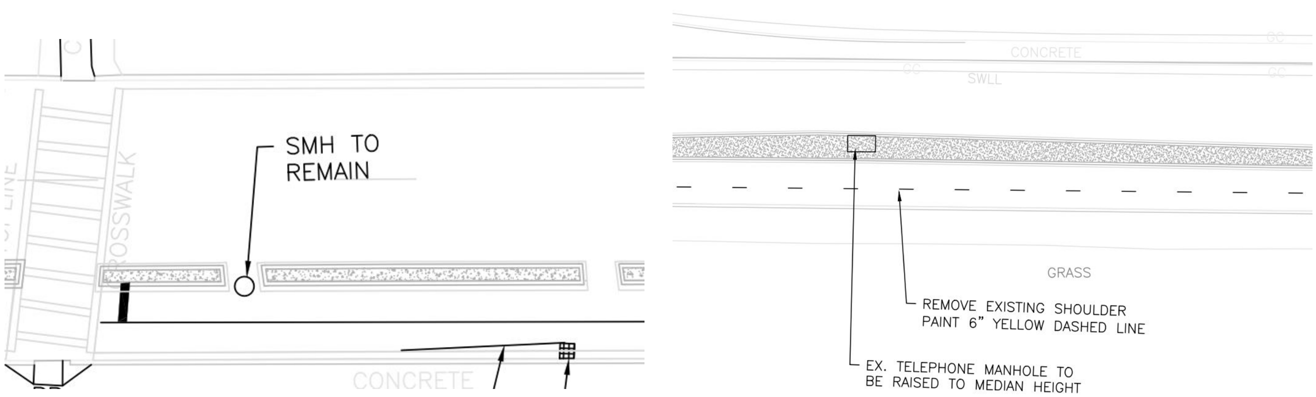


Figure 43: Median cut for manholes (left) and manhole risers within the median (right)

5.1.3 - Preliminary Cost Estimate

The *MassDOT Standard Items* list was used to properly breakdown and estimate the cost associated with the later design recommendations as shown below in Table 6 (MassDOT). With a 25% contingency, as suggested by our sponsors at Stantec, our final cost estimate came to $2.3M, which equates to roughly $540/ft.

Table 6: Cost estimation for the final design

ITEM	Unit	Amount	Unit Price	Total Price
12 INCH REFLECTORIZED WHITE LINE (PAINTED)	ft	1,743	$3.80	**$6,625**
6 INCH REFLECTORIZED YELLOW LINE (PAINTED)	ft	460	$0.69	**$317**
6 INCH REFLECTORIZED WHITE LINE (PAINTED)	ft	4,840	$0.69	**$3,340**
BENCHES	each	5	$2,641.09	**$13,205**
BIKE CROSSINGS - GREEN PAINT	sq ft	10,365	$1.40	**$14,511**
BIKE LANE MARKINGS	each	26	$500.00	**$13,000**
BIKE LANE PAINT (6 INCH REFLECTORIZED YELLOW, PAINTED)	ft	2,444	$0.69	**$1,686**
BIKE RACKS	each	1	$962.93	**$963**
CEMENT CONCRETE	cubic yd	178	$1,200.00	**$213,600**
CEMENT CONCRETE SIDEWALK	sq ft	400	$7.13	**$2,852**
DETECTION WARNING PLATE	each	12	$160.00	**$1,920**
GRANITE CURB REMOVE AND RESET	ft	180	$29.13	**$5,243**
GRANITE CURB (TYPE VB)	ft	5,600	$44.04	**$246,624**
GRANITE CURB TYPE VB (CURVED)	ft	716	$53.76	**$38,492**
GRAVEL BORROW	cubic yd	662	$45.00	**$29,790**
HMA FOR PATCHING	tons	210	$225.00	**$47,250**
INSTALLING LOOP SENSORS FOR BIKES	each	4	$390.00	**$1,560**
MAINTENANCE OF TRAFFIC CONTROL SIGNAL SYSTEMS	LS	1	$37,333.33	**$37,333**
MANHOLE RISER	each	1	$200.00	**$200**
MEDIAN REMOVED (CONCRETE)	sq ft	575	$4.00	**$2,300**
MEDIAN REMOVED (GRANITE CURB)	ft	155	$5.00	**$775**
MILLING	sq yd	5	$7.00	**$35**
MOUNTABLE GRANITE CURB	ft	300	$64.00	**$19,200**
NEW HANDHOLES	each	2	$1,368.09	**$2,736**
NEW SIGNS/POSTS	each	10	$25.08	**$251**
NEW TRAFFIC CABINETS	each	1	$2,000.00	**$2,000**
NEW TRAFFIC SIGNALS (BIKE SIGNALS)	each	6	$650.00	**$3,900**
PAINT LINES&SYMBOLS REMOVED	ft	756	$1.96	**$1,482**
REMOVE&RESET GAS/WATER GATES	each	1	$667.33	**$667**
REMOVE&RESET MANHOLES	each	1	$365.59	**$366**
REMOVE&RESET SIGNS/POSTS	each	1	$150.00	**$150**
REMOVE&RESET TRAFFIC SIGNALS	LS	1	$4,833.33	**$4,833**
SAWCUT	ft	6,900	$3.36	**$23,184**
STANDARD SIGNAL POST FOUNDATION SD3.030	each	4	$1,697.43	**$6,790**
STEEL PLATE FOR DRAINAGE CUT IN MEDIAN	each	1	$400.00	**$400**
TACK COAT	gal	70	$8.25	**$578**
TRASH RECEPTACLE	each	5	$2,110.50	**$10,553**
TREE PROTECTION	each	70	$354.10	**$24,787**
TREE REMOVAL (<24")	each	4	$1,340.02	**$5,360**
UNCLASSIFIED EXCAVATION	cubic ft	24,532	$40.00	**$981,280**
			Base Total:	$1,763,514
			With Contingency:	$2.3M

5.2 - Design Implications

The design discussed above, which will be further developed, will have both positive and negative implications. Most obviously, it will provoke changes in the local traffic patterns. There will be minimal detours required during construction because only one side of the road will be impacted, but some lanes will have to be closed. After construction, the traffic pattern will not change dramatically but will operate with one less lane throughout the project scope. We believe the roadways can handle existing traffic volumes even without this lane for vehicles. We also believe future traffic volumes will not overwhelm these roads, especially considering the negative growth rate seen between 2006 and 2015. Additionally, vehicle volumes may decrease further due to drivers choosing to bike instead, most notably to the beach. The new bike lanes may also impact traffic by reducing average speeds due to narrower lanes and added awareness of bicyclists.

Our analysis of the impact of lane configuration changes at the intersection of Market and Broad Street confirmed the minimal impact these changes will have on traffic flow (Table 7). According to HCS simulations (found in Appendix H) of the intersection before and after the bicycle lanes are installed, the LOS and average delay will remain approximately the same.

During the morning peak hour, approach delays are expected to increase in the westbound direction and decrease in the north and southbound lanes. During the evening peak hour the opposite trends are expected, but these changes all average to less than a one second change in total intersection delay.

Table 7: Traffic flow comparison at Market and Broad Street

		Westbound		Southbound		Northbound	
		Existing	**Proposed**	**Existing**	**Proposed**	**Existing**	**Proposed**
Approach LOS, Delay (s)	AM	A, 7.2	B, 14.0	A, 10.0	A, 7.7	A, 9.9	A, 7.3
	PM	B, 14.4	B, 14.0	A, 8.8	A, 8.0	A, 7.6	A, 9.4

		Existing	Proposed
Intersection LOS, Delay (s)	AM	A, 9.0	A, 9.9
	PM	B, 10.3	B, 10.5

One undoubtedly positive implication of this design is its limited impact on the environment. The new lanes will be incorporated into the existing roadway, so there won't be any addition of impervious surface area, which is especially important in a flood zone. The bike lanes also will not overstep the boundaries of any abutting parks or greenspaces. The new infrastructure will draw pedestrians and cyclists to these outdoor community spaces from the towns currently connected by the Northern Strand Trail and will prove a sustainable design over the years as more bike networks can be connected.

New bicycle accommodations will also draw traffic to Lynn businesses. The Waterfront Master Plan stated the economic potential in this area, provided convenient access to the numerous businesses along the Lynnway both on the waterfront and across the street, easily accessible via the pedestrian bridge. The bike lanes will also bring accessibility and recreation to those living in the nearby residential buildings and attending the community college on the Lynnway.

Added recreational opportunities and accessibility to parks are just two of many benefits to the community of Lynn. This project will also improve accommodations in compliance with the Americans with Disabilities Act, allowing those with big and small wheels to go to the playground and the beach. Cyclists currently sharing the roadway with vehicles will be much safer in a separated lane, and pedestrians will be safer on rehabilitated sidewalks. Notes from past meetings with local residents indicated further future developments this project could lead to, such as tool racks for bikes and trash bag dispensers along the path. We would also hope to include benches, trash receptacles, planter boxes, and map displays if the budget allows. As the Gateway Cities Parks Program has identified, many people living in Lynn are disadvantaged and deserving of these improvements.

References

"2010 ADA Standards for Accessible Design." US Department of Justice, 15 September 2010, https://www.ada.gov/regs2010/2010ADAStandards/2010ADAstandards.htm#marker-1012120. Accessed 27 October 2020.

About Us. Bike to the Sea Foundation, https://biketothesea.org/about-us/.

"Complete Streets Funding Program Guidance." MassDOT, January 2016, https://www.mass.gov/doc/complete-streets-funding-program-guidance/download.

Construction Project Estimator. MassDOT - Highway Division, n.d., https://hwy.massdot.state.ma.us/CPE/About_PrelimEstimate.aspx.

"Downtown Traffic Study." Beta Group, Inc., *City of Lynn*, March 2005, http://www.cityoflynnoecd.net/documents/resource/Downtown%20Lynn%20Traffic%20Study.pdf.

Fay, Spofford, & Thorndike, LLC. "2006 Lynn Traffic Data." 2006.

"FEMA Flood Map Service Center." FEMA. https://msc.fema.gov/portal/search?AddressQuery=lynn%2C%20mas#searchresultsanchor. Accessed October 2020.

Funding for Community Transportation. MassMobility. n.d., https://www.mass.gov/info-details/funding-for-community-transportation

"Guide for Development of Bicycle Facilities." AASHTO, 2012, https://njdotlocalaidrc.com/perch/resources/aashto-gbf-4-2012-bicycle.pdf

Highway Capacity Manual 2010. City of SeaTac*,* 2010. https://www.seatacwa.gov/home/showdocument?id=11371. Accessed 9 November 2020.

"How Communities are Paying for Innovative On-Street Bicycle Infrastructure." Advocacy Advance, June 2014, https://bikeleague.org/sites/default/files/PayingForInnovativeInfrastructure.pdf

Lynn Waterfront Master Plan Report. EDIC, City of Lynn, 2007, http://www.ediclynn.org/files/LynnFinalReport_LowRes_9-07.pdf.

Massachusetts Community Health and Healthy Aging Funds. Massachusetts Department of Public Health and Executive Office of Elder Affairs. n.d. https://mahealthfunds.org/

Northern Strand Community Trail. The Lawrence & Lillian Solomon Foundation, https://www.solomonfoundation.org/projects/northern-strand/.

"Policy Guide". Massachusetts Office of Coastal Zone Management. October 2011. https://www.mass.gov/files/documents/2016/08/qc/czm-policy-guide-october2011.pdf. Accessed 9 November 2020.

"Priority Corridors Lynnway Appendices." CTPS & Boston MPO, June 2016, https://www.bostonmpo.org/data/pdf/studies/highway/2015_priority_corridors/2015_Priority_Corridors_Lynnway_Appendices.pdf.

"Route 1A/Lynnway/Carroll Parkway Study in Lynn." CTPS & Boston MPO, June 2016, http://www.ctps.org/data/pdf/studies/highway/2015_priority_corridors/2015_Priority_Corridors_Lynnway.pdf.

Separated Bike Lane Planning & Design Guide. MassDOT, 2015. https://www.mass.gov/lists/separated-bike-lane-planning-design-guide.

Separated Bike Lane Planning and Design Guide. FHWA, 2015. https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/separated_bikelane_pdg/.

"Shared Use Path Planning and Design Guide Cost Estimating Tool Guidance Document." Mass Trails, n.d., https://www.mass.gov/guides/shared-use-path-planning-and-design-guide. Accessed 2020.

Standard Items. MassDOT Highway Division Manuals and Publications, 1 February 2018, https://www.mass.gov/files/documents/2018/02/01/eng_nomen.pdf. Accessed 6 November 2020.

Tarko, Andrew P., and Rafael I. Perez-Cartagena. "Variability Of A Peak Hour Factor At Intersections." *Transportation Research Board*, National Association of City Transportation Officials, 2005. https://nacto.org/docs/usdg/variability_of_a_peak_hour_factor_at_intersections_tarko.pdf.

Urban Bikeway Design Guide. National Association of City Transportation Officials, August 2013, https://nacto.org/publication/urban-bikeway-design-guide/intersection-treatments/through-bike-lanes/

Appendices
Appendix A: Project Proposal

Northern Strand Community Trail On-Road Extension:
Project Proposal

October 9th, 2020

By:
Lily Spicer
Maggie Ostwald
Sarah Kwatinetz

Advisors:
Leonard Albano
Suzanne LePage

Capstone Design Statement

This project entails designing a portion of the on-road extension of the Northern Strand Community trail in Lynn, MA. The team must supply improved on-road bicycle accommodations, evaluate different types of on-road facilities, perform signalized intersection analysis, while preserving on-street parking and minimizing impact on traffic, the environment, and people. To best provide Stantec with a comprehensive design and to fulfill the Worcester Polytechnic Institute (WPI) capstone criteria for Accrediting Engineering Programs by the Accreditation Board for Engineering and Technology (ABET), the following eight constraints will be considered:

Economic:

Cost analysis is an important factor in choosing a design, as the chosen design must fit within the proposed budget for the project. The team will fulfill this real-life constraint by evaluating the costs for each design and subsequently using these as a factor in the decision process of design selection.

Environmental:

It is crucial to ensure in any project that there are limited or no consequences on the environment. Ensuring limited environmental impact of a project can also affect project funding. This project may require an environmental analysis of design alternatives such that environmental impact can be considered in the choosing of a final design.

Social and Political:

The team will be working closely with our sponsor, Stantec, to familiarize ourselves with the needs of the residents of Lynn. In doing so, the project team will attempt to address residents' and trail users' concerns regarding the project and to propose a design solution which fits those needs, and to create a design that is accessible to all.

Ethical:

This project will abide by the American Society of Civil Engineers (ASCE) Code of Ethics for all civil engineers as to ensure the safety and welfare of the public, protect the reputation of WPI or Stantec, and to maintain professionalism, honesty, and virtue.

Health and Safety:

This project seeks to improve safety for bicyclists by designing dedicated accommodations for bicyclists of all levels of expertise. The team will work alongside Stantec and the City of Lynn to ensure all safety guidelines are followed as well as utilizing MassDOT standards.

Constructability:

Constructability is an important design constraint in selecting a final design proposal. Design alternatives must be feasible and practical for implementation with limited construction time. Constructability is also a significant consideration in planning for economic constraints.

Sustainability:

The team aims to produce designs for bicycle accommodations that will benefit the City of Lynn and will serve the needs of the trail users for many years. The team will design with maintenance implications in mind and consider factors such as sea level rise in decision making. The implementation of bike paths is also a sustainable alternative to personal vehicle travel, and greater accessibility may lead more individuals to choose this form of transportation.

COVID-19:

The team will account for the inconsistencies of the new traffic count data due to the effects of the pandemic. We will use old traffic count data and adjust accordingly to represent typical data.

Table of Contents

Table of Figures

1.0 - Introduction

The Northern Strand Community Trail, also known as the Bike to the Sea Trail, is a 11.5-mile bicycle path and walking trail located in Eastern Massachusetts. After connecting the towns of Everett, Malden, Revere, and Saugus, the design for the trail transforms to an on-road section in Lynn. This extension will incorporate dedicated bicycle accommodations to improve accessibility and safety without compromising other roadway facilities. For decades, the City of Lynn, Bike to the Sea, Inc., and the Solomon Foundation, have actively worked towards this on-road extension of the trail. Now, Stantec has stepped in as the resident engineer and construction manager to implement the idea.

This MQP aims to provide our sponsor, Stantec, with a series of design options for the on-road extension of the Northern Strand Community Trail between Market Street and Nahant Beach, to ultimately complete the trail. To achieve this, this MQP team will meet the following objectives:

1. Understand the existing operational conditions for the signalized intersections of Market Street and Broad Street, Market Street and the Lynnway, and the rotary.
2. Identify and analyze the design constraints for the existing trails and the proposed on-road bike path.
3. Provide multiple design options for the new on-road bike path.
4. Select the best design of bicycle accommodations based on design constraints.

2.0 - Background

The Northern Strand Community Trail, also known as the Bike to the Sea Trail, is a 11.5-mile bicycle path and walking trail, connecting Everett, Malden, Revere, and Saugus, and eventually Lynn, Massachusetts ("Northern Strand", n.d.). The trail follows the former Saugus Branch Railroad and is designed to extend onto complete streets, incorporating pedestrian and bike-friendly roadside facilities, to reach Nahant Beach.

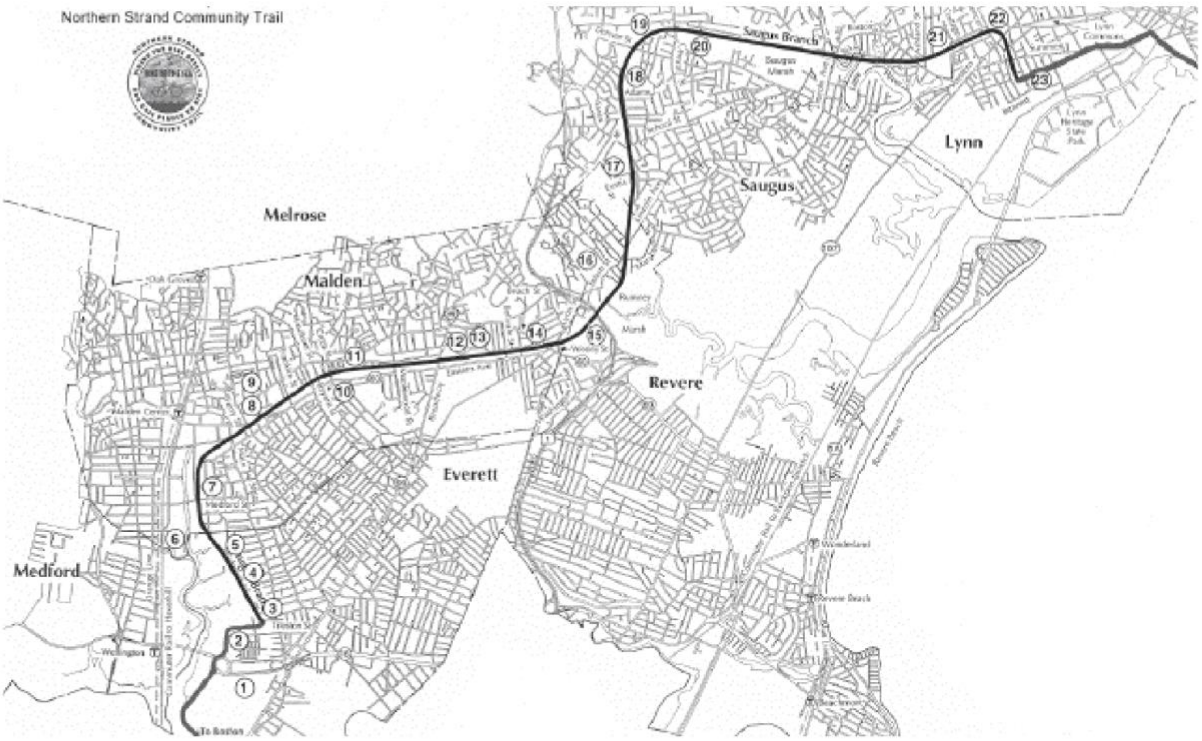


Figure 1: Map of the Northern Strand Community Trail (City of Malden Master Plan)

2.1 - History of the Trail

Figure 2: Timeline of Events

Founded in 1993, Bike to the Sea, Inc. (B2C) was the first organization to advocate for the Northern Strand Community Trail. This non-profit historically pushes to "[connect] communities by building and improving shared-use paths and promoting safe and happy trail use for all ages and abilities" ("About Us", n.d.). Shortly after, the trail was adopted into the Metropolitan Area Planning Council (MAPC) regional bicycle trail plans, the DEM statewide trails plan (now DCR/EEA), and was included into the route between Boston and Maine in the East Coast Greenway, a 3000-mile trail spanning from Maine to Florida ("Northern Strand").

After nearly a decade of lease negotiations with the MBTA, Everett, Malden, Saugus and Revere entered 99-year leases in 2005 ("Northern Strand"). Things looked promising for B2C, but progress was halted as state policy required communities to front the costs for planning and design. Over the next few years, with help from Rails to Trails, REI, local donors, B2C, and a non-profit from Nevada called Iron Horse Preservation, rough trails were completed out of recycled asphalt ("Northern Strand"). The new trails were popular with residents; however, it was clear a paved pathway was needed. Everett and Malden eventually paved their local portions using Gateway Parks funds, meals tax, and general revenue bonds.

The Iron Horse Preservation had troubles finishing the Revere section of the trail and garnering support from residents of Lynn, so in 2016, the Solomon Foundation began involvement to assist with grants and technical aspects of the project ("Northern Strand"). By 2018, the Solomon Foundation had partnered with the City of Lynn to work on the design for the extension to Nahant Beach.

The extension into Lynn was met with resistance from its residents initially, as more pushing issues like crime and sewage backups took priority. Without support from the City of Lynn and its residents, B2C had trouble obtaining funds for the project and its design. By 2019, however, with more success in Everett, Malden, Saugus, and Revere, and persistent advocacy, the Executive Office of Energy and Environment (EEA) of Massachusetts was able to commit to fund the whole project through the Gateway City Parks Program. This greatly improved the overall project's efficiency, as instead of multiple municipalities working together, it was now one trail project. This was largely in part due to the Governor's and MassDOT's shift in how they handle state, municipal, and non-profit-joint projects, and because of the Solomon

Foundation's and the Deputy Chief of Staff's vision of the trail as a state-level project. ("Northern Strand").

2.2 - Project and Funding

Most of the project funding comes from the Gateway City Parks Program, a Massachusetts grant funding program for creating and restoring parks and recreation in select cities. This grant has provided $1.5M for design, $11M for construction of the Northern Strand, and $8M for construction of the Lynn on-street extension (projected). The Solomon and Barr Foundations, as a part of the 'A Greener Greater Boston' program have contributed $102,500. The City of Lynn also contributed $37,500 to the budget. ("Northern Strand").

Major stakeholders in this project are Bike to the Sea, Inc., The Solomon Foundation, The Barr Foundation, MA Department of Energy and Environmental Affairs, the cities the trail passes through, and their residents. Stantec is providing construction management services and acting as the resident engineer, and Brown, Richardson, and Rowe, Inc. is providing construction administration services.

2.3 - Existing Conditions

The 11.5-mile trail runs through Everett, Malden, Revere, Saugus, and Lynn, Massachusetts. The rail-trail portion of the trail is under construction for route improvements, while the on-road extension, shown in Figure 3, is still in the design phase. Stantec has been working on the design for the rail-trail portion as well as the entirety of the on-road extension; however, this MQP focuses on only a portion of the Lynn extension. This reaches from the T station on Market Street to Nahant Beach. Within the MQP scope, we have identified two major project areas – Market Street to the Lynnway, and the Lynnway to Nahant Beach.

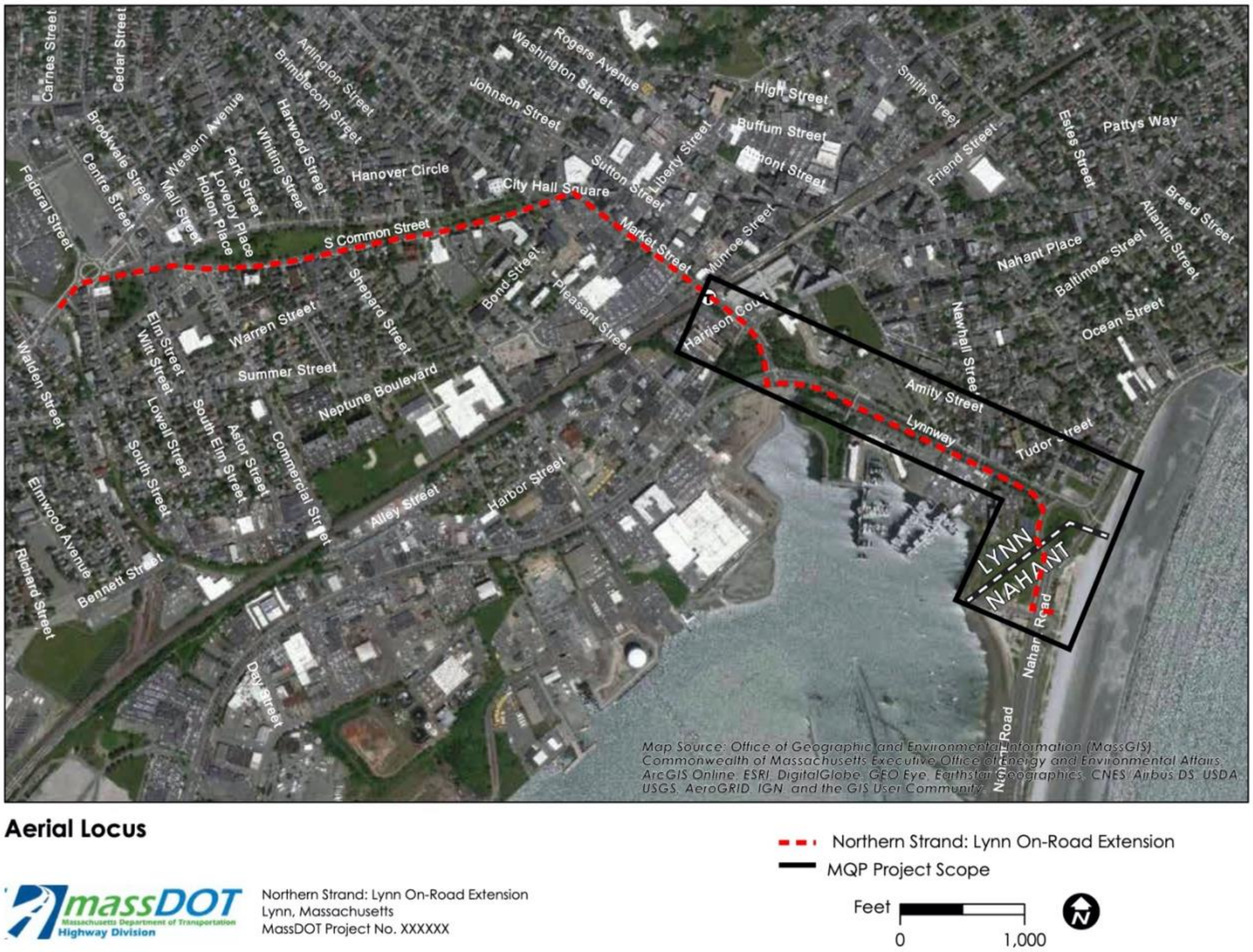


Figure 3: On-Road Extension with MQP Project Scope (Boxed)

2.3.1 - Outside of Project Scope: Rail Trail and On-Road Trail (Western Ave to Market St.)

The trail outside of MQP project scope, shown in Figure 4, includes the existing rail-trail along the old Saugus railroad and the on-road extension down South Common Street to the T Station on Market Street in Lynn.

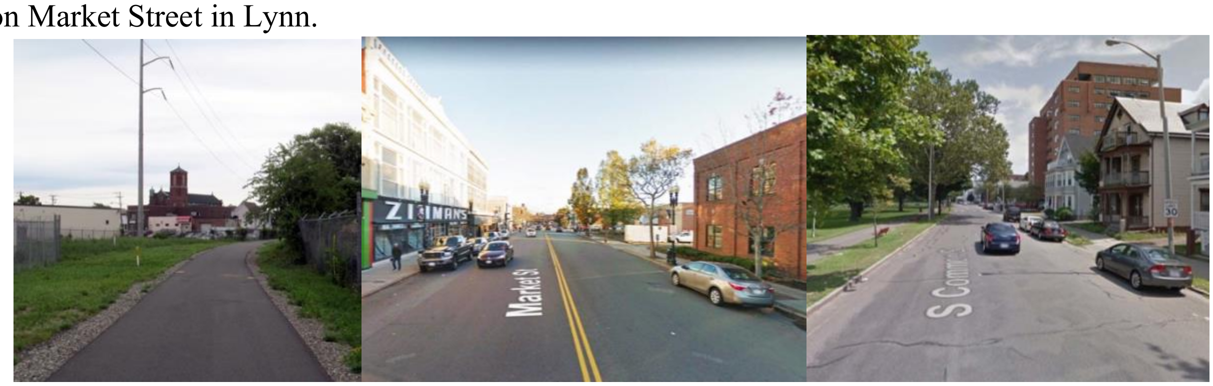


Figure 4: The trail in Malden and the proposed on-road extension route via Market Street and S. Common Street in Lynn, MA (User PI.1415926535 on google and google street view)

In the extension design, many considerations such as the traffic loads, intersection design, environmental restraints, cost, constructability, the preservation of on-street parking, biker safety, and more are being evaluated to guide Stantec's final design. This design will eventually tie-in to our design at the T-stop on Market Street.

2.3.2 - Project Zone 1: Market Street (Broad Street to the Lynnway)

The Northern Strand Community trail on-road extension through Lynn continues down Market street towards the Lynnway. This 0.1-mile stretch features a T-stop, the intersection of Broad Street and Market Street, and the intersection of Market Street and the Lynnway. Market Street, in between Broad Street and State Street, features two lanes in each direction as well as short-term parking (see Figure 5). After Broad Street, the stretch of Market Street has no parking. This area currently has no bike infrastructure in place.

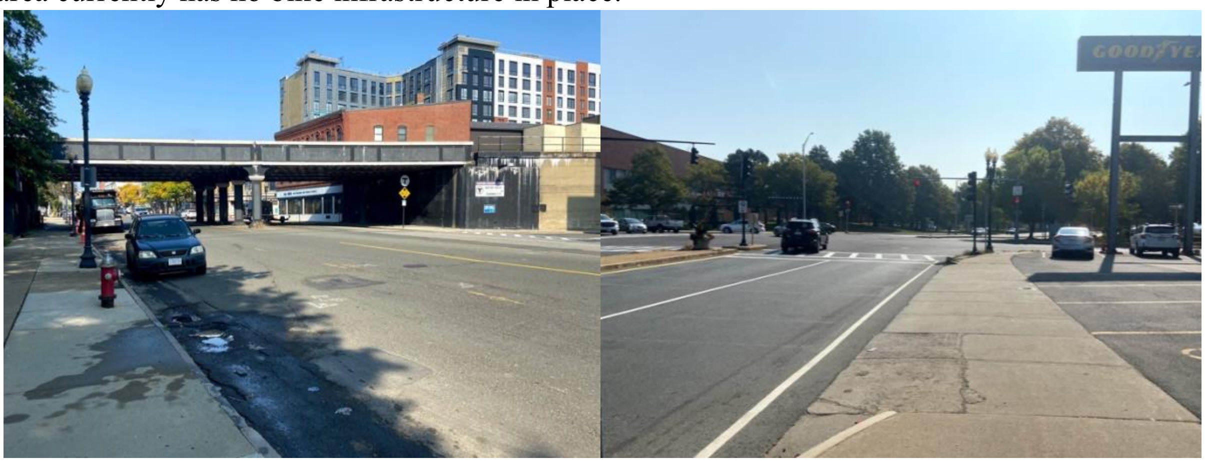


Figure 5: Market Street near the Intersection of Market St. and Broad St.

It is clear that Market Street would benefit from the addition of bike infrastructure because, "the [current] expanse of pavement and lack of any markings makes crossing the street or biking along it unsafe" and the wide lanes encourage speeding ("Northern Strand").

2.3.3 - Project Zone 2: the Lynnway (from Market Street to Nahant Beach)

The second portion of the on-road extension within our MQP scope is the 0.7 mile stretch from the intersection of Market Street and the Lynnway to the trail's ending at Nahant Beach. Each direction of the Lynnway, shown in Figure 6, has three lanes of moderately high-speed traffic, which runs along the coastline. At Nahant Beach, there is a large traffic circle with three traffic lanes.

Figure 6: Lynnway Eastbound (left) and Westbound (right), Sept. 2020

2.4 - Key Standards and Documents

The team will be referencing bike accommodation best practices presented in the AASHTO *Guide for Development of Bike Facilities,* MassDOT's *Separated Bike Lane Planning & Design Guide,* and MassDOT's *Complete Streets Funding Program Guidance.* These references will allow us to create designs that are consistent with the rest of the traffic industry and adhere to safety recommendations.

3.0 - Methodology

The goal of this project is to provide our sponsor, Stantec, with a series of design options for the on-road bike extension of the Northern Strand Community Trail to improve bicycle accommodations near Nahant Beach, resulting in the completion of the trail. This MQP project will achieve this by completing the following objectives.

Objectives:

1. Understand the existing operational conditions for the signalized intersections of Market Street and Broad Street, Market Street and the Lynnway, and the rotary.
2. Identify and analyze the design constraints for the existing trails and the proposed on-road bike path.
3. Provide multiple design options for the new on-road bike path.
4. Select the best design of bicycle accommodations based on design constraints.

3.1 - Objective 1

Understand the existing operational conditions for the signalized intersections of Market Street and Broad Street, Market Street and the Lynnway, and the rotary.

3.1.1 - Evaluate existing uses

Understanding the existing conditions of the site involves the analysis of three intersections and consideration of the roadways between them. We plan on collecting recent and accurate data regarding vehicle, bike, and pedestrian use of the project area wherever possible. The recent data collected will be cross-referenced with historical data in light of the foreseeable impact of COVID-19; see 3.1.7 for more details. This data may be obtained from our own traffic counts or from preexisting and adaptable counts. Gaining an understanding of the existing conditions in this area will aid in identifying how the intersections could be altered without significantly decreasing the level of service.

3.1.2 - Intersection Analysis: Market Street and Broad Street

The intersection of Market St. and Broad St., shown in Figure 7, is a signalized four-way intersection with Broad St. in the westbound direction being one-way. We will use Highway Capacity Software to determine the current level of service of this intersection by completing a manual traffic count or adjusting existing traffic counts.

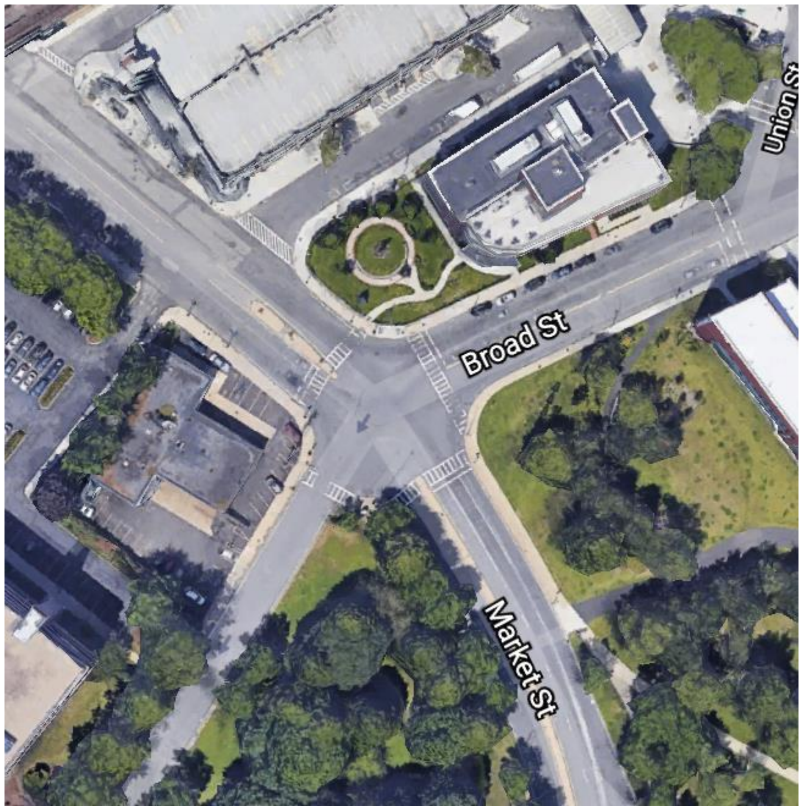


Figure 7: Intersection of Market St. and Broad St. (Google Earth, 2020)

3.1.3 - Intersection Analysis: Market Street and the Lynnway

The intersection of Market St. and the Lynnway, a state highway, is a signalized three-way intersection. See Figure 8. Recent construction has added a fourth direction, providing access to a new development located south of the intersection. The most recent traffic study of this intersection occurred in 2006, so more recent information will be gathered if possible.

Figure 8: Intersection of Market St and the Lynnway (Google Earth, 2020)

3.1.4 - Intersection Analysis: Rotary

The rotary in Figure 9 connects the Lynnway with Lynn Shore Drive and Nahant Road, but for the purpose of this project it will be used to safely direct bicyclists to and from Nahant Beach. The use of the lanes in this roundabout will be important in deciding where bike accommodations can be included.

Figure 9: Rotary intersection of the Lynnway and Nahant Rd. (Google Earth, 2020)

3.1.5 - Other Landmarks

Just north of the intersection of Market St. and Broad St. is a T station and a bus stop, close to the north-western portion of our scope. These stations, while not associated with intersections, likely generate considerable pedestrian activity. It is also important to consider how the location of the beginning of this off-road trail will be incorporated into the use of these public transit facilities.

3.1.6 - Existing On-road Facilities

In addition to the intersections within our scope, the facilities included along the roadway are significant constraints in design development. The number of lanes, width of lanes and shoulders, and presence of curb cuts and on-street parking are a few of the factors that will be noted in analysis of the existing conditions. If final designs require significant changes in the existing on-road facilities, resulting level of service analyses will be considered in the evaluation criteria when selecting a preferred design.

3.1.7 - Considering COVID-19

The ongoing pandemic is a significant challenge in collecting accurate traffic data. New traffic counts alone will not represent the true data, as travel has been lessened by remote work and school and adjusted business operations. A creative and calculated combination of existing counts, new counts, and appropriate adjustment factors will allow us to develop a more complete picture of the local traffic. In some cases, it will be best to develop a conversion coefficient to compare old and new data from before and during the pandemic, and adjust the new data accordingly.

3.2 - Objective 2

Identify and analyze the design constraints for the existing trails and the proposed on-road bike path.

3.2.1 - Utility crossings

We will be obtaining AutoCAD survey files of the existing project site upon approval by the project owners. These drawings will help us locate the utilities along the roadway as well as provide general roadway and intersection geometries. Knowing this is important in proposing structurally feasible design options. These utilities provide service to the surrounding areas which include a new residential living facility, a community college, numerous businesses, and various on-street facilities (traffic lights, streetlights, etc.). In proposing designs, we will consider added construction costs and time that may be incurred from moving or avoiding utilities crossings.

3.2.2 - Environmental considerations

Since the project site is next to the ocean, the weather, specifically rainfall, will have to be taken greatly into consideration for the design. We will be obtaining surveying drawings of the existing project site. The surveying drawings and flood maps of the area (i.e. Figure 10) will be used to evaluate whether there is proper drainage out of the project site and that the future implementations will withstand the conditions. The changing of future conditions may become a concern with due research on predicted sea level rise and other climatic factors.

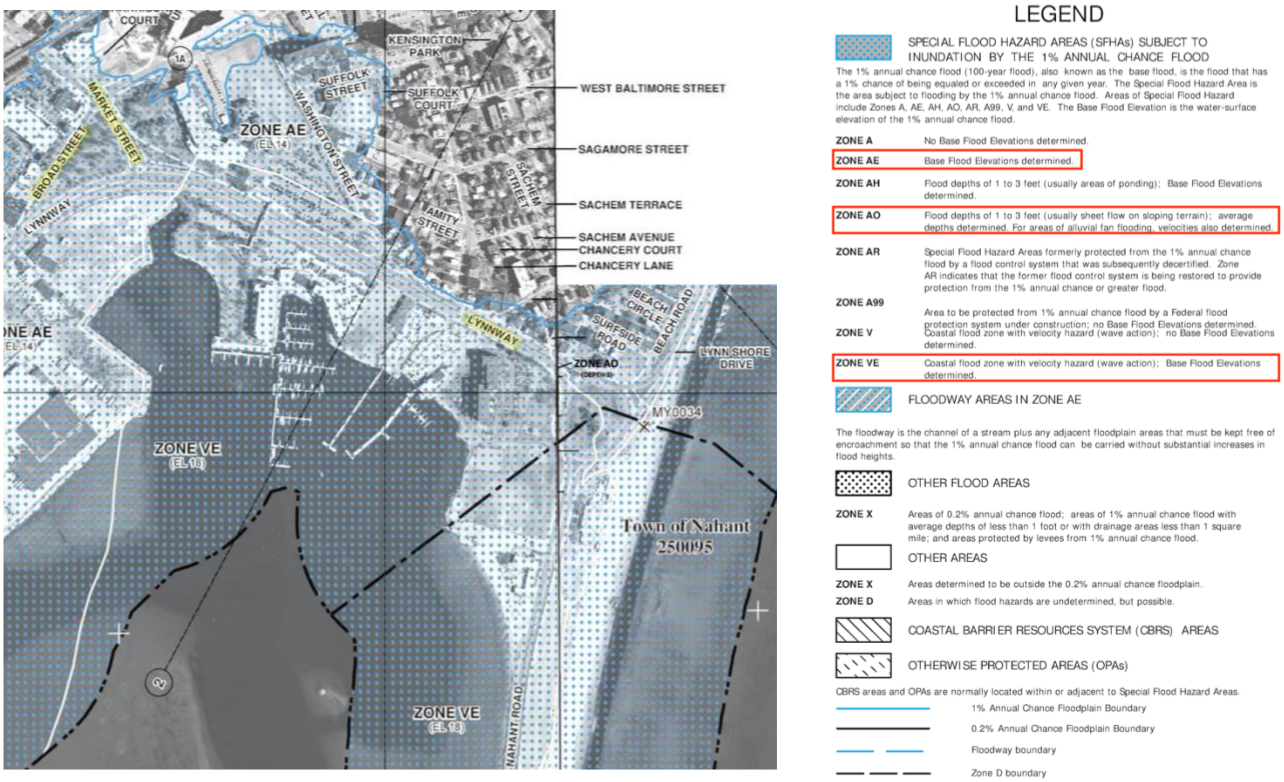


Figure 10: Flood map and legend of the project site and surrounding area

There are several greenspaces and trees along the project route, some of the areas being owned by DCR. We will gather information about the surrounding greenspaces to ensure we only construct within the bounds of the project and that the drainage is appropriate for the location's proximity to the ocean.

3.2.3 - Evaluate existing sidewalk, roadway, and shoulder conditions

We will use the AutoCAD drawings, street view maps, and observation to evaluate the existing conditions along the route and determine if the sidewalk, lane, and shoulder widths are being optimized for the current level of service. There is a sidewalk along at least one side of the roadway and there is little to no shoulder throughout the project site, but there are multiple lanes of traffic along the whole length of the route. From this, we will be able to identify the best placement and arrangement for implementing a bike path. Specific intersections will be evaluated in terms of biker safety and vehicle traffic impacts.

Project Zone 1: Market Street (Broad St to Lynnway)

There has been a recent development constructed at the intersection of Market Street and the Lynnway. Because of this, that intersection underwent a recent redesign to accommodate the changes. With that in consideration, we will try to maintain the existing conditions there while still implementing a bike lane along the trail. The intersection of Broad Street and Market Street is within close proximity to a T stop and bus stop; therefore, pedestrian traffic is to be anticipated.

Project Zone 2: Lynnway (from Market St to Nahant Beach)
The east and west-bound portions of the roadway are separated by a median. The east-bound side has incoming traffic from several parking lots for the marina and some DCR-owned greenspaces. The west-bound side has some on-street parking in front of many businesses, incoming traffic from four streets, outgoing traffic from two streets, and potential foot traffic from the North Shore Community College campus. We will evaluate how the differences along the Lynnway will dictate our design proposal on either side of the roadway.

3.2.4 - What the community wants
In 2018, there were a series of public meetings held for the towns (Everett, Revere, Malden, Saugus, and Lynn) through which the trail runs. We will obtain the minutes from these meetings and identify the key outcomes. Many of these meetings discussed the future of the off-road portion of the trail but we will consider both those outcomes and the outcome from the Lynn public meeting. Since the on-road extension is still under design, we have the greatest opportunity to give the community a chance to see their input being implemented into the final design.

3.3 - Objective 3
Provide multiple design options for the new on-road bike path.

The findings from objectives one and two will dictate the proposed design options. The level of service analyses will help to evaluate how much the geometry of the roadway will have to change. Consideration will be taken at each intersection to allow for proper functionality and biker safety. Once the existing operational conditions are evaluated, there are numerous constraints that will inevitably shape the designs. Some constraints cannot be compromised, but others can so we will find which constraints those are and determine where there is flexibility in order to provide thorough design options.

We will primarily be using MassDOT's *Separated Bike Lane Planning & Design Guide* and the AASHTO *Guide for Development of Bike Facilities* as a starting point for our designs. The Massachusetts *Complete Streets Funding Program Guidance* document will also be a great reference regarding best practices, prioritization of constraints, and safety auditing. After our own data collection and observations, we can better adapt current best practices to our project.

3.4 - Objective 4
Select the best design of bicycle accommodations based on design constraints.

3.4.1 - Capstone Design Constraints
Determining the best design for biking accommodations along and near the Lynnway will stem from the initial eight constraints that act as the framework for this project. The economic, environmental, social and political, ethical, health and safety, constructability, sustainability, and

COVID-19 constraints, which were further outlined in the Capstone Design Statement, allow for the consideration and weighing of a broad spectrum of factors.

3.4.2 - Cost and Constructability

The Cost Estimating Tool, published by MassTrails of MassDOT in 2018, and the Construction Project Estimator, published by MassDOT, will be influential in determining the feasibility of the design options for this project. This tool will also aid in the quantitative comparison of one option against another based on their estimated implementation costs.

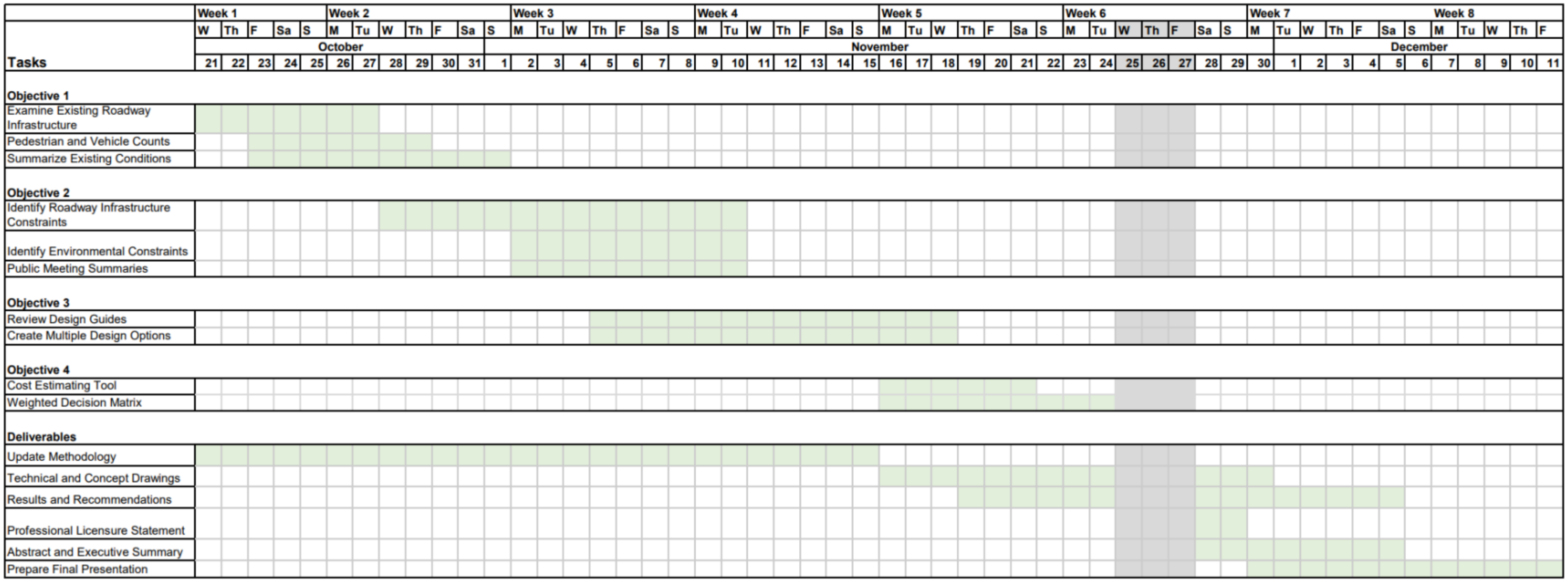
3.4.3 - Weighted Decision Matrix

To ensure inclusion of all eight design constraints, a weighted design matrix will be used to rank alternatives. Key criteria required of potential designs will be drawn from each of the constraints and assigned weights reflecting their importance. Traffic constraints, such as resulting level of service of adjusted intersection designs, will be one of the considered criteria in the matrix. The design alternatives will be compared by identifying how thoroughly they achieve each of the criteria.

3.4.4 - Deliverable for Stantec

The team's final design plans will be presented to Stantec in the form of concept designs and technical drawings alongside explanations of the design choice. These plans will be considered by Stantec in combination with existing plans they have developed to finalize development of the on-road extension of the trail.

3.4.5 - MQP Gantt Chart



References

(1) “About Us”. (n.d.). [website] *Bike to the Sea, Inc.* Accessed from: https://biketothesea.org/about-us/

(2) “Complete Streets Funding Program Guidance”. (n.d.). [website] *MassDOT.* Accessed from: https://www.mass.gov/doc/complete-streets-funding-program-guidance/download

(3) “Construction Project Estimator”. (n.d.). [online database tool] *MassDOT.* Accessed from: https://hwy.massdot.state.ma.us/CPE/About_PrelimEstimate.aspx

(4) “FEMA Flood Map Service Center”. (n.d.). [website] *FEMA.* Accessed from: https://msc.fema.gov/portal/search?AddressQuery=lynn%2C%20mas#searchresultsanchor

(5) “Northern Strand Community Trail”. (n.d.). [website] *The Lawrence & Lillian Solomon Foundation.* Accessed from: https://www.solomonfoundation.org/projects/northern-strand/

(6) “Separated Bike Lane Planning & Design Guide”. (2015). [website] *MassDOT.* Accessed from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide

(7) “Shared Use Path Planning and Design Guide Cost Estimating Tool Guidance Document”. (2018). [website] *Mass Trails.* Accessed from: https://www.mass.gov/guides/shared-use-path-planning-and-design-guide

Appendix B: Existing Ramps, Driveways, and On-street Parking


Market St
Market St
Broad St
Broad St
Broad St
Market St
Market St
Market St
Union St
Bobby From Boston
Vintage clothing store
Goodyear Auto Service
Tire shop
Brid Shool
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
1A
Legend:
Pedestrian Ramp
Pedestrian Ramp
(not ADA compliant)
On-street Parking
Driveway
Google
(42°27'41"N 70°56'45"W) 2,049 ft

Legend:
Pedestrian Ramp
Pedestrian Ramp (not ADA compliant)
On-street Parking
Driveway
Andrea's Liquors
Liquor store
W Baltimore St
Newhall St
Saqamore St
Richdale Convenience Store
Convenience store
Lynn Heritage State Pa
Marina
Lynnway
Washington St
Caribbean Market
Google
(42°27'34"N 70°56'31"W) 2,253 ft

12:16 PM Thu Oct 22
91%
Sachem Ave
Beach Cir
Tudor St
Tudor St
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
Lynnway
Johnny's Market
Convenience store
ATM
Nahant Rd
Nahant Rd
Nahant Rd
Nahant Beach And Playground
Legend:
Pedestrian Ramp
Pedestrian Ramp (not ADA compliant)
On-street Parking
Driveway
Google
(42°27'25"N 70°56'14"W) 2,443 ft

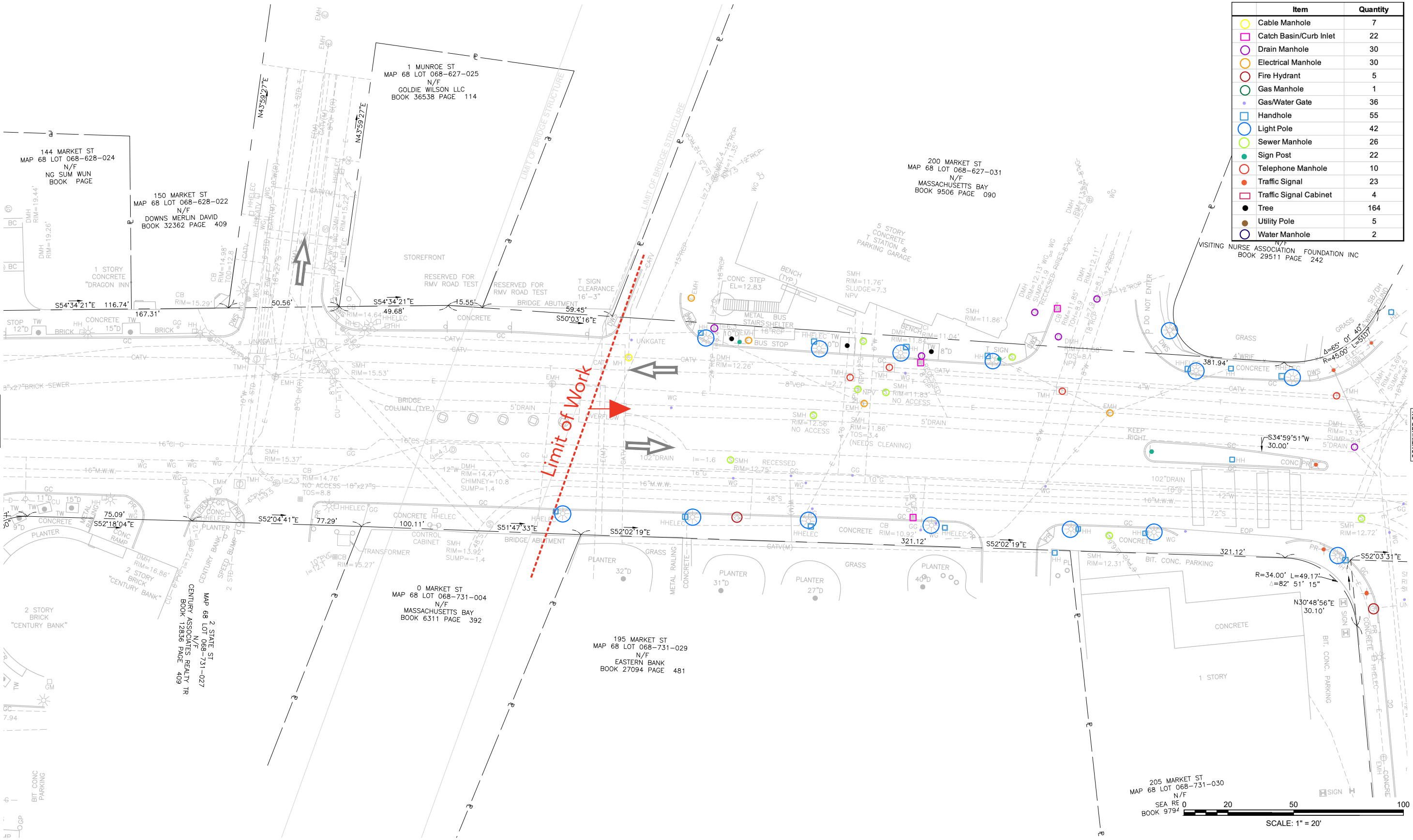
Appendix C: Utilities Map Markup

LYNN & NAHANT, MA
THE NORTHERN STRAND - ON-ROAD EXTENSION TO NAHANT BEACH

STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MA	-	21	110
PROJECT FILE NO.			

CONSTRUCTION PLANS
PART 12 OF 20

Item	Quantity
Cable Manhole	7
Catch Basin/Curb Inlet	22
Drain Manhole	30
Electrical Manhole	30
Fire Hydrant	5
Gas Manhole	1
Gas/Water Gate	36
Handhole	55
Light Pole	42
Sewer Manhole	26
Sign Post	22
Telephone Manhole	10
Traffic Signal	23
Traffic Signal Cabinet	4
Tree	164
Utility Pole	5
Water Manhole	2

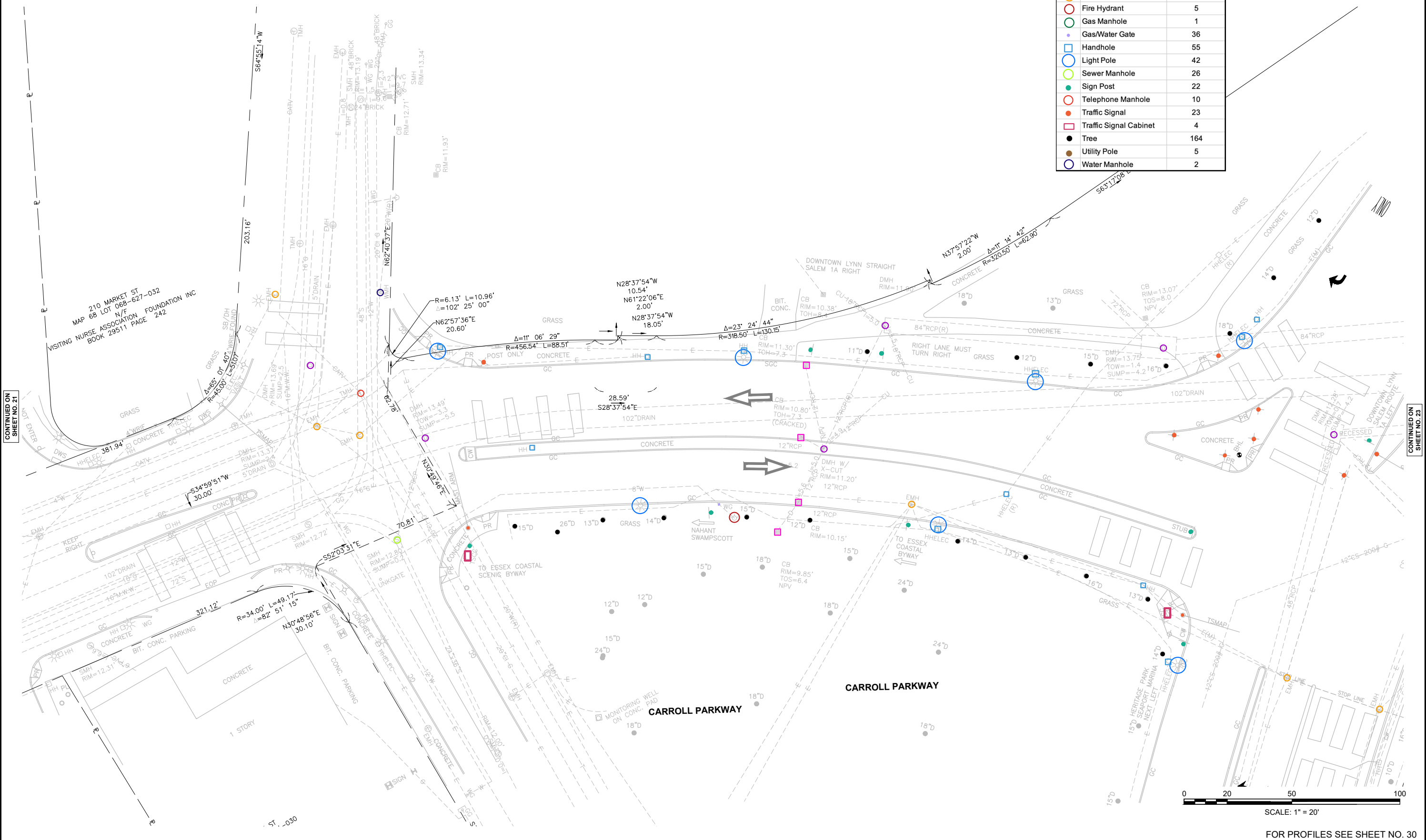


Plotted on 21-Oct-2020 10:30 AM
ON-ROAD_CONST_PLANS.DWG

STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MA	-	22	110
PROJECT FILE NO.			

CONSTRUCTION PLANS
PART 13 OF 20

Item	Quantity
Cable Manhole	7
Catch Basin/Curb Inlet	22
Drain Manhole	30
Electrical Manhole	30
Fire Hydrant	5
Gas Manhole	1
Gas/Water Gate	36
Handhole	55
Light Pole	42
Sewer Manhole	26
Sign Post	22
Telephone Manhole	10
Traffic Signal	23
Traffic Signal Cabinet	4
Tree	164
Utility Pole	5
Water Manhole	2



CONTINUED ON SHEET NO. 21

CONTINUED ON SHEET NO. 23

FOR PROFILES SEE SHEET NO. 30

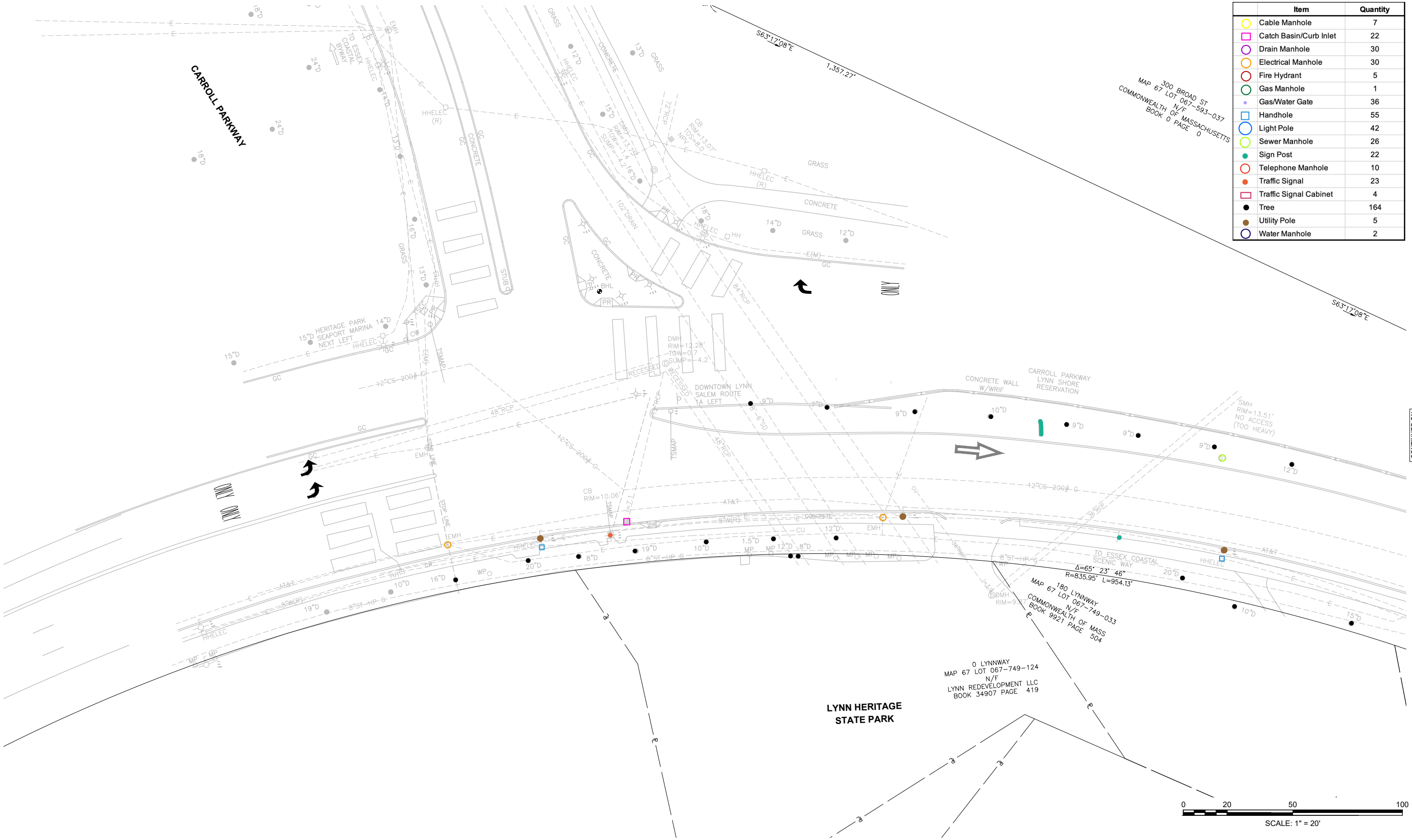
LYNN & NAHANT, MA
THE NORTHERN STRAND - ON-ROAD EXTENSION TO NAHANT BEACH

STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MA	-	23	110
PROJECT FILE NO.			

CONSTRUCTION PLANS
PART 14 OF 20

Item	Quantity
Cable Manhole	7
Catch Basin/Curb Inlet	22
Drain Manhole	30
Electrical Manhole	30
Fire Hydrant	5
Gas Manhole	1
Gas/Water Gate	36
Handhole	55
Light Pole	42
Sewer Manhole	26
Sign Post	22
Telephone Manhole	10
Traffic Signal	23
Traffic Signal Cabinet	4
Tree	164
Utility Pole	5
Water Manhole	2

CONTINUED ON SHEET NO. 22



CONTINUED ON SHEET NO. 24

0 20 50 100
SCALE: 1" = 20'

FOR PROFILES SEE SHEET NO. 30

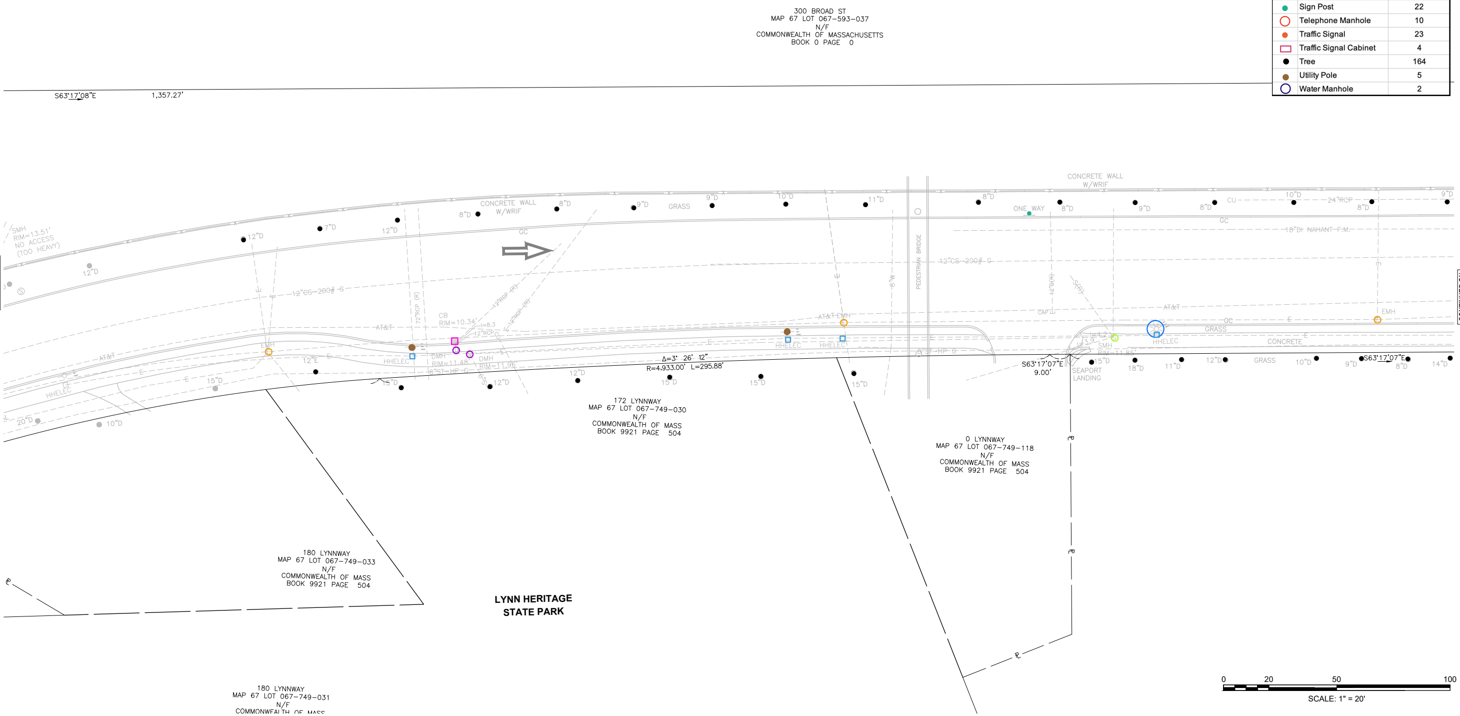
Plotted on 21-Oct-2020 10:31 AM
ON-ROAD_CONST_PLANS.DWG

LYNN & NAHANT, MA
THE NORTHERN STRAND - ON-ROAD
EXTENSION TO NAHANT BEACH

STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MA	-	24	110
PROJECT FILE NO.			

CONSTRUCTION PLANS
PART 15 OF 20

Item	Quantity
Cable Manhole	7
Catch Basin/Curb Inlet	22
Drain Manhole	30
Electrical Manhole	30
Fire Hydrant	5
Gas Manhole	1
Gas/Water Gate	36
Handhole	55
Light Pole	42
Sewer Manhole	26
Sign Post	22
Telephone Manhole	10
Traffic Signal	23
Traffic Signal Cabinet	4
Tree	164
Utility Pole	5
Water Manhole	2



CONTINUED ON SHEET NO. 23

CONTINUED ON SHEET NO. 25

0 20 50 100
SCALE: 1" = 20'

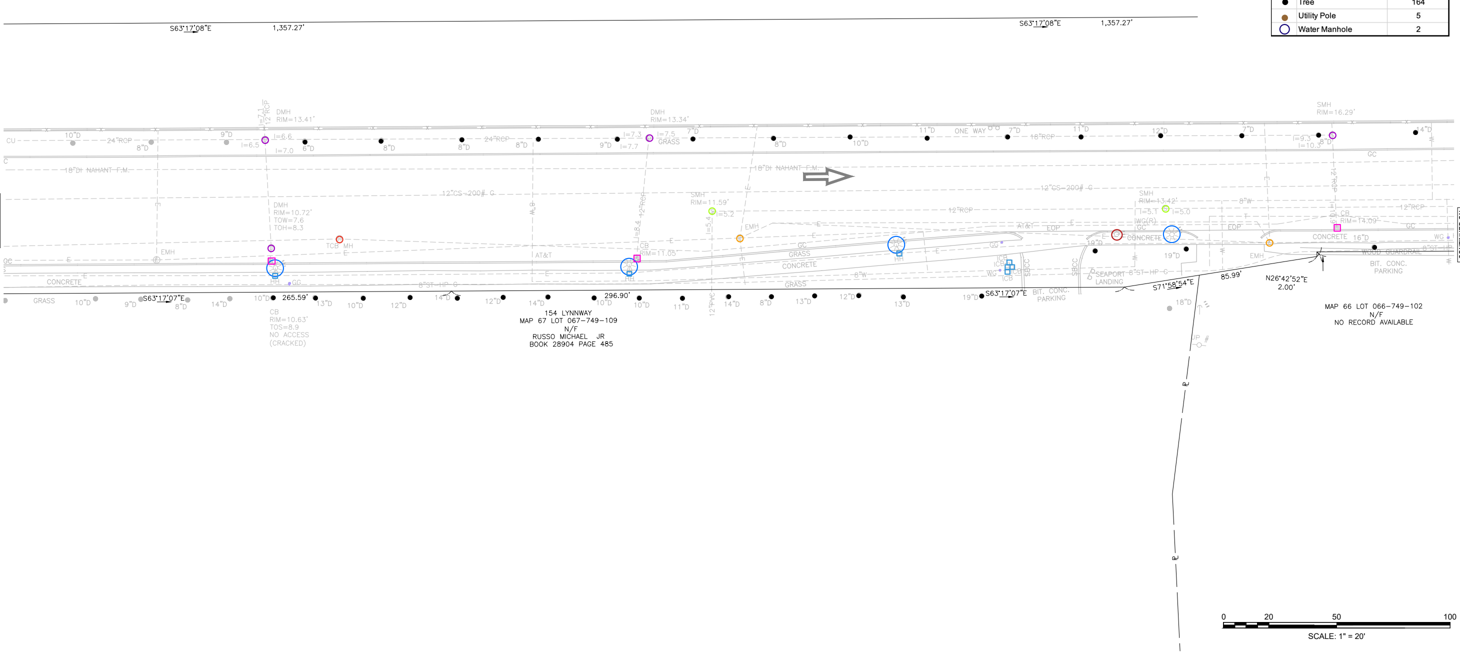
Plotted on 21-Oct-2020 10:32 AM
ON-ROAD_CONST_PLANS.DWG

LYNN & NAHANT, MA
THE NORTHERN STRAND - ON-ROAD EXTENSION TO NAHANT BEACH

STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MA	-	25	110
PROJECT FILE NO.			

CONSTRUCTION PLANS
PART 16 OF 20

Item	Quantity
Cable Manhole	7
Catch Basin/Curb Inlet	22
Drain Manhole	30
Electrical Manhole	30
Fire Hydrant	5
Gas Manhole	1
Gas/Water Gate	36
Handhole	55
Light Pole	42
Sewer Manhole	26
Sign Post	22
Telephone Manhole	10
Traffic Signal	23
Traffic Signal Cabinet	4
Tree	164
Utility Pole	5
Water Manhole	2



CONTINUED ON SHEET NO. 24

CONTINUED ON SHEET NO. 26

0 20 50 100
SCALE: 1" = 20'

Plotted on 21-Oct-2020 10:32 AM
ON-ROAD_CONST_PLANS.DWG

LYNN & NAHANT, MA
THE NORTHERN STRAND - ON-ROAD EXTENSION TO NAHANT BEACH

STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MA	-	26	110
PROJECT FILE NO.			

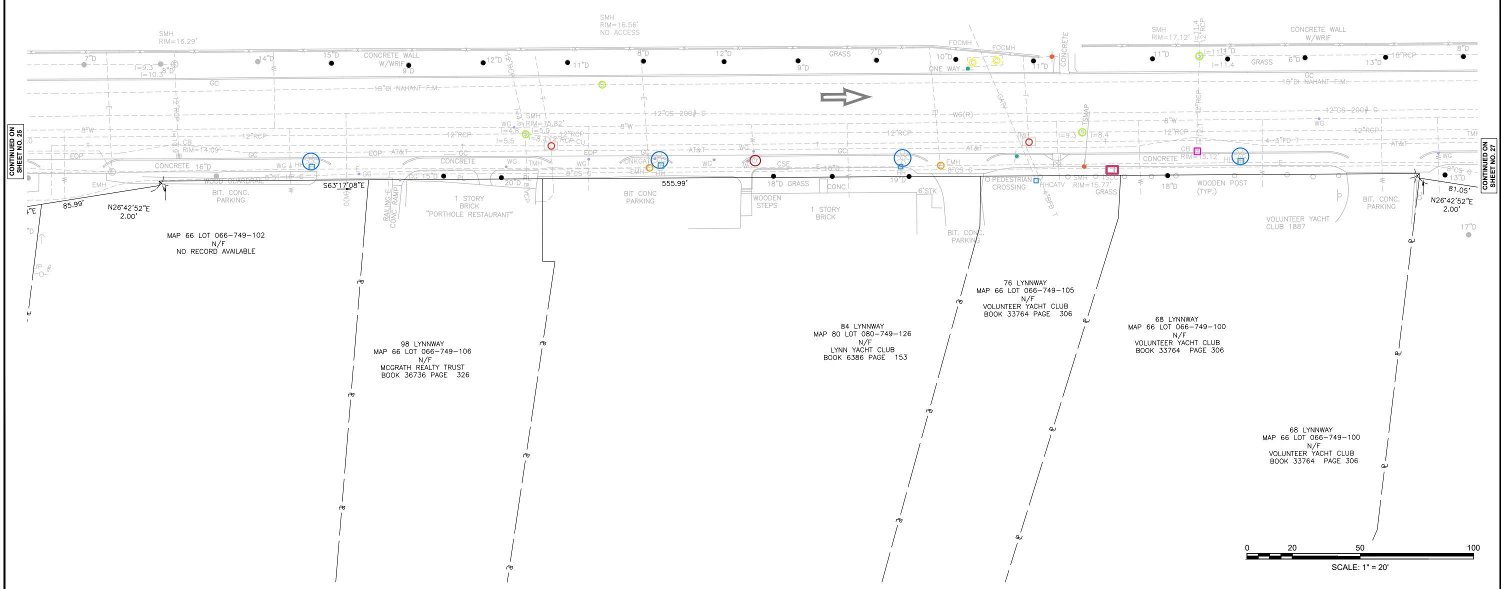
CONSTRUCTION PLANS
PART 17 OF 20

Item	Quantity
Cable Manhole	7
Catch Basin/Curb Inlet	22
Drain Manhole	30
Electrical Manhole	30
Fire Hydrant	5
Gas Manhole	1
Gas/Water Gate	36
Handhole	55
Light Pole	42
Sewer Manhole	26
Sign Post	22
Telephone Manhole	10
Traffic Signal	23
Traffic Signal Cabinet	4
Tree	164
Utility Pole	5
Water Manhole	2

Plotted on 21-Oct-2020 10:32 AM

ON-ROAD_CONST_PLANS.DWG

300 BROAD ST
MAP 67 LOT 067-593-037
N/F
COMMONWEALTH OF MASSACHUSETTS
BOOK 0 PAGE 0



LYNN & NAHANT, MA
THE NORTHERN STRAND - ON-ROAD EXTENSION TO NAHANT BEACH

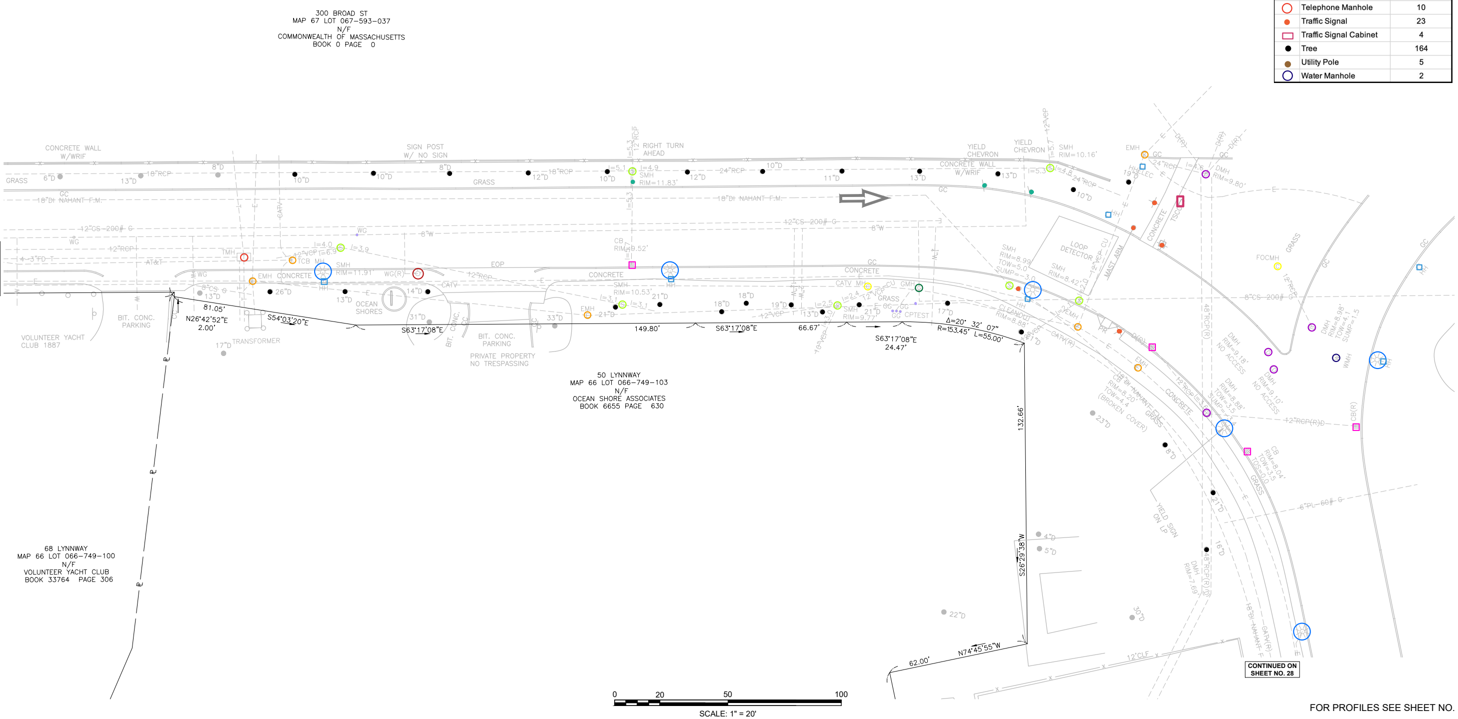
STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MA	-	27	110
PROJECT FILE NO.			

CONSTRUCTION PLANS
PART 18 OF 20

Item	Quantity
Cable Manhole	7
Catch Basin/Curb Inlet	22
Drain Manhole	30
Electrical Manhole	30
Fire Hydrant	5
Gas Manhole	1
Gas/Water Gate	36
Handhole	55
Light Pole	42
Sewer Manhole	26
Sign Post	22
Telephone Manhole	10
Traffic Signal	23
Traffic Signal Cabinet	4
Tree	164
Utility Pole	5
Water Manhole	2

Plotted on 21-Oct-2020 10:33 AM
ON-ROAD_CONST_PLANS.DWG

CONTINUED ON SHEET NO. 26



CONTINUED ON SHEET NO. 28

FOR PROFILES SEE SHEET NO. 31

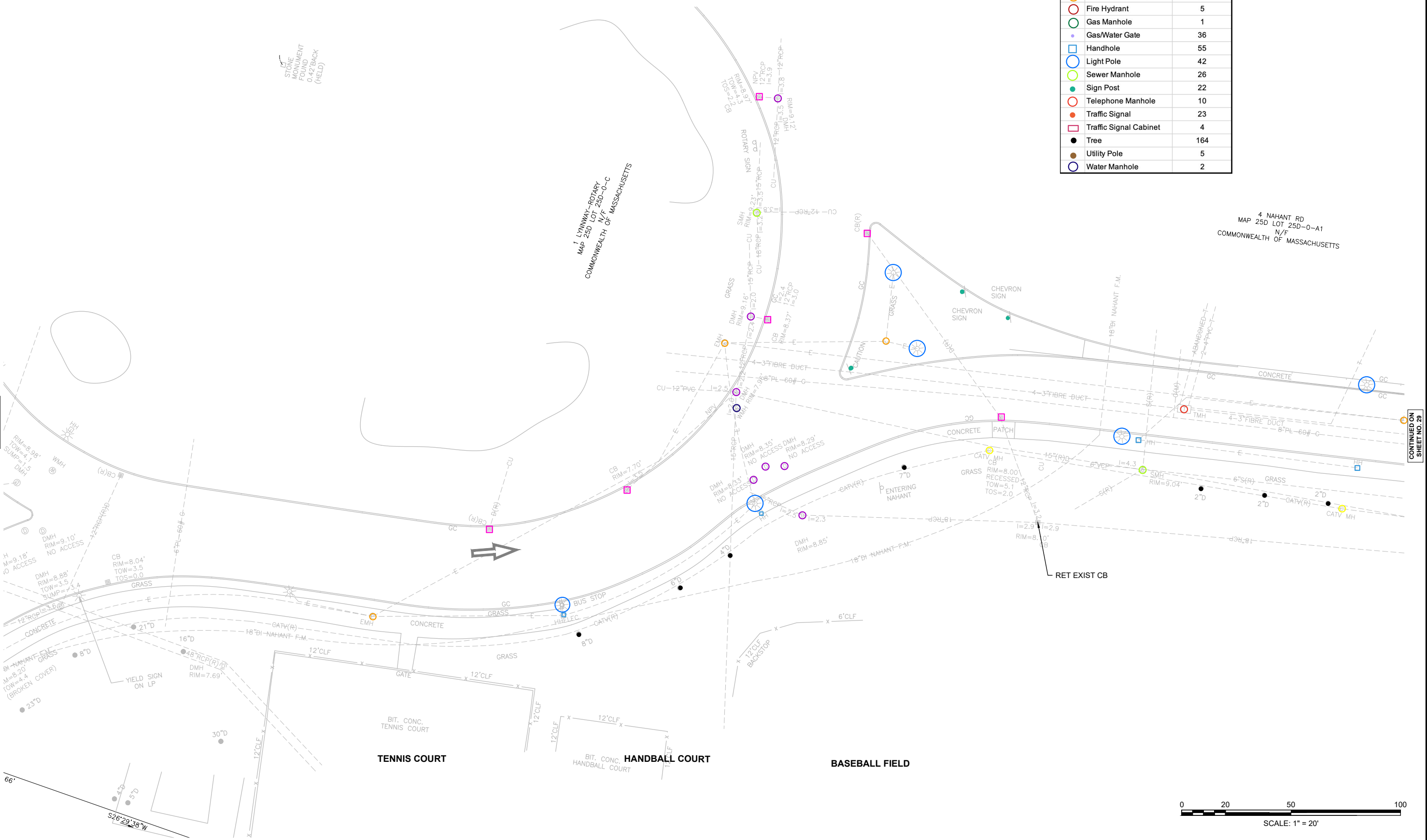
LYNN & NAHANT, MA
THE NORTHERN STRAND - ON-ROAD EXTENSION TO NAHANT BEACH

STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MA	-	28	110

PROJECT FILE NO.

CONSTRUCTION PLANS
PART 19 OF 20

Item	Quantity
Cable Manhole	7
Catch Basin/Curb Inlet	22
Drain Manhole	30
Electrical Manhole	30
Fire Hydrant	5
Gas Manhole	1
Gas/Water Gate	36
Handhole	55
Light Pole	42
Sewer Manhole	26
Sign Post	22
Telephone Manhole	10
Traffic Signal	23
Traffic Signal Cabinet	4
Tree	164
Utility Pole	5
Water Manhole	2



0 20 50 100
SCALE: 1" = 20'

FOR PROFILES SEE SHEET NO. 31

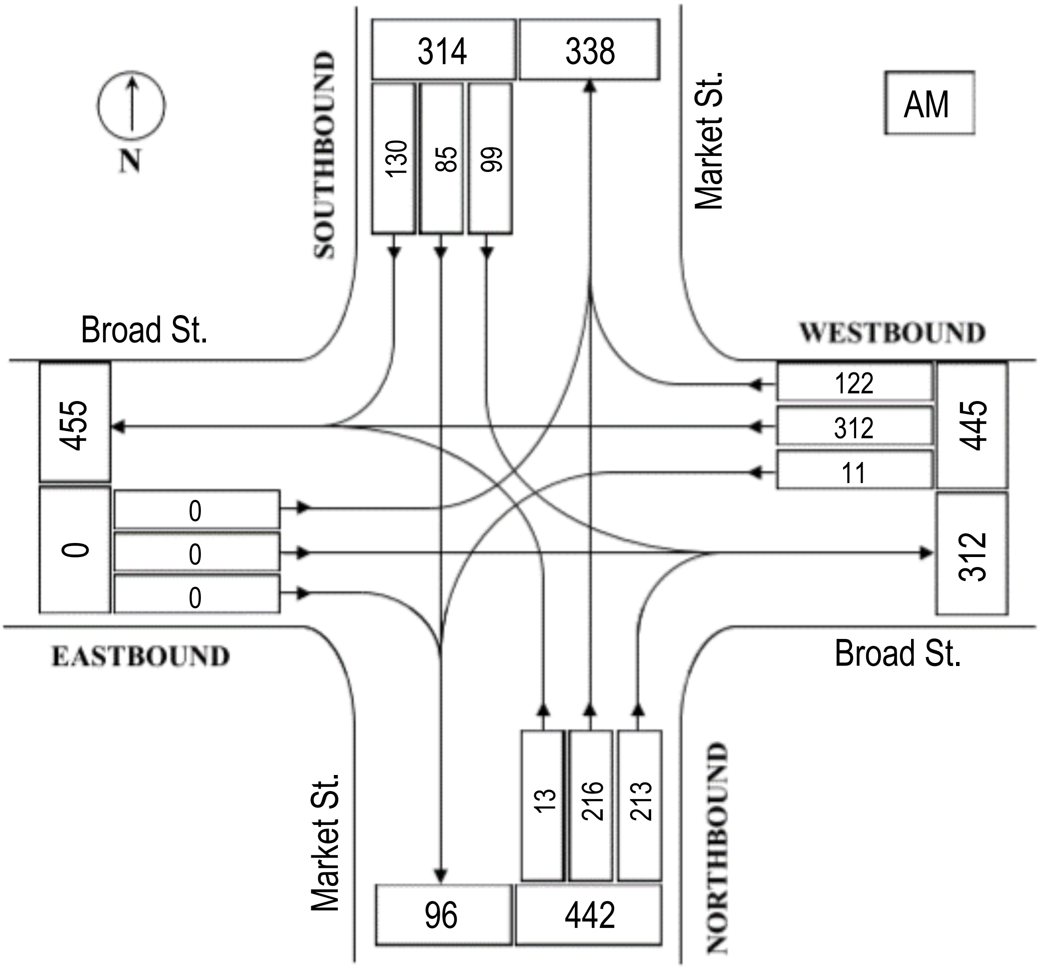
Plotted on 21-Oct-2020 10:33 AM
ON-ROAD_CONST_PLANS.DWG

Appendix D: Turning Movement Counts

INTERSECTION TURNING MOVEMENT COUNT

CITY: Lynn, MA **DATE:** 10/28/20 **DAY OF WEEK:** Wednesday

INTERSECTION: Market St. and Broad St.

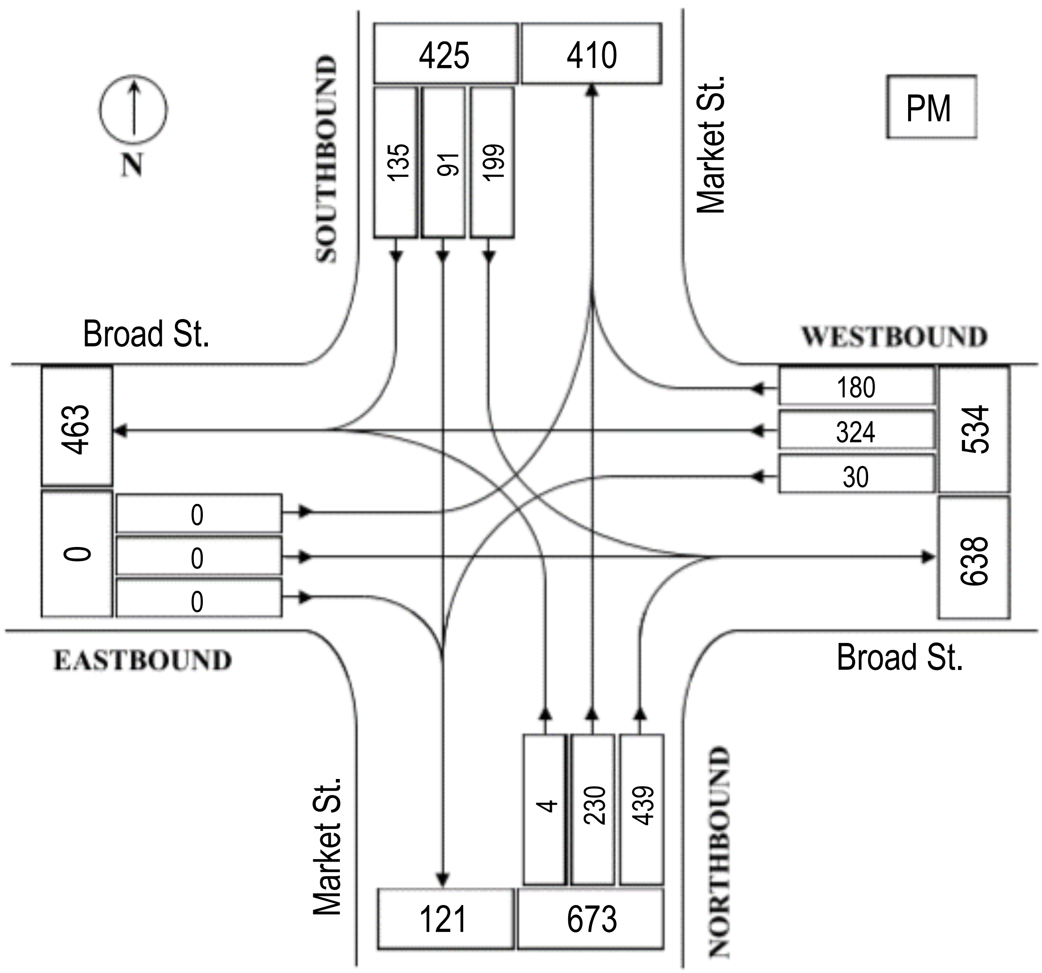


STREET	ENTERING VOLUMES	PERCENT OF FLOW	TIME OF COUNT
Market St. NB	442	36.80%	7:15 – 8:15 AM
Market St. SB	314	26.15%	
Broad St. EB	0	0%	PHF = .95
Broad St. WB	445	37.05%	
			VEHICLES COUNTED
			ALL VEHICLES: 1201
TOTAL	1201	100.0%	TRUCKS: 107
			PERCENT TRUCKS: 8.91%

Template provided by CMRPC

INTERSECTION TURNING MOVEMENT COUNT

CITY: Lynn, MA **DATE:** 10/28/20 **DAY OF WEEK:** Wednesday
INTERSECTION: Market St. and Broad St.

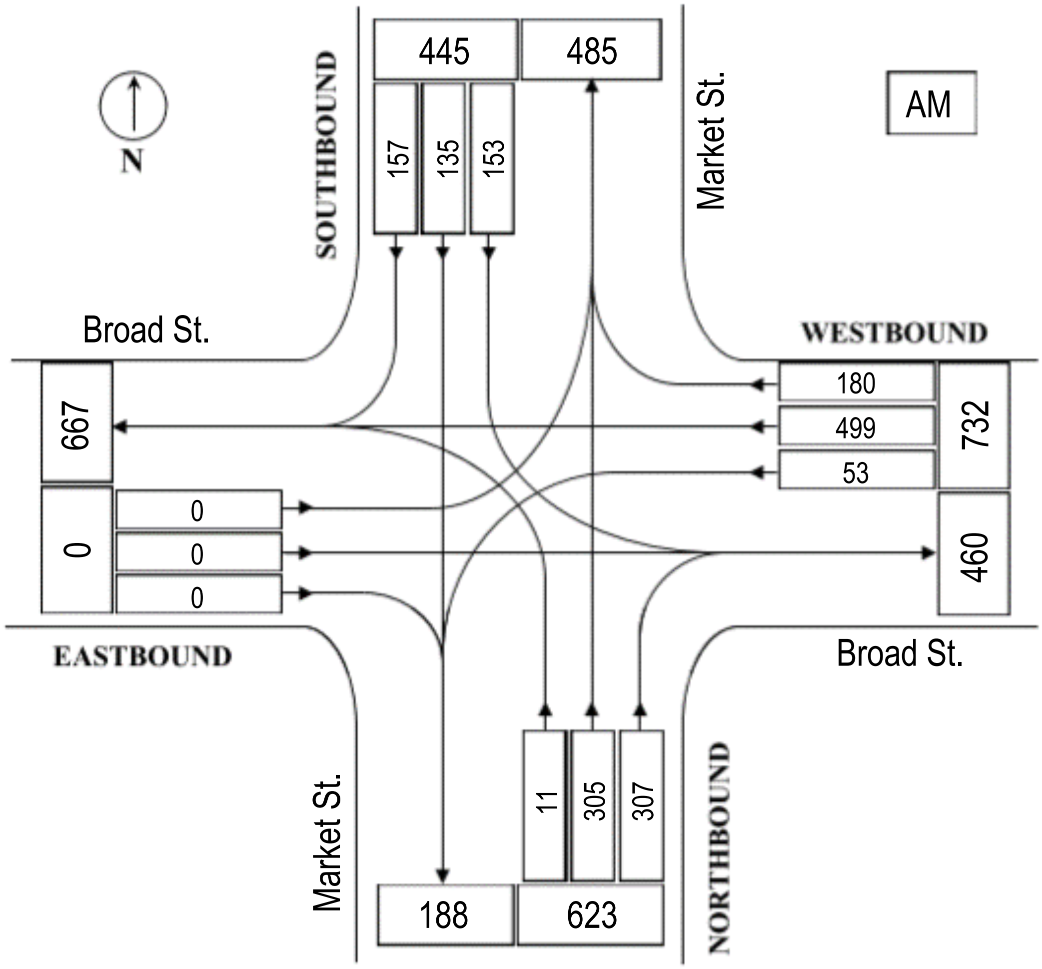


STREET	ENTERING VOLUMES	PERCENT OF FLOW	TIME OF COUNT
Market St. NB	673	41.24%	4:15 – 5:15 PM
Market St. SB	425	26.04%	
Broad St. EB	0	0%	PHF = .99
Broad St. WB	534	32.72%	
			VEHICLES COUNTED
			ALL VEHICLES: 1632
TOTAL	1632	100.0%	TRUCKS: 64
			PERCENT TRUCKS: 3.92%

Template provided by CMRPC

INTERSECTION TURNING MOVEMENT COUNT

CITY: Lynn, MA DATE: 5/28/15 DAY OF WEEK: Thursday
INTERSECTION: Market St. and Broad St.

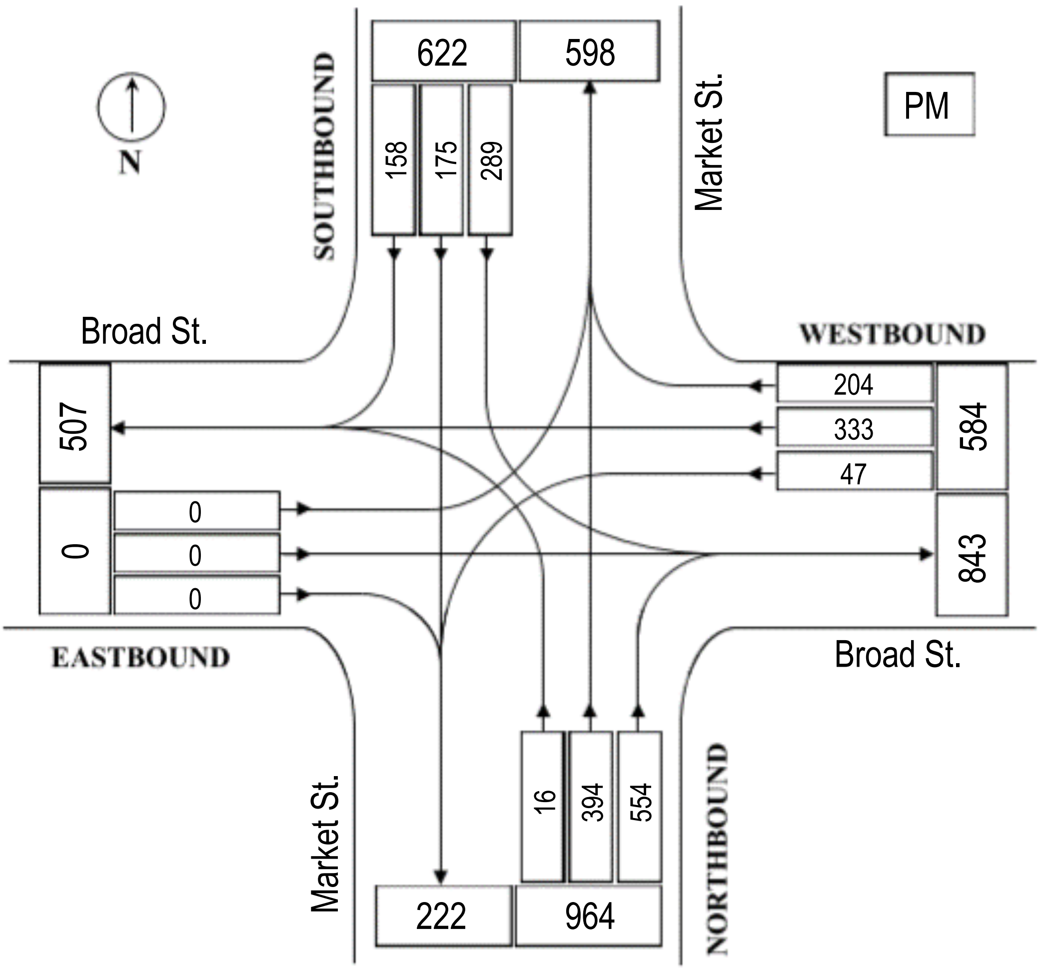


STREET	ENTERING VOLUMES	PERCENT OF FLOW	TIME OF COUNT
Market St. NB	623	34.61%	7:45 – 8:45 AM
Market St. SB	445	24.72%	
Broad St. EB	0	0%	PHF = .95
Broad St. WB	732	40.67%	
			VEHICLES COUNTED
			ALL VEHICLES: 1800
TOTAL	1800	100.0%	TRUCKS: 248
			PERCENT TRUCKS: 13.78%

Template provided by CMRPC

INTERSECTION TURNING MOVEMENT COUNT

CITY: Lynn, MA **DATE:** 5/28/15 **DAY OF WEEK:** Thursday
INTERSECTION: Market St. and Broad St.

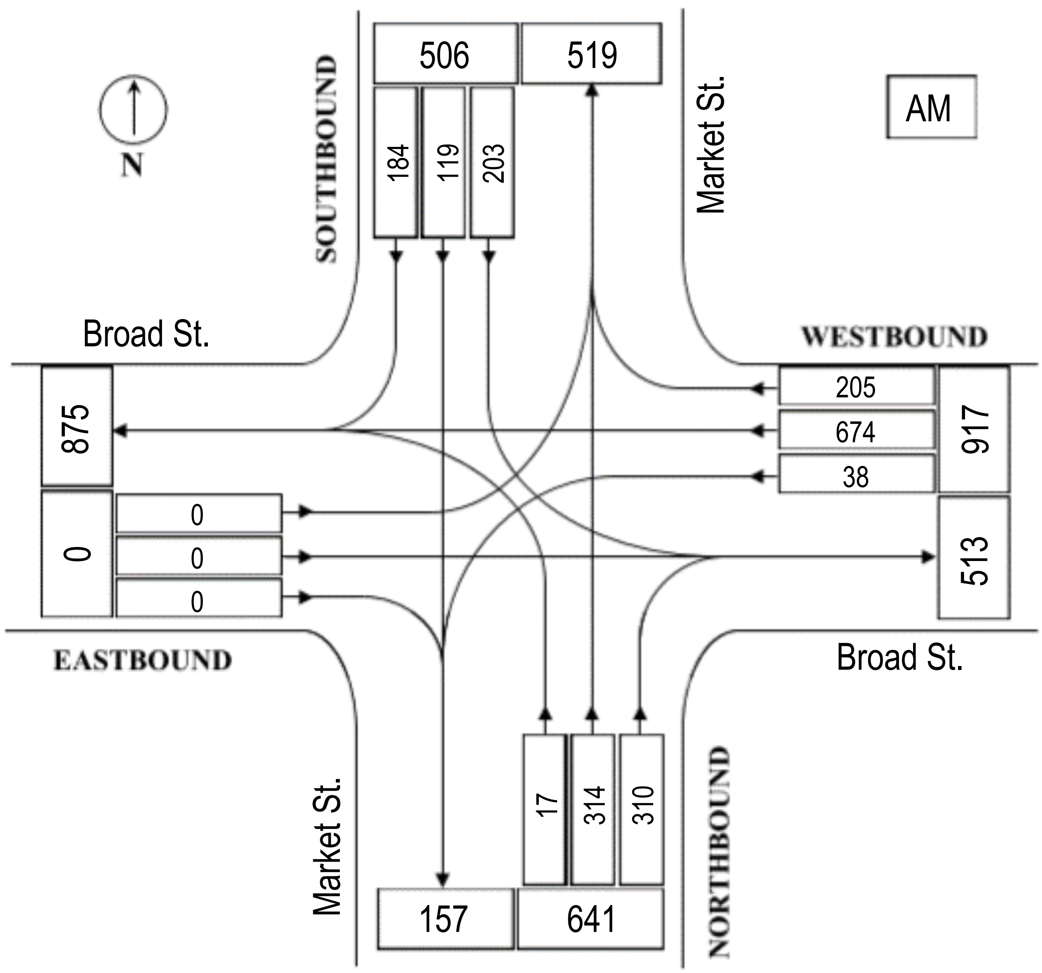


STREET	ENTERING VOLUMES	PERCENT OF FLOW	TIME OF COUNT
Market St. NB	964	44.43%	4:30 – 5:30 PM
Market St. SB	622	28.66%	
Broad St. EB	0	0%	PHF = .92
Broad St. WB	584	26.91%	
			VEHICLES COUNTED
			ALL VEHICLES: 2170
TOTAL	2170	100.0%	TRUCKS: 244
			PERCENT TRUCKS: 11.24%

Template provided by CMRPC

INTERSECTION TURNING MOVEMENT COUNT

CITY: Lynn, MA **DATE:** 3/22/06 **DAY OF WEEK:** Wednesday
INTERSECTION: Market St. and Broad St.

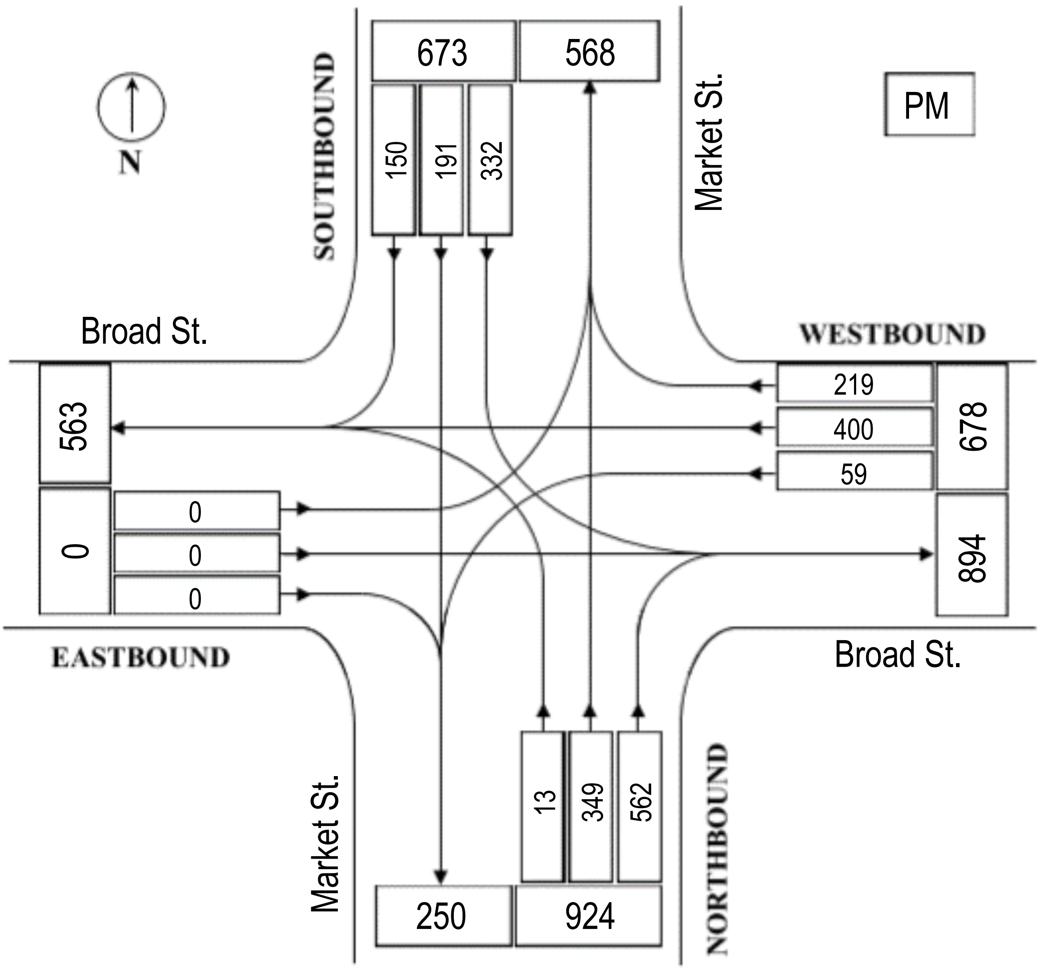


STREET	ENTERING VOLUMES	PERCENT OF FLOW	TIME OF COUNT
Market St. NB	641	31.06%	7:30 – 8:30 AM
Market St. SB	506	24.53%	
Broad St. EB	0	0%	PHF = .86
Broad St. WB	917	44.43%	
			VEHICLES COUNTED
			ALL VEHICLES: 2064
TOTAL	2064	100.0%	TRUCKS:
			PERCENT TRUCKS:

Template provided by CMRPC

INTERSECTION TURNING MOVEMENT COUNT

CITY: Lynn, MA **DATE:** 3/22/06 **DAY OF WEEK:** Wednesday
INTERSECTION: Market St. and Broad St.

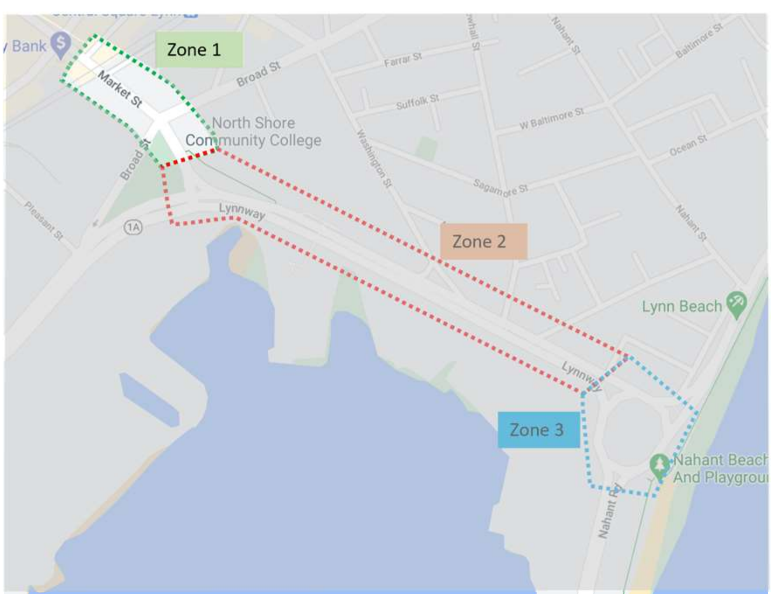


STREET	ENTERING VOLUMES	PERCENT OF FLOW	TIME OF COUNT
Market St. NB	924	40.62%	4:30 – 5:30 PM
Market St. SB	673	29.58%	
Broad St. EB	0	0%	PHF = .94
Broad St. WB	678	29.80%	
			VEHICLES COUNTED
			ALL VEHICLES: 2275
TOTAL	2275	100.0%	TRUCKS:
			PERCENT TRUCKS:

Template provided by CMRPC

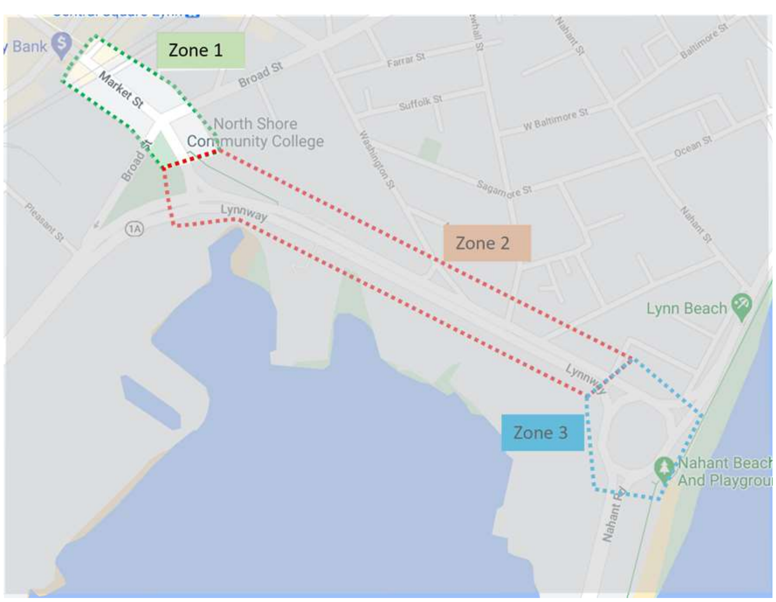
Appendix E: Preliminary Designs

Zone 1: Segment 1
2-way down Market St.



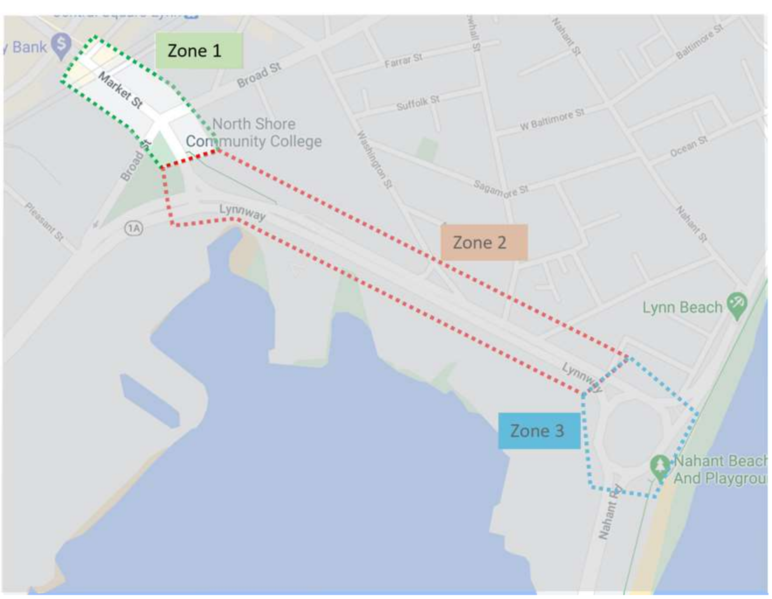
Zone 1: Segment 2

2-way down Market St.



Zone 1: Segment 2 - Alternative

2-way down Market St.

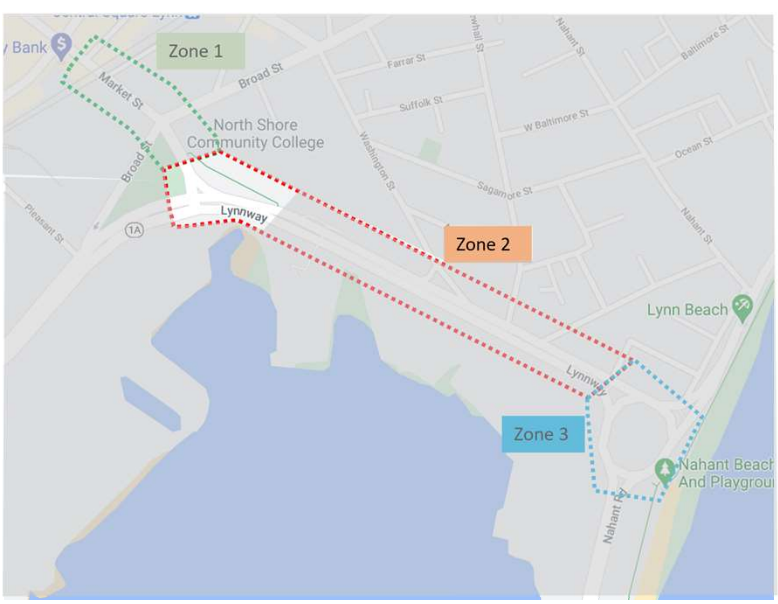


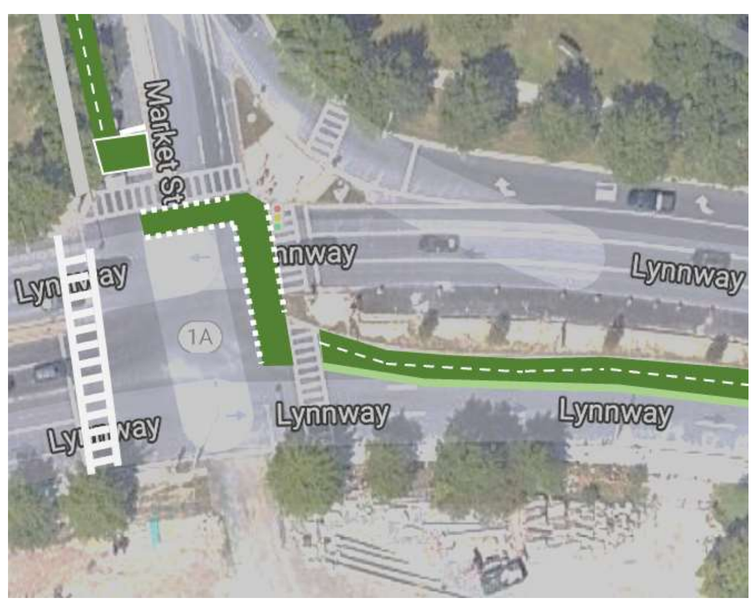
Zone 2:

Crossing of Market St. and the Lynnway – Right-Side Bike Lanes

Zone 2:

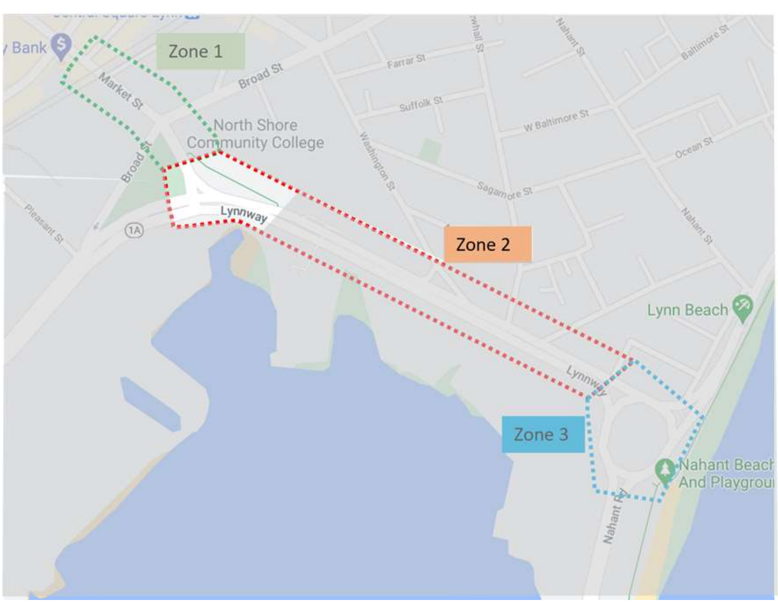
Crossing of Market St. and the Lynnway – Median Bike Lanes



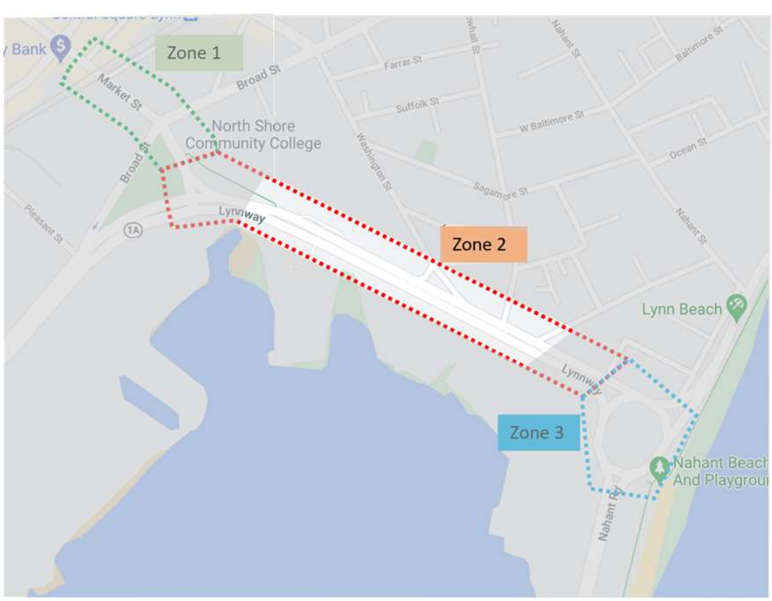


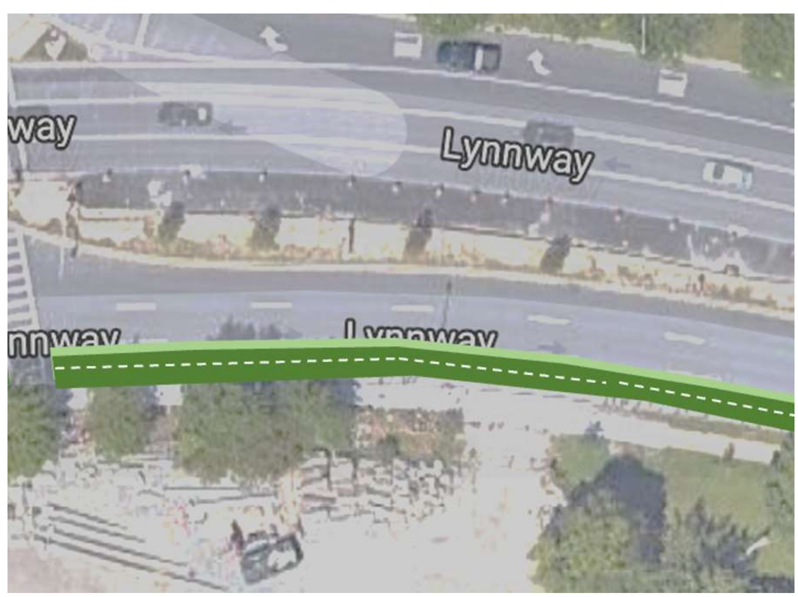
Zone 2:

Crossing of Market St. and the Lynnway – Median Bike Lanes



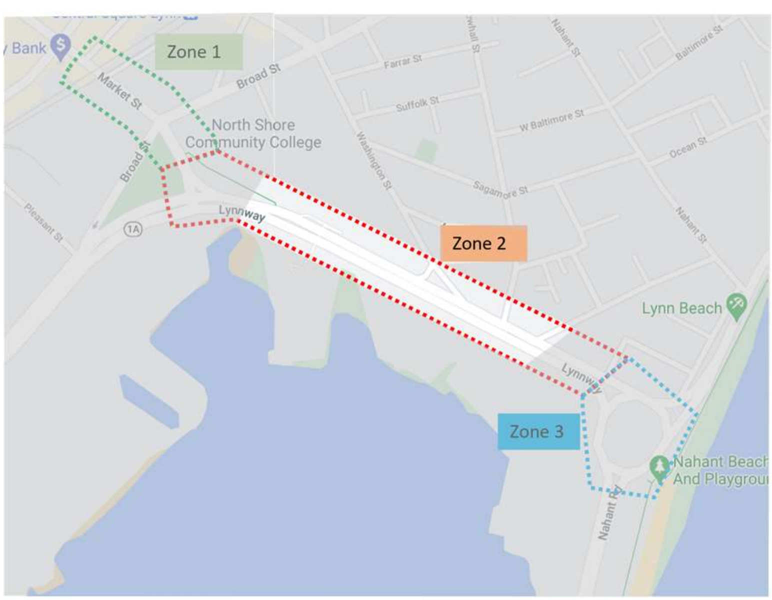
Zone 2:
Right-Side Lanes on Lynnway

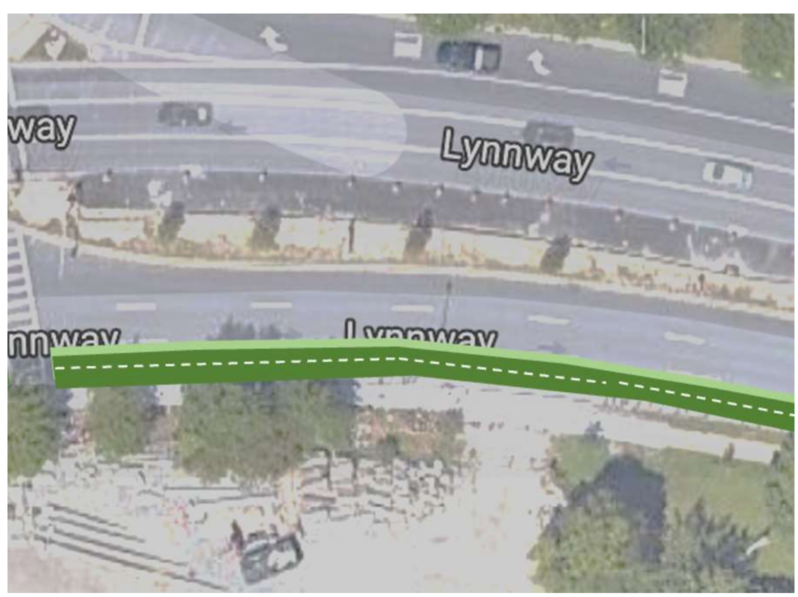




Driveway Detail

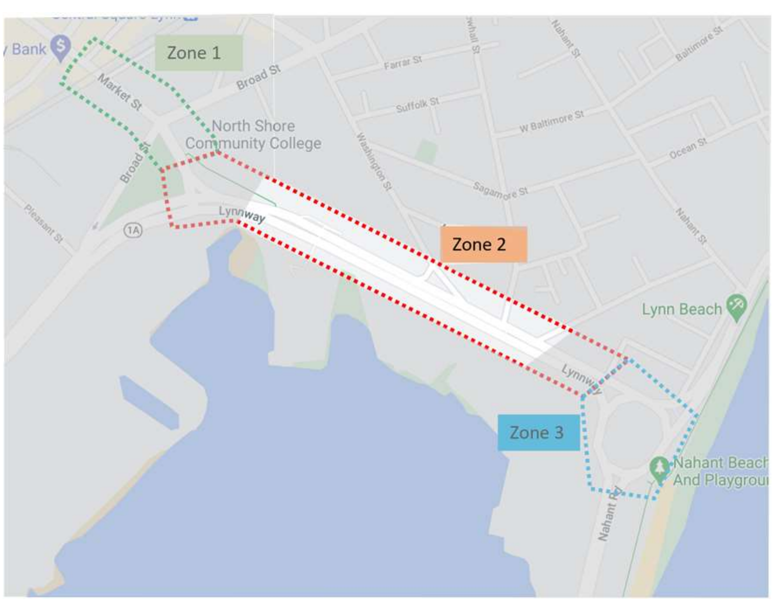
Lynnway Right-Side Lanes

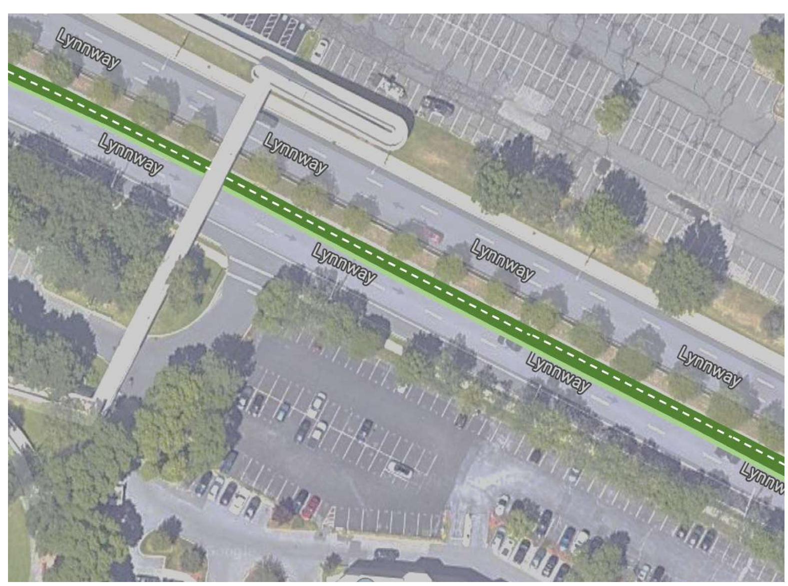




Zone 2:

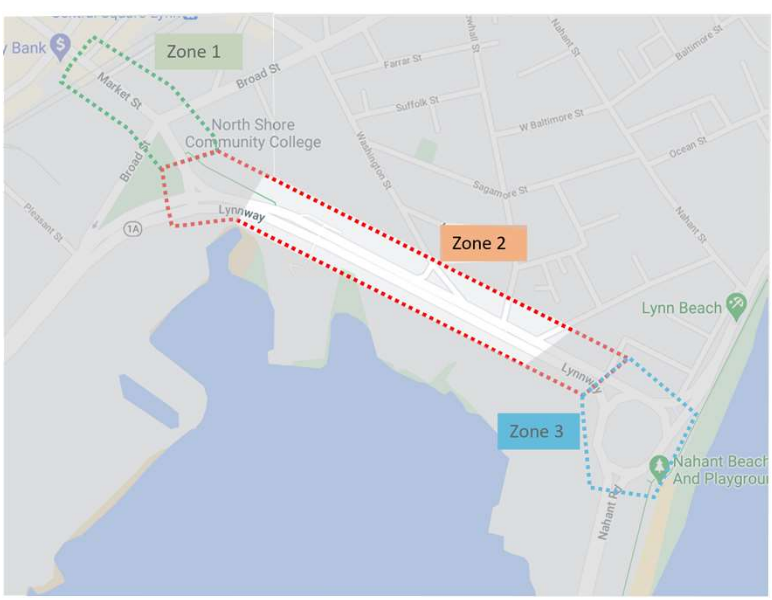
2-way down the Lynnway – Median

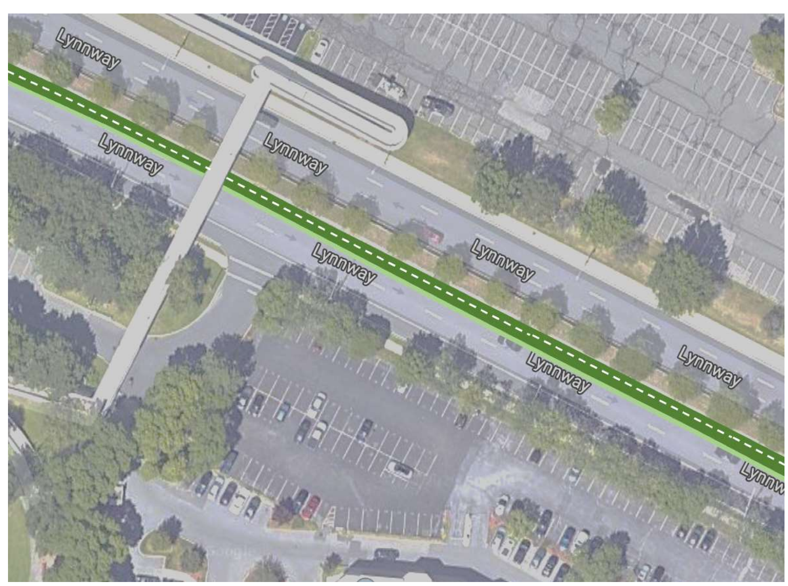




Crosswalk Detail

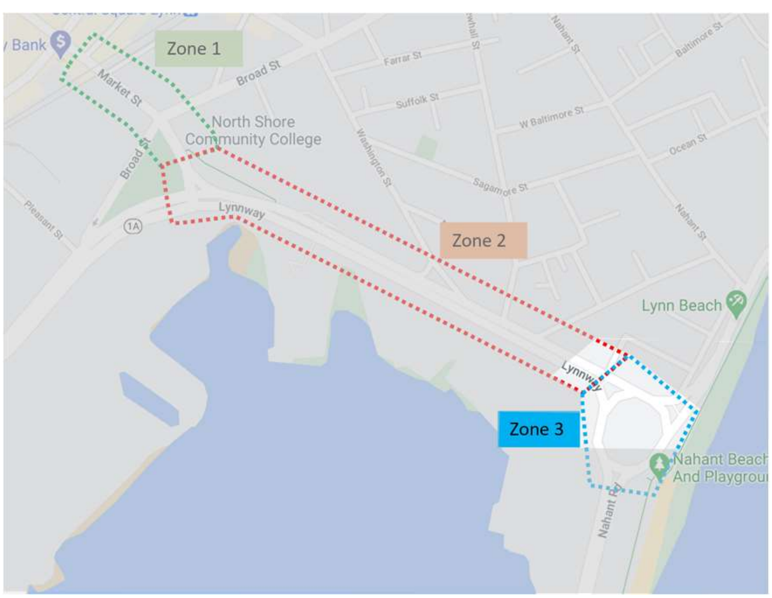
Entrance/Exit of Median Lynnway Bike Lanes





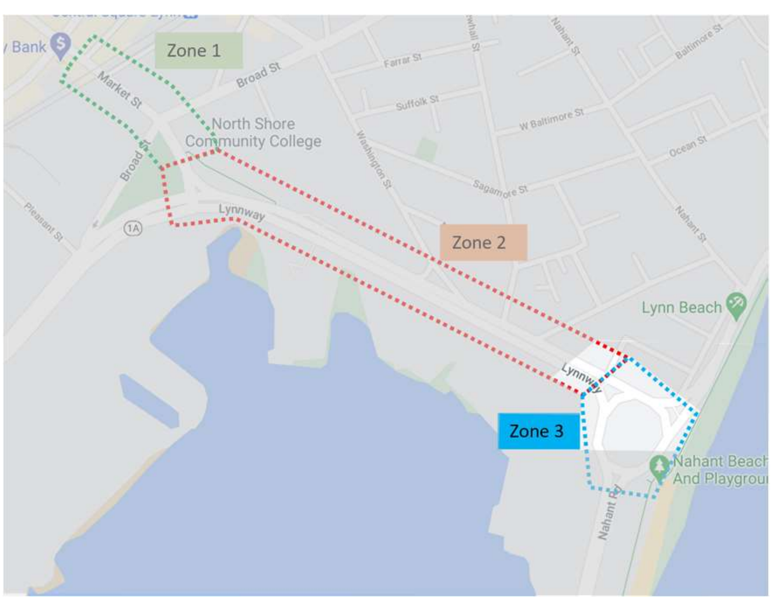
Zone 3: Rotary Entrance

Right-Side Bike Lane Design



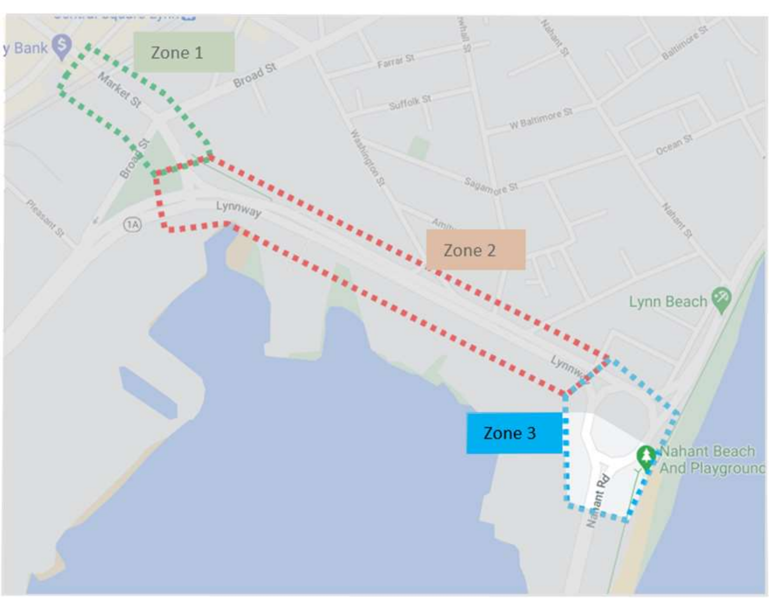
Zone 3: Rotary Entrance

Median Bike Lane Design



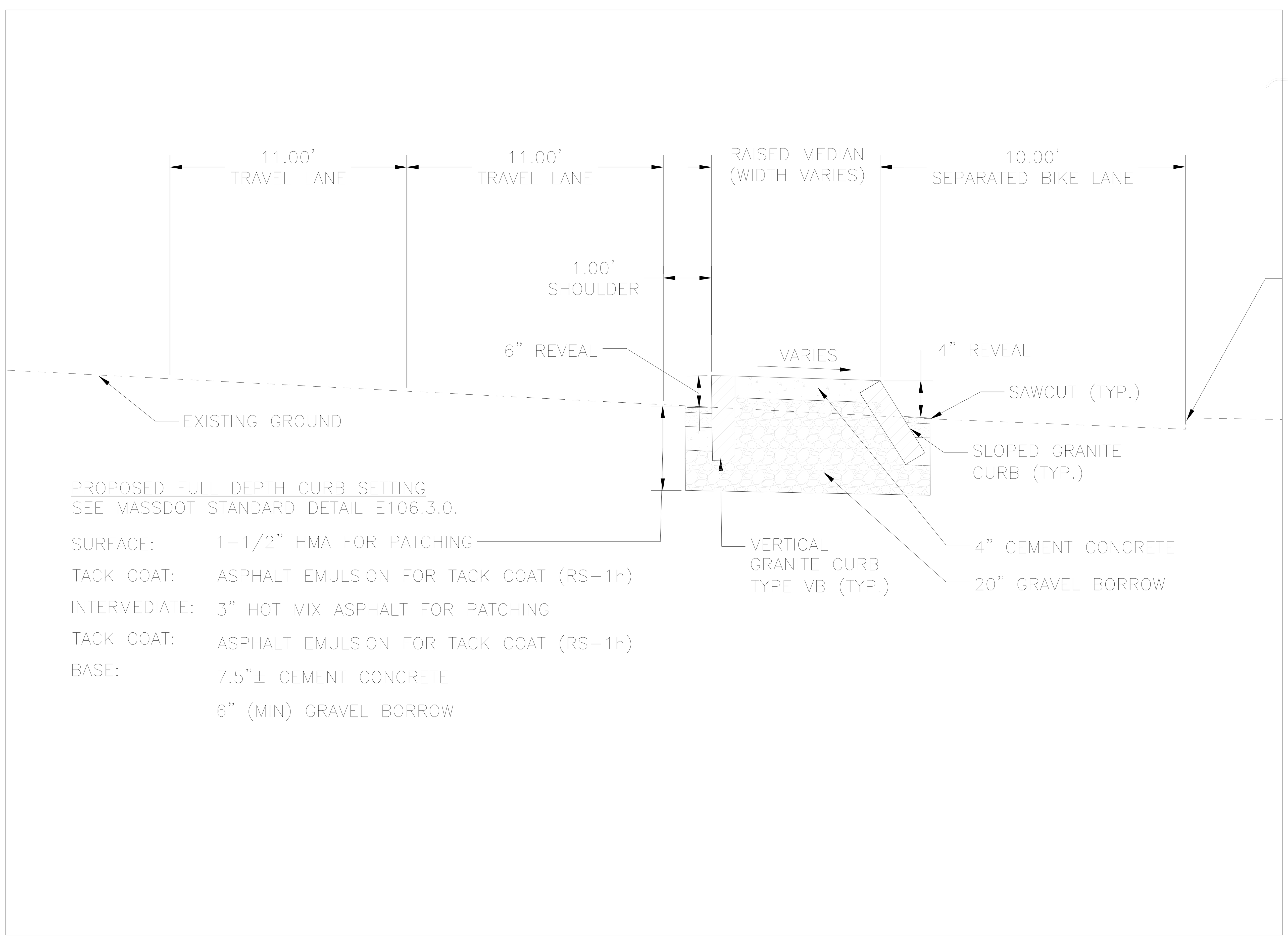
Zone 3: Nahant Beach Entrance

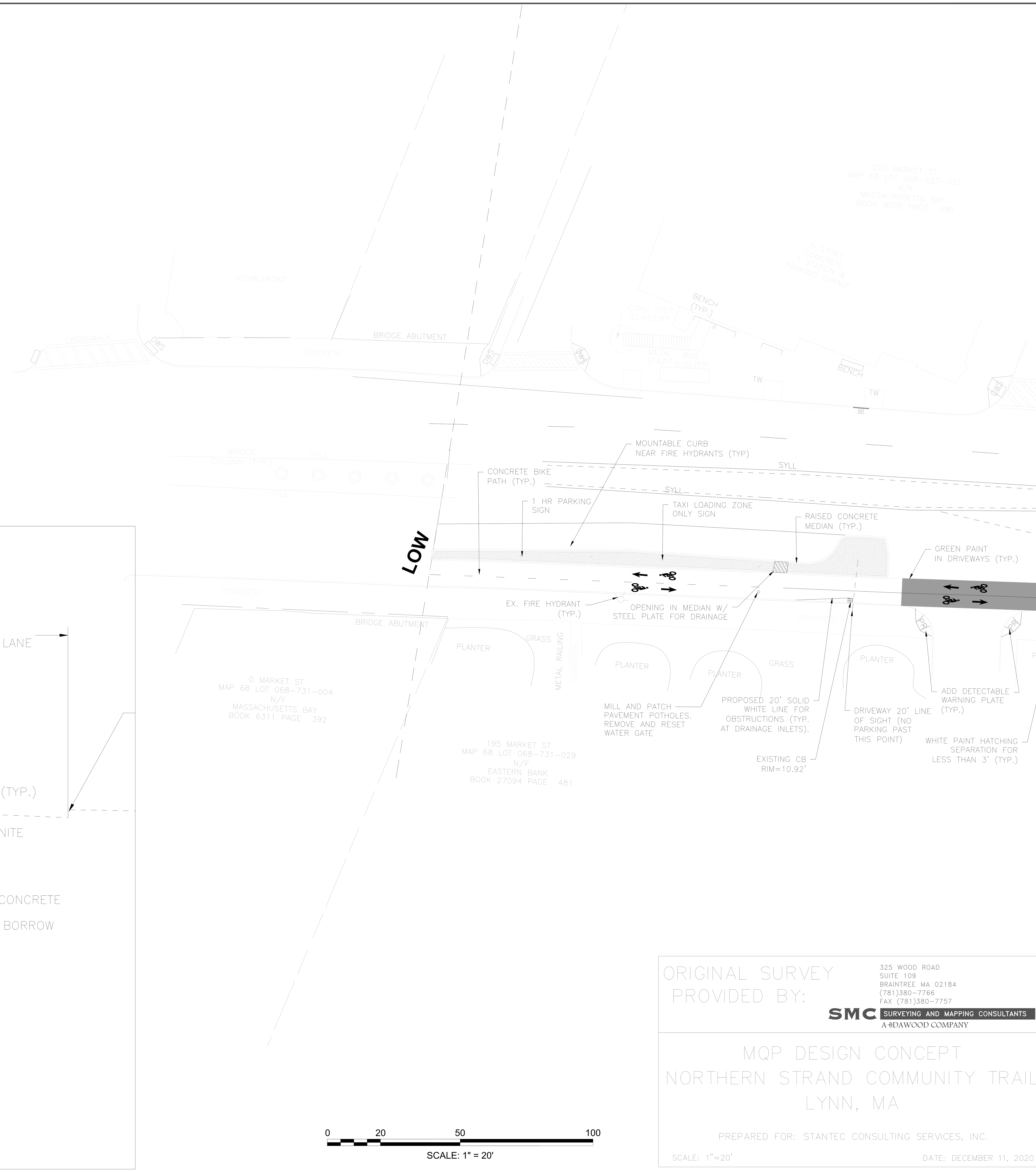
End of project scope



Appendix F: Final Design - AutoCAD Drawings

TYPICAL CROSS SECTION





ORIGINAL SURVEY PROVIDED BY:

325 WOOD ROAD
SUITE 109
BRAINTREE MA 02184
(781)380-7766
FAX (781)380-7757

SMC SURVEYING AND MAPPING CONSULTANTS
A DAWOOD COMPANY

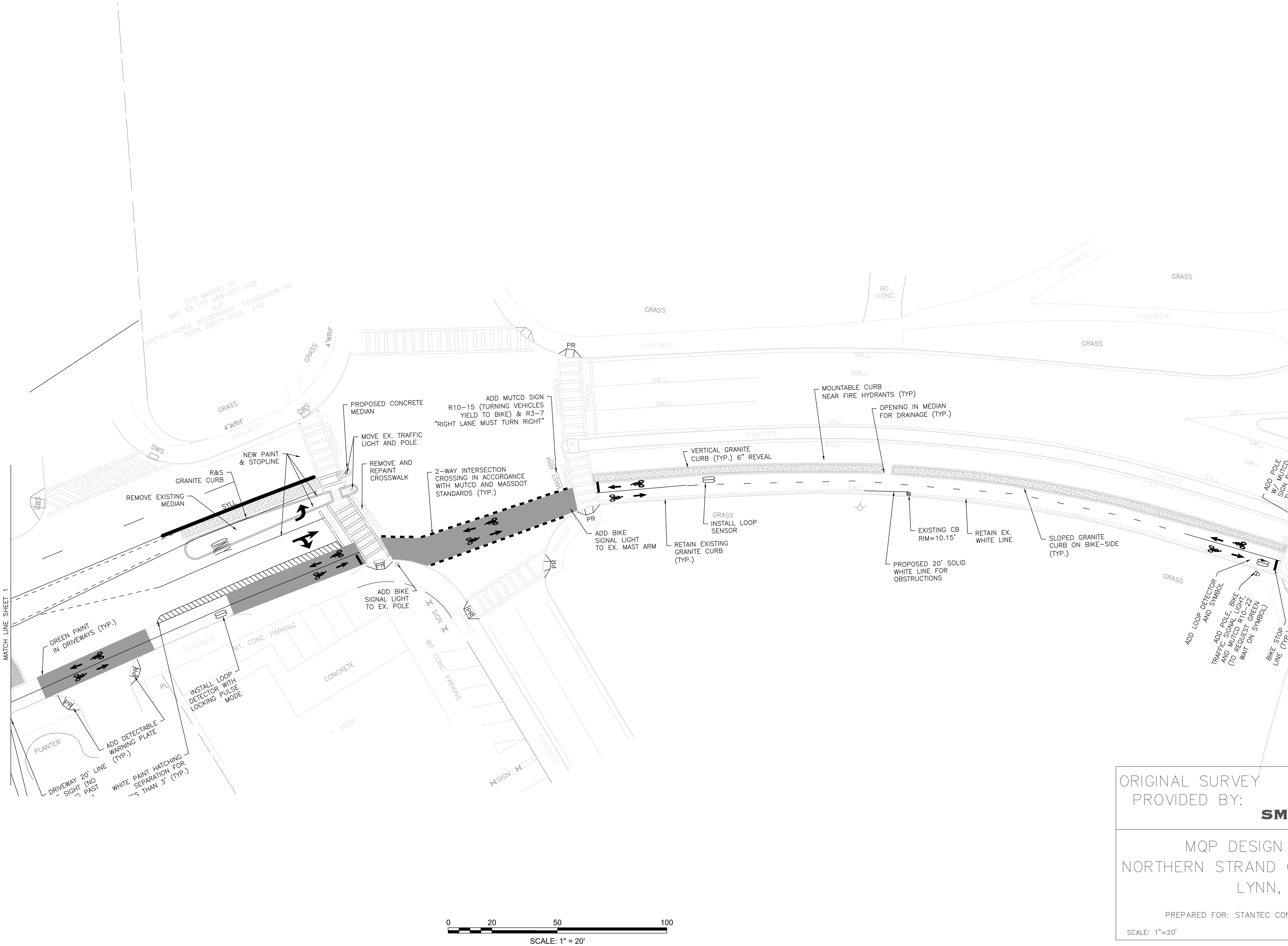
MQP DESIGN CONCEPT
NORTHERN STRAND COMMUNITY TRAIL
LYNN, MA

PREPARED FOR: STANTEC CONSULTING SERVICES, INC.

SCALE: 1"=20'

DATE: DECEMBER 11, 2020

SHEET 1 OF 8



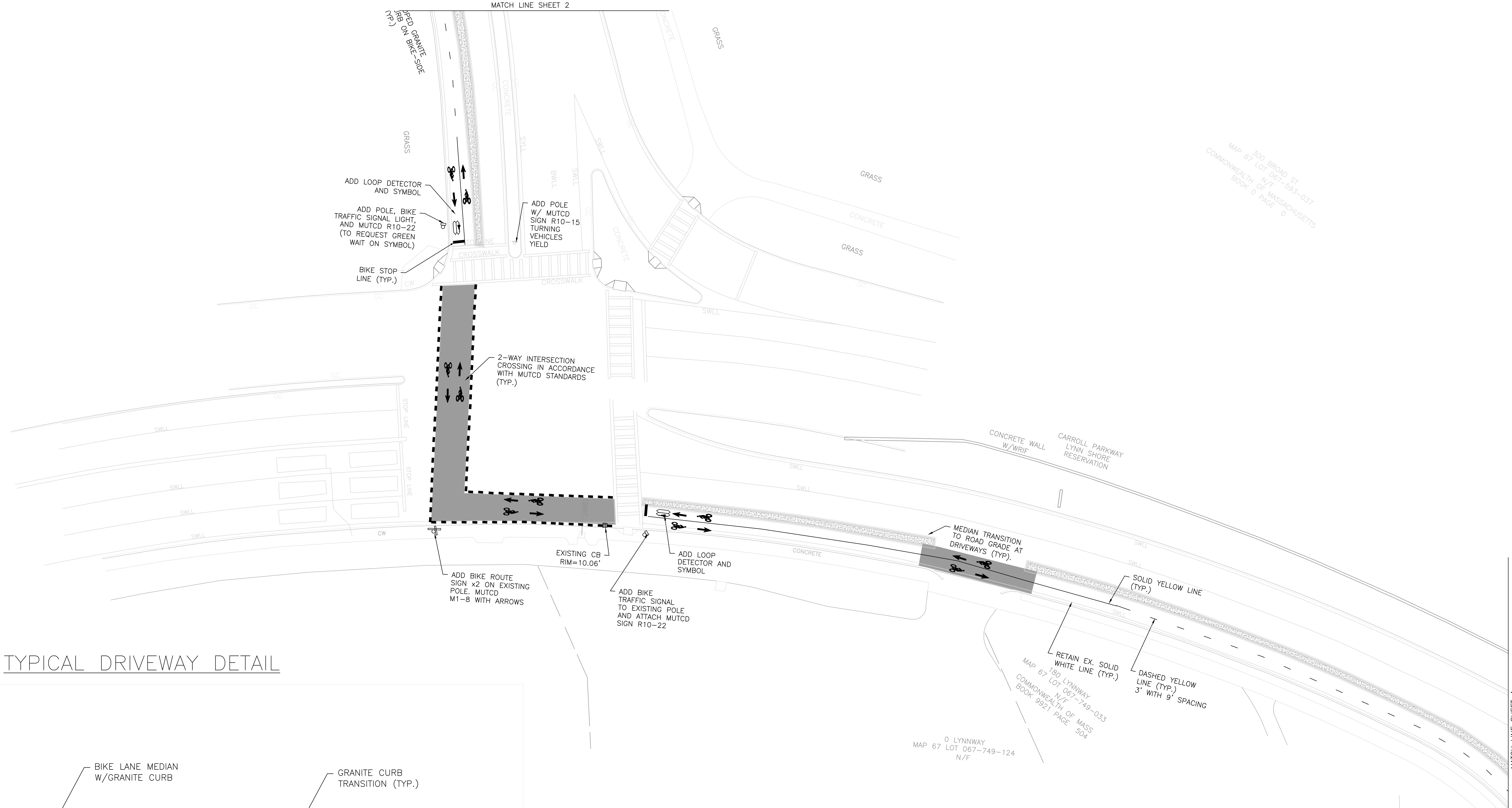
ORIGINAL SURVEY PROVIDED BY:

325 WOOD ROAD
SUITE 109
BRAINTREE MA 02184
(781)380-7766
FAX (781)380-7757
SMC SURVEYING AND MAPPING CONSULTANTS
A DAWOOD COMPANY

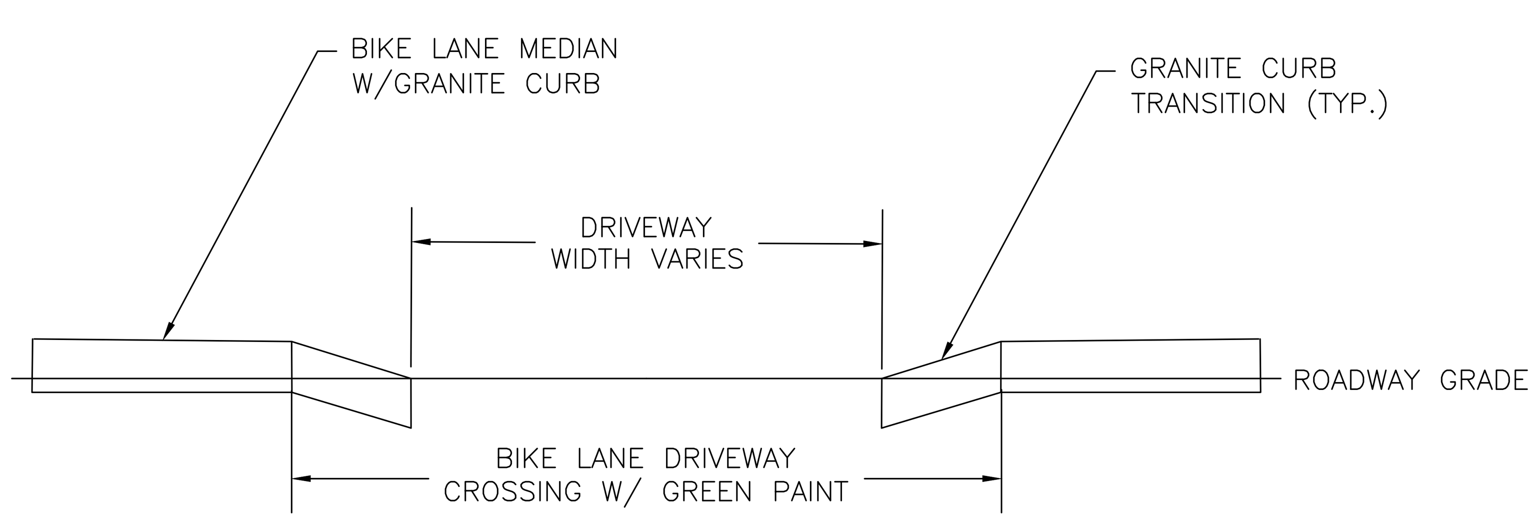
MQP DESIGN CONCEPT
NORTHERN STRAND COMMUNITY TRAIL
LYNN, MA

PREPARED FOR: STANTEC CONSULTING SERVICES, INC.

SCALE: 1"=20'   DATE: DECEMBER 11, 2020



TYPICAL DRIVEWAY DETAIL



0 20 50 100
SCALE: 1" = 20'

ORIGINAL SURVEY PROVIDED BY:

325 WOOD ROAD
SUITE 109
BRAINTREE MA 02184
(781)380-7766
FAX (781)380-7757

SMC SURVEYING AND MAPPING CONSULTANTS
A DAWOOD COMPANY

MQP DESIGN CONCEPT
NORTHERN STRAND COMMUNITY TRAIL
LYNN, MA

PREPARED FOR: STANTEC CONSULTING SERVICES, INC.

SCALE: 1"=20'
DATE: DECEMBER 11, 2020

0 20 50 100
SCALE: 1" = 20'

ORIGINAL SURVEY PROVIDED BY:

325 WOOD ROAD
SUITE 109
BRAINTREE MA 02184
(781)380-7766
FAX (781)380-7757

SMC SURVEYING AND MAPPING CONSULTANTS
A GDAWOOD COMPANY

MQP DESIGN CONCEPT
NORTHERN STRAND COMMUNITY TRAIL
LYNN, MA

PREPARED FOR: STANTEC CONSULTING SERVICES, INC.

SCALE: 1"=20'
DATE: DECEMBER 11, 2020

ORIGINAL SURVEY PROVIDED BY:

325 WOOD ROAD
SUITE 109
BRAINTREE MA 02184
(781)380-7766
FAX (781)380-7757
SMC SURVEYING AND MAPPING CONSULTANTS
A DAWOOD COMPANY

MQP DESIGN CONCEPT
NORTHERN STRAND COMMUNITY TRAIL
LYNN, MA

PREPARED FOR: STANTEC CONSULTING SERVICES, INC.

SCALE: 1"=20' DATE: DECEMBER 11, 2020

ORIGINAL SURVEY PROVIDED BY:

325 WOOD ROAD
SUITE 109
BRAINTREE MA 02184
(781)380-7766
FAX (781)380-7757

SMC SURVEYING AND MAPPING CONSULTANTS
A DAWOOD COMPANY

MQP DESIGN CONCEPT
NORTHERN STRAND COMMUNITY TRAIL
LYNN, MA

PREPARED FOR: STANTEC CONSULTING SERVICES, INC.

SCALE: 1"=20' DATE: DECEMBER 11, 2020

SHEET 6 OF 8

ORIGINAL SURVEY PROVIDED BY:

325 WOOD ROAD
SUITE 109
BRAINTREE MA 02184
(781)380-7766
FAX (781)380-7757

SMC SURVEYING AND MAPPING CONSULTANTS
A DAWOOD COMPANY

MQP DESIGN CONCEPT
NORTHERN STRAND COMMUNITY TRAIL
LYNN, MA

PREPARED FOR: STANTEC CONSULTING SERVICES, INC.

SCALE: 1"=20'

DATE: DECEMBER 11, 2020

ORIGINAL SURVEY PROVIDED BY:

325 WOOD ROAD
SUITE 109
BRAINTREE MA 02184
(781)380-7766
FAX (781)380-7757

SMC SURVEYING AND MAPPING CONSULTANTS
A DAWOOD COMPANY

MQP DESIGN CONCEPT
NORTHERN STRAND COMMUNITY TRAIL
LYNN, MA

PREPARED FOR: STANTEC CONSULTING SERVICES, INC.

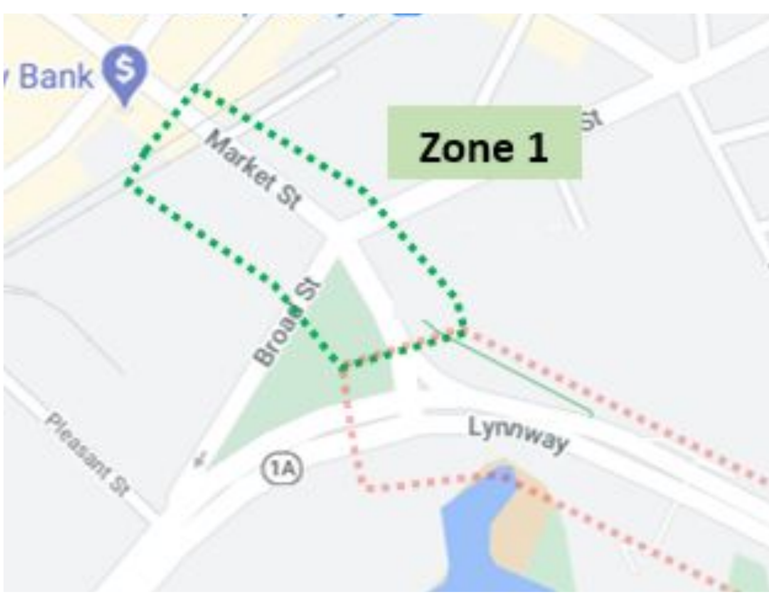
SCALE: 1"=20'

DATE: DECEMBER 11, 2020

Appendix G: Final Design - Perspective and Aerial Drawings

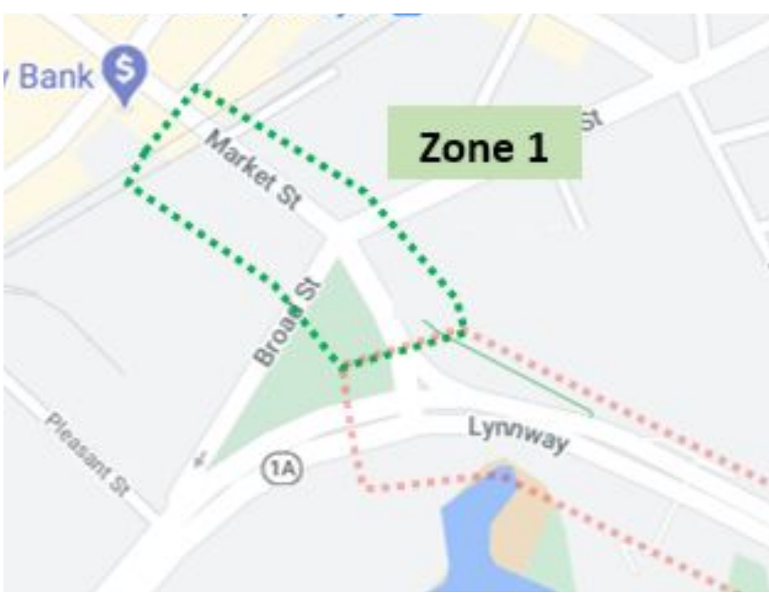
Zone 1: Market Street

Beginning of Project Scope and Taxi Stand



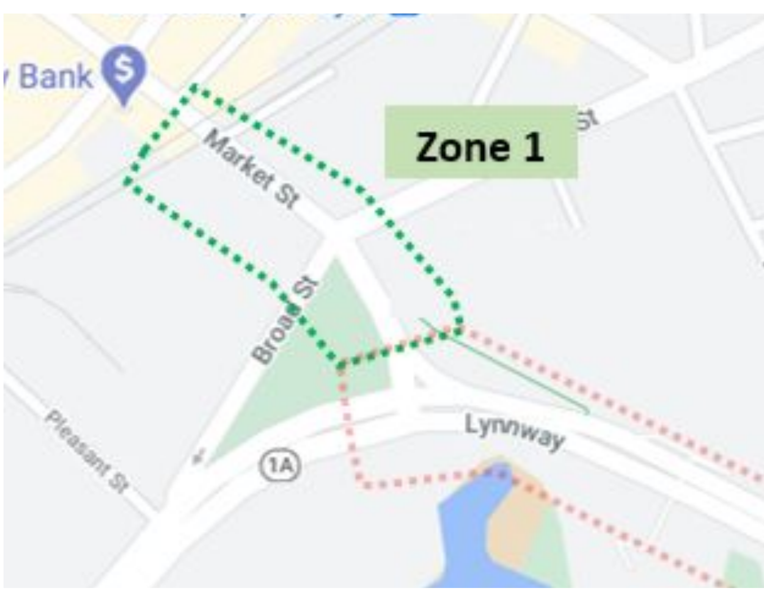
Zone 1: Intersection of Market and Broad Street

Goodyear Tire Driveway Detail



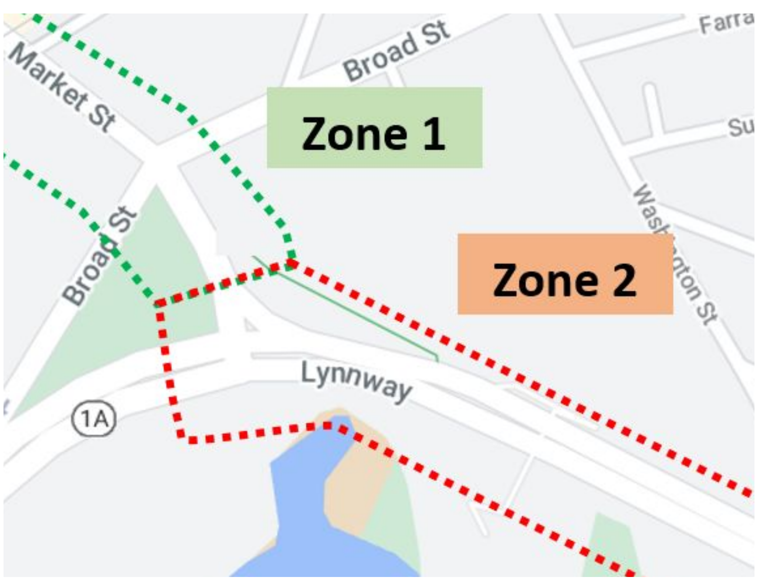
Zone 1: Market Street

Right-Side Bike Lanes



Zone 1 to 2: Intersection of Market Street and Lynnway

Right-Side Bike Lanes

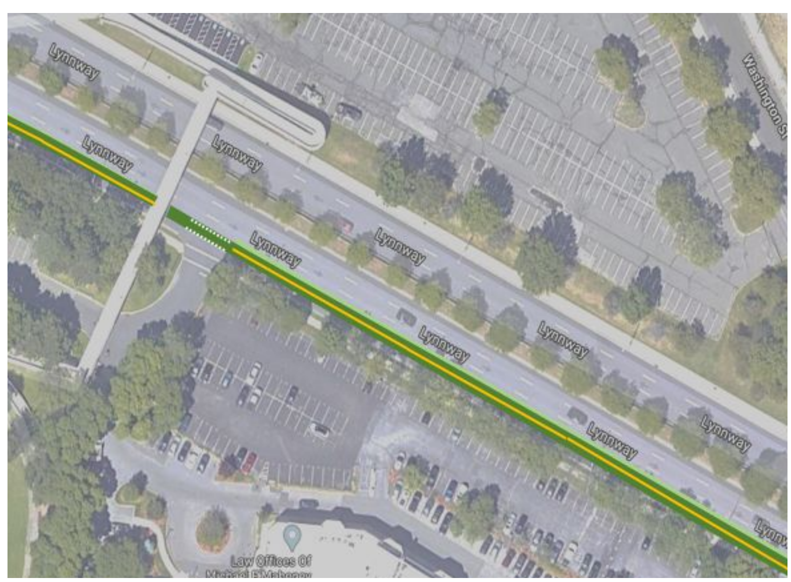


Zone 2: Lynnway

Right-Side Bike Lanes

Zone 2: Driveway Detail

Right-Side Bike Lanes on Lynnway

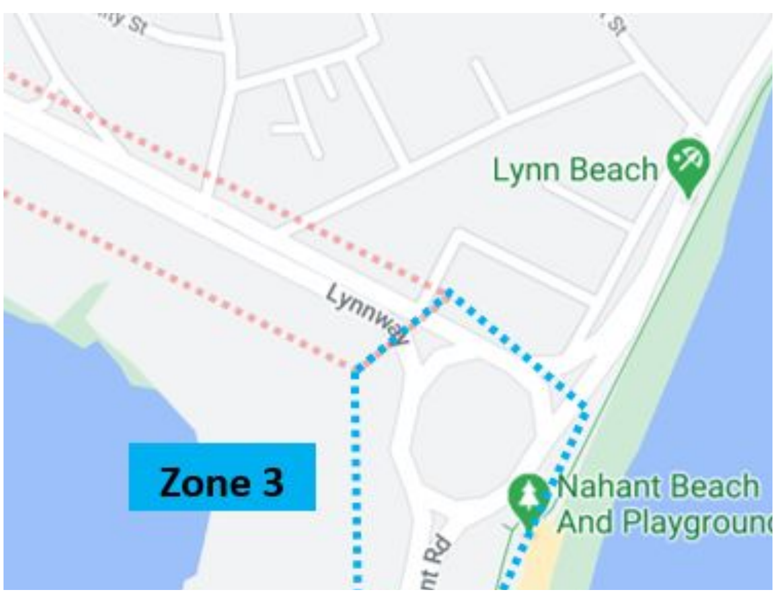


Zone 2: Median Detail

Right-Side Bike Lanes on Lynnway

Zone 3: Nahant Rotary Entrance

Right-Side Bike Lanes

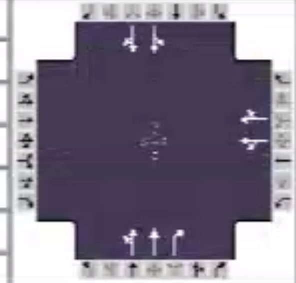


Zone 3: Nahant Beach Entrance
End of Trail

Appendix H: Highway Capacity Software Reports

HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency	WPI MQP			Duration, h	0.25
Analyst	LS/MO/SK	Analysis Date	Oct 28, 2020	Area Type	Other
Jurisdiction		Time Period	7:15 - 8:15 AM	PHF	0.95
Intersection	Market St @ Broad St	Analysis Year	2020	Analysis Period	1> 7:00
File Name	OPT Market Broad 2020 AM.xus				
Project Description	Existing 3.5-Way 2020 AM				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h				11	312	122	13	216	213	99	85	130

Signal Information											
Cycle, s	36.0	Reference Phase	2	Green	11.0	15.0	0.0	0.0	0.0	0.0
Offset, s	0	Reference Point	End	Yellow	3.0	3.0	0.0	0.0	0.0	0.0
Uncoordinated	Yes	Simult. Gap E/W	On	Red	2.0	2.0	0.0	0.0	0.0	0.0
Force Mode	Fixed	Simult. Gap N/S	On							

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase				8		2		6
Case Number				12.0		7.0		8.0
Phase Duration, s				20.0		16.0		16.0
Change Period, ($Y+R_c$), s				5.0		5.0		5.0
Max Allow Headway (*MAH*), s				3.1		3.3		3.3
Queue Clearance Time (g_s), s				5.6		6.5		5.8
Green Extension Time (g_e), s				0.7		0.9		1.0
Phase Call Probability				1.00		1.00		1.00
Max Out Probability				0.02		0.62		0.46

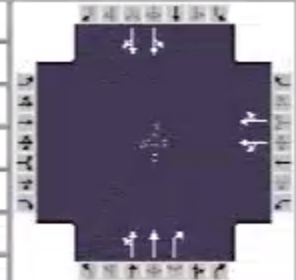
Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement				3	8	18	5	2	12	1	6	16
Adjusted Flow Rate (v), veh/h				254		215	127	115	224	178		153
Adjusted Saturation Flow Rate (s), veh/h/ln				1739		1574	1672	1558	1464	1369		1475
Queue Service Time (g_s), s				3.6		3.3	0.0	2.0	4.5	1.8		2.9
Cycle Queue Clearance Time (g_c), s				3.6		3.3	2.0	2.0	4.5	3.8		2.9
Green Ratio (g/C)				0.42		0.42	0.31	0.31	0.31	0.31		0.31
Capacity (c), veh/h				725		656	622	476	447	577		451
Volume-to-Capacity Ratio (X)				0.350		0.327	0.204	0.241	0.501	0.308		0.339
Available Capacity (c_a), veh/h				725		656	622	476	447	577		451
Back of Queue (Q), veh/ln (95th percentile)				1.5		1.2	1.0	0.9	1.9	1.4		1.2
Queue Storage Ratio (RQ) (95th percentile)				0.11		0.10	0.07	0.07	0.15	0.11		0.09
Uniform Delay (d_1), s/veh				7.2		7.1	9.4	9.4	10.3	9.9		9.7
Incremental Delay (d_2), s/veh				0.1		0.1	0.1	0.1	0.3	0.1		0.2
Initial Queue Delay (d_3), s/veh				0.0		0.0	0.0	0.0	0.0	0.0		0.0
Control Delay (d), s/veh				7.3		7.2	9.4	9.5	10.6	10.0		9.8
Level of Service (LOS)				A		A	A	A	B	A		A
Approach Delay, s/veh / LOS	0.0			7.2		A	10.0		A	9.9		A
Intersection Delay, s/veh / LOS	9.0						A					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.8	C	2.7	B	2.2	B	2.4	B
Bicycle LOS Score / LOS			0.9	A	0.9	A	0.8	A

Copyright © 2020 University of Florida, All Rights Reserved.

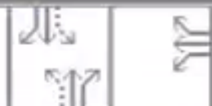
HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency	WPI MQP			Duration, h	0.25
Analyst	LS/MO/SK	Analysis Date	Oct 28, 2020	Area Type	Other
Jurisdiction		Time Period	4:15 - 5:15 PM	PHF	0.99
Intersection	Market St @ Broad St	Analysis Year	2020	Analysis Period	1> 7:00
File Name	OPT Market Broad 2020 PM.xus				
Project Description	Existing 3.5-Way 2020 PM				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (v), veh/h				30	324	180	4	230	439	199	91	135

Signal Information										
Cycle, s	49.0	Reference Phase	2							
Offset, s	0	Reference Point	End	Green	24.0	15.0	0.0	0.0	0.0	0.0
Uncoordinated	Yes	Simult. Gap E/W	On	Yellow	3.0	3.0	0.0	0.0	0.0	0.0
Force Mode	Fixed	Simult. Gap N/S	On	Red	2.0	2.0	0.0	0.0	0.0	0.0



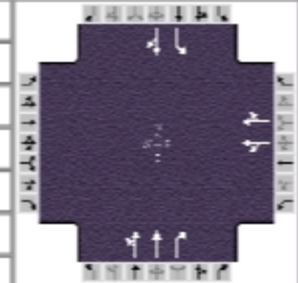
Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase				8		2		6
Case Number				12.0		7.0		8.0
Phase Duration, s				20.0		29.0		29.0
Change Period, ($Y+R_c$), s				5.0		5.0		5.0
Max Allow Headway (MAH), s				3.1		3.3		3.3
Queue Clearance Time (g_s), s				8.5		11.9		7.1
Green Extension Time (g_e), s				0.7		0.4		2.5
Phase Call Probability				1.00		1.00		1.00
Max Out Probability				0.15		1.00		0.02

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement				3	8	18	5	2	12	1	6	16
Adjusted Flow Rate (v), veh/h				296		244	236	0	443	216		214
Adjusted Saturation Flow Rate (s), veh/h/ln				1835		1626	1841	1679	1563	1250		1613
Queue Service Time (g_s), s				6.5		6.0	0.0	0.0	9.9	5.0		3.8
Cycle Queue Clearance Time (g_c), s				6.5		6.0	3.7	0.0	9.9	5.1		3.8
Green Ratio (g/C)				0.31		0.31	0.49	0.49	0.49	0.49		0.49
Capacity (c), veh/h				562		498	976	822	766	754		790
Volume-to-Capacity Ratio (X)				0.526		0.490	0.242	0.000	0.579	0.286		0.270
Available Capacity (c_a), veh/h				562		498	976	822	766	754		790
Back of Queue (Q), veh/ln (95th percentile)				4.1		3.3	1.9	0.0	4.6	1.8		1.7
Queue Storage Ratio (RQ) (95th percentile)				0.30		0.24	0.14	0.00	0.33	0.13		0.12
Uniform Delay (d_1), s/veh				14.1		13.9	7.3	0.0	8.9	7.7		7.4
Incremental Delay (d_2), s/veh				0.5		0.3	0.0	0.0	0.7	0.1		0.1
Initial Queue Delay (d_3), s/veh				0.0		0.0	0.0	0.0	0.0	0.0		0.0
Control Delay (d), s/veh				14.5		14.2	7.4	0.0	9.6	7.7		7.4
Level of Service (LOS)				B		B	A	A	A	A		A
Approach Delay, s/veh / LOS	0.0			14.4		B	8.8		A	7.6		A
Intersection Delay, s/veh / LOS	10.3						B					
Multimodal Results	EB			WB			NB			SB		
Pedestrian LOS Score / LOS	2.8		C	2.7		B	2.2		B	2.4		B
Bicycle LOS Score / LOS				0.9		A	1.0		A	0.8		A

Copyright © 2020 University of Florida, All Rights Reserved. HCS 2010™ Streets Version 6.50 Generated: 12/4/2020 1:54:40 PM

HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency	WPI MQP			Duration, h	0.25
Analyst	LS/MO/SK	Analysis Date	Oct 28, 2020	Area Type	Other
Jurisdiction		Time Period	7:15 - 8:15 AM	PHF	0.95
Intersection	Market St @ Broad St	Analysis Year	2020	Analysis Period	1> 7:00
File Name	NEW Market Broad 2020 AM.xus				
Project Description	Proposed 3.5-Way 2020 AM				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h				11	312	122	13	216	213	99	85	130

Signal Information										
Cycle, s	49.0	Reference Phase	2							
Offset, s	0	Reference Point	End	Green	24.0	15.0	0.0	0.0	0.0	0.0
Uncoordinated	Yes	Simult. Gap E/W	On	Yellow	3.0	3.0	0.0	0.0	0.0	0.0
Force Mode	Fixed	Simult. Gap N/S	On	Red	2.0	2.0	0.0	0.0	0.0	0.0

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase				8		2		6
Case Number				12.0		7.0		6.0
Phase Duration, s				20.0		29.0		29.0
Change Period, ($Y+R_c$), s				5.0		5.0		5.0
Max Allow Headway (*MAH*), s				3.1		3.3		3.3
Queue Clearance Time (g_s), s				7.8		6.5		6.6
Green Extension Time (g_e), s				0.6		1.6		1.5
Phase Call Probability				1.00		1.00		1.00
Max Out Probability				0.08		0.00		0.02

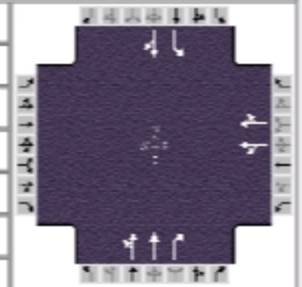
Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement				3	8	18	5	2	12	1	6	16
Adjusted Flow Rate (v), veh/h				254		215	125	116	224	104	226	
Adjusted Saturation Flow Rate (s), veh/h/ln				1739		1574	1659	1558	1464	1172	1632	
Queue Service Time (g_s), s				5.8		5.4	0.0	2.0	4.5	2.6	4.0	
Cycle Queue Clearance Time (g_c), s				5.8		5.4	2.0	2.0	4.5	4.6	4.0	
Green Ratio (g/C)				0.31		0.31	0.49	0.49	0.49	0.49	0.49	
Capacity (c), veh/h				532		482	894	763	717	673	799	
Volume-to-Capacity Ratio (X)				0.477		0.445	0.140	0.152	0.313	0.155	0.283	
Available Capacity (c_a), veh/h				532		482	894	763	717	673	799	
Back of Queue (Q), veh/ln (95th percentile)				3.4		2.9	0.9	0.9	1.8	0.9	1.9	
Queue Storage Ratio (RQ) (95th percentile)				0.26		0.22	0.07	0.07	0.14	0.07	0.14	
Uniform Delay (d_1), s/veh				13.8		13.7	6.9	6.9	7.5	8.2	7.4	
Incremental Delay (d_2), s/veh				0.2		0.2	0.0	0.0	0.1	0.0	0.1	
Initial Queue Delay (d_3), s/veh				0.0		0.0	0.0	0.0	0.0	0.0	0.0	
Control Delay (d), s/veh				14.1		13.9	6.9	6.9	7.6	8.2	7.5	
Level of Service (LOS)				B		B	A	A	A	A	A	
Approach Delay, s/veh / LOS	0.0			14.0	B		7.3	A		7.7	A	
Intersection Delay, s/veh / LOS	9.9						A					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.4	B	2.7	B	2.2	B	2.4	B
Bicycle LOS Score / LOS			0.9	A	0.9	A	1.0	A

Copyright © 2020 University of Florida, All Rights Reserved.

HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency	WPI MQP			Duration, h	0.25
Analyst	LS/MO/SK	Analysis Date	Oct 28, 2020	Area Type	Other
Jurisdiction		Time Period	4:15 - 5:15 PM	PHF	0.99
Intersection	Market St @ Broad St	Analysis Year	2020	Analysis Period	1> 7:00
File Name	NEW Market Broad 2020 PM.xus				
Project Description	Proposed 3.5-Way 2020 PM				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h				30	324	180	4	230	439	199	91	135

Signal Information											
Cycle, s	50.0	Reference Phase	2								
Offset, s	0	Reference Point	End	Green	24.0	16.0	0.0	0.0	0.0	0.0	
Uncoordinated	Yes	Simult. Gap E/W	On	Yellow	3.0	3.0	0.0	0.0	0.0	0.0	
Force Mode	Fixed	Simult. Gap N/S	On	Red	2.0	2.0	0.0	0.0	0.0	0.0	

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase				8		2		6
Case Number				12.0		7.0		6.0
Phase Duration, s				21.0		29.0		29.0
Change Period, ($Y+R_c$), s				5.0		5.0		5.0
Max Allow Headway (*MAH*), s				3.1		3.3		3.3
Queue Clearance Time (g_s), s				8.5		12.3		7.4
Green Extension Time (g_e), s				0.8		2.3		2.3
Phase Call Probability				1.00		1.00		1.00
Max Out Probability				0.09		0.10		0.08

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement				3	8	18	5	2	12	1	6	16
Adjusted Flow Rate (v), veh/h				296		244	236	0	443	201	228	
Adjusted Saturation Flow Rate (s), veh/h/ln				1835		1626	1841	1679	1563	1166	1716	
Queue Service Time (g_s), s				6.5		6.0	0.0	0.0	10.3	5.4	4.0	
Cycle Queue Clearance Time (g_c), s				6.5		6.0	3.8	0.0	10.3	5.4	4.0	
Green Ratio (g/C)				0.32		0.32	0.48	0.48	0.48	0.48	0.48	
Capacity (c), veh/h				587		520	957	806	750	704	823	
Volume-to-Capacity Ratio (X)				0.503		0.469	0.247	0.000	0.591	0.286	0.277	
Available Capacity (c_a), veh/h				587		520	957	806	750	704	823	
Back of Queue (Q), veh/ln (95th percentile)				4.1		3.3	2.0	0.0	4.9	1.8	2.0	
Queue Storage Ratio (RQ) (95th percentile)				0.30		0.24	0.15	0.00	0.36	0.13	0.14	
Uniform Delay (d_1), s/veh				13.8		13.6	7.8	0.0	9.4	8.2	7.8	
Incremental Delay (d_2), s/veh				0.3		0.2	0.0	0.0	0.9	0.1	0.1	
Initial Queue Delay (d_3), s/veh				0.0		0.0	0.0	0.0	0.0	0.0	0.0	
Control Delay (d), s/veh				14.0		13.8	7.8	0.0	10.3	8.3	7.9	
Level of Service (LOS)				B		B	A	A	B	A	A	
Approach Delay, s/veh / LOS	0.0			14.0		B	9.4		A	8.0		A
Intersection Delay, s/veh / LOS	10.5						B					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.4	B	2.7	B	2.2	B	2.4	B
Bicycle LOS Score / LOS			0.9	A	1.0	A	1.2	A

Copyright © 2020 University of Florida, All Rights Reserved.