
ALTERNATIVES ANALYSIS REPORT

Project No. 604694

**Intersection Improvements to Gorham Street at Lowell Connector
Lowell, MA**



Prepared for and submitted to:



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KEY FINDINGS OF THE STUDY

This report summarizes the results of an alternatives analysis study conducted by CDR Maguire to evaluate options for improving safety and traffic operations at the intersection of Gorham Street and the Lowell Connector in Lowell, Massachusetts. Key findings of the study are listed below.

- Recommended improvements:
 - 1) Based on a comprehensive evaluation of the intersection geometrics and traffic safety and operational analyses performed as part of this study, a multi-lane roundabout option was determined to be the preferred alternative for the Gorham Street/Lowell Connector intersection (Alternative 4B). The capacity analysis indicates that a roundabout would service traffic with nominal delay (Level of Service A) on all approaches, greatly reducing the existing congestion issues at the intersection.
 - 2) Roadway improvements are recommended for Gorham Street from the Lowell Connector intersection north to just beyond the Gorham Street/Highland Street/Elm Street intersection to accommodate a second northbound travel lane (Alternatives 12 and 23). These roadway improvements would include restriping and minor roadway widening, as well as signal improvements at the northern intersection.
- For planning and funding purposes, the estimated construction cost for a multi-lane roundabout at the intersection and roadway improvements on Gorham Street is approximately \$1,425,000.
- There are several existing traffic safety and operational issues at this intersection, including:
 - 1) Abrupt termination of Lowell Connector, a 4-lane freeway facility, at its intersection with Gorham Street;
 - 2) Transition of dual eastbound left-turn lanes on the Lowell Connector to a single northbound receiving lane on Gorham Street, requiring an immediate merge condition within the signalized intersection; and
 - 3) Over-saturated traffic conditions during both AM and PM peak hours, resulting in “spillback” and rear-end collisions associated with the adjacent Gorham Street/Highland Street/Elm Street intersection due to limited traffic capacity.

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ATTACHMENT ENCLOSED IN SLEEVE, BACK OF REPORT

Preferred Alternatives, 40-scale plan, showing:

- Lowell Connector – Roundabout Alternative Plan (Alternative 4B)
- Elm Street/Highland Street – Two Northbound Through Lanes (Alternative 23)
- Gorham Street – Additional Northbound Lane (Alternative 12)

INTRODUCTION

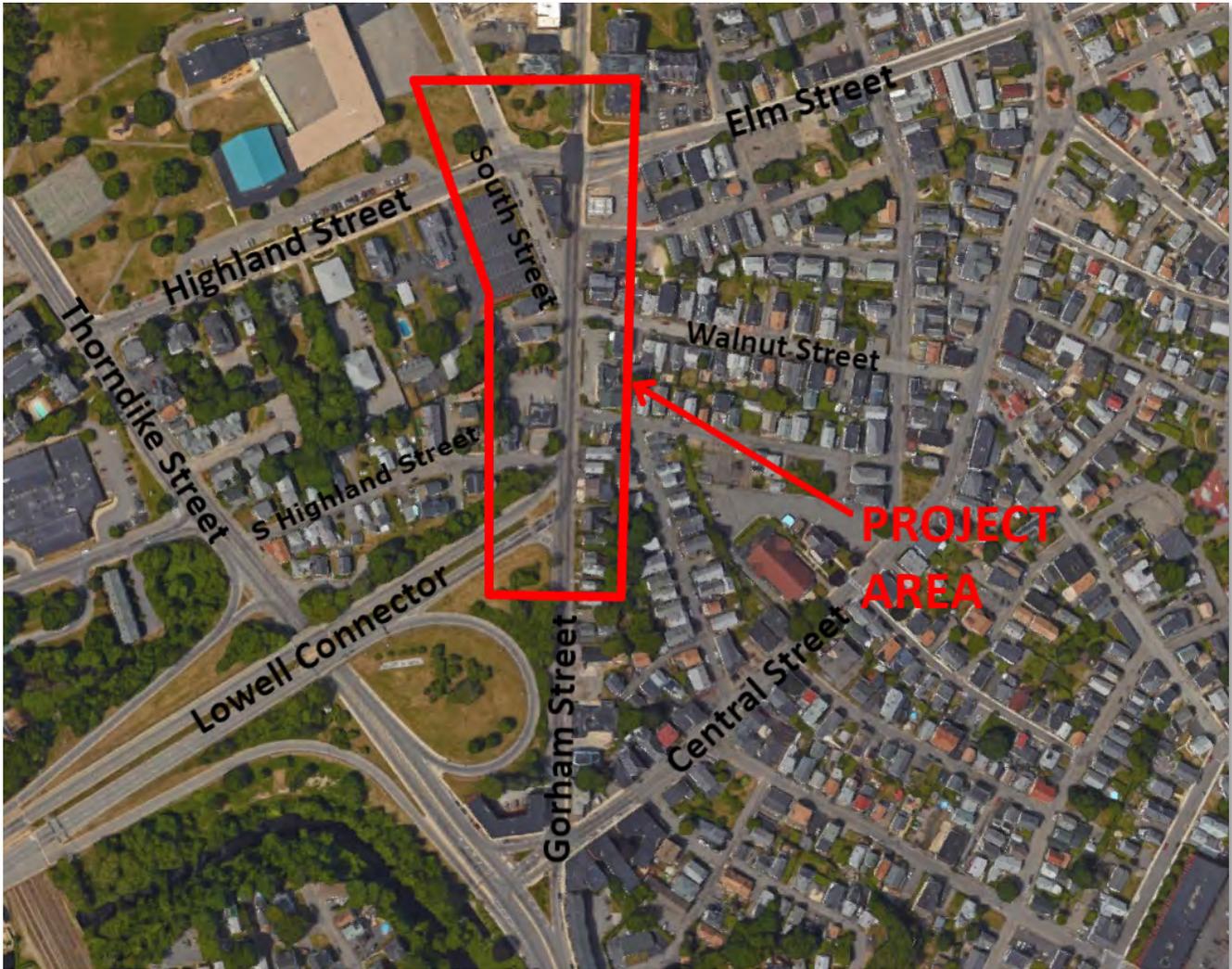
The primary purpose of this project is to identify and mitigate safety and operational issues associated with the traffic flow at the intersection of Gorham Street and the Lowell Connector in Lowell, Massachusetts. This signalized intersection marks the northern terminus of the Lowell Connector, a four-lane freeway facility at this point. Gorham Street is a two-lane, two-way urban arterial.

There are serious safety concerns at this intersection. One primary concern is the abrupt termination of the freeway facility at this intersection, as there have been a number of vehicular strikes on the private retaining walls directly opposite the Lowell Connector terminus. A second safety issue involves the dual left-turn lanes from eastbound Lowell Connector feeding into a single northbound receiving lane on Gorham Street, forcing a merge within the intersection. Additional safety-related concerns will also be discussed in this analysis report.

In addition to the safety issues, there are also congestion issues associated with this intersection. Spillback from the intersection of Gorham Street/Highland Street/Elm Street, located approximately 700 feet to the north, impacts the current operation of the Lowell Connector intersection. In order to perform a complete analysis of the intersection, the existing signalized intersection of Gorham Street with Elm and Highland Streets, as well as the connecting segment of Gorham Street, is included in the study area. An outline of the full project area is shown in the locus map of **Figure 1**.

This report documents existing conditions of the highway and its traffic operations, evaluates proposed improvement alternatives for each of three sites into which the project area has been segmented, identifies the preferred combination of alternatives, and examines impacts on construction-phase traffic and long-term operations.

Figure 1 – Locus Map



EXISTING CONDITIONS

EXISTING ROADWAY CONDITIONS

The study area includes the following major roadways, which are categorized according to the MassDOT Office of Transportation Planning functional classifications:

The Lowell Connector is a 2.5-mile long divided freeway facility, classified as an urban principal arterial roadway under MassDOT jurisdiction. It is aligned in a generally north-south direction, connecting Gorham Street in Lowell to Interstate Route 495 and U.S. Route 3 in Chelmsford. At the northern end of the freeway facility in Lowell, the roadway meets Gorham Street, an urban principal arterial roadway, and continues in a southwesterly direction. This project is located at the northern terminus of the Lowell Connector at Gorham Street. In the project area, northbound Lowell Connector corresponds to the eastbound approach to the intersection of Gorham Street/Lowell Connector.

The Lowell Connector is primarily a six-lane highway (3 lanes in each direction) from the Route 3 and I-495 interchanges at its southern end to the partial cloverleaf ramp system at Thorndike Street, approximately 350 to 1500 feet south of Gorham Street where the highway section is reduced to a four-lane facility. Lanes are 11 to 12 feet wide, and a grass center median is provided, measuring 20 feet or more in width. The outside shoulder varies from 0 to 10 feet in width. Guardrail lines one or both sides of the median along most of its length, as well as most of the outside roadway edges. The posted speed limit is 55 miles per hour (MPH), which aligns with state speed regulations; the posted speed reduces to 35 MPH in the northbound direction for the final 0.2 miles on the approach to its terminus at Gorham Street. The section of the roadway in the project vicinity has pavement in fair condition. As it is a limited-access facility, there are no directly adjacent land uses and no pedestrian accommodations.

Gorham Street is classified as an urban principal arterial and falls under local jurisdiction. Approximately 600 feet south of the Lowell Connector intersection, Gorham Street intersects with Thorndike Street and the south end of Central Street in a complex manner that requires southbound vehicles on Gorham Street to turn first right then left in order to remain on Gorham Street. Northbound vehicles on Gorham Street bear to the right at the fork in the roadway in order to stay on Gorham Street, where the left branch of the fork becomes Thorndike Street. The Gorham Street south leg of that intersection and the Thorndike Street north leg are also designated State Route 3A. Northbound vehicles access the Lowell Connector by bearing left at the fork onto Thorndike Street and then turning left onto the ramp to southbound Lowell Connector located approximately 850 feet to the north.

In the vicinity of this project, Gorham Street is a two-way, two-lane road, 32 to 37 feet in width, with scattered parking restrictions. Both the northbound and southbound travel lanes of Gorham Street are 12 feet in width, with variable offsets or parking lanes. South of the Lowell Connector, an 8-foot parking lane is striped on the west side of the road. The north leg of the Lowell Connector intersection finds the double yellow centerline shifted west of center for the first 130 feet, maximizing the available northbound pavement width for the two lanes of left-turning traffic coming off the Lowell Connector merging into the single receiving lane. The remaining section of Gorham Street is striped approximately in the middle of the street.

Granite curbs with low reveal are provided on both sides of the roadway, as are bituminous sidewalks 4 to 8 feet in width that transition to concrete to the south of the project area and at the intersection with Elm and Highland Streets. The Lowell Regional Transit Authority (LRTA) Route 3 bus operates in both directions on this segment of Gorham Street. Formal bus stops are marked in at least one location within the project area, but passengers can flag a bus to stop at any safe point along the route. The speed limit is not posted on Gorham Street but is assumed to be 30 MPH which is typical for a roadway such as this in a thickly settled area. The pavement in the project area is in poor to fair condition.

In the project area, land use along Gorham Street is a mix of residential and commercial properties. Several of the residential properties close to the intersection with the Lowell Connector do not have driveways. The Middlesex County Superior Court building is located on the northeast corner of the intersection with Highland and Elm Streets.

EXISTING INTERSECTION CONDITIONS

Gorham Street/Lowell Connector is a signalized intersection that effectively acts as a skewed T-intersection. Its three primary legs are the northbound and southbound approaches of Gorham Street and the Lowell Connector's eastbound approach. The existing signal can be activated by a loop detector located in a residential driveway opposite the Lowell Connector, but it is not a significant operational feature.

The Gorham Street northbound approach consists of a single lane. Left turns are prohibited on this approach, so the lane serves through movements plus the rare right-turn into the east-leg residential driveway. The Gorham Street southbound approach consists of a single through lane, with a channelized right-turn lane onto the Lowell Connector branching off of the through lane approximately 75 feet in advance of the stop line. The right-turn movement is a free movement with no signal control and no conflicting movements. Generally, 2 to 4 vehicles can queue on the through movement before blocking vehicles from making the free right-turn movement onto the Lowell Connector.

The eastbound approach from the Lowell Connector is skewed approximately 33 degrees from perpendicular. It consists of two left-turn lanes, with a channelized, stop-controlled right-turn lane branching off approximately 50 feet in advance of the stop line. The north leg of Gorham Street has just one wide receiving lane for the two eastbound left-turn lanes. This requires vehicles on that movement to merge from two lanes to one in about 130 feet.

The intersection's westbound "approach" is a residential driveway. As previously mentioned, a loop detector activates the signal. There are two signal heads for vehicles exiting the driveway. Vehicles exiting the driveway technically must turn left or right onto Gorham Street. The entrance to the Lowell Connector is north of the driveway. Accessing the Lowell Connector from Gorham Street would require an illegal left turn. Across from the Lowell Connector eastbound approach, the sidewalk is protected by two short sections of guardrail.

South Highland Street intersects Gorham Street on the west side immediately north of the entrance to westbound lanes of the Lowell Connector. Southbound vehicles turning right onto the Lowell Connector use the extra pavement width provided by South Highland Street to separate from southbound through-moving traffic sooner than they would be able to otherwise.

The actuated, uncoordinated signal operates in three phases. The first phase serves eastbound Lowell Connector with a maximum green time of 55 seconds. The second phase serves northbound and southbound Gorham Street with a maximum green time of 40 seconds. The third phase, which is activated extremely rarely, serves the residential driveway that acts as the east leg of the intersection and has a maximum green time of 8 seconds.

There are no pedestrian accommodations (phasing, signal heads, pushbuttons, etc.) at this intersection. Pedestrian activity is limited to the sidewalk on the east side of Gorham Street, as there are no sidewalks, ramps, or crosswalks across the Lowell Connector west leg. Pedestrians traveling on the west side of the roadway must cross north of the intersection at the mid-block crosswalk located just south of Keene Street, approximately 150 feet north of the southbound approach's stop line. There are no marked crosswalks on the south side of the intersection until Central Street, approximately 550 feet south of the northbound approach's stop line.

The predominant vehicular movements at this intersection are between the north and west legs: the eastbound left-turn movement exiting the Lowell Connector towards the downtown area and the southbound right-turn movement from the direction of downtown onto the Lowell Connector.

Gorham Street/Highland Street/Elm Street is a signalized intersection with four approaches, with Highland Street as the eastbound approach (west leg) and Elm Street as the westbound approach (east leg).

The Gorham Street northbound and southbound approaches are striped as single lanes, approximately 16 feet wide, accommodating left-turn, through, and right-turn movements. The wide lanes allow for one or two left-turning vehicles to queue within the intersection awaiting a gap in conflicting traffic while permitting through and right-turning vehicles to pass them on the right.

The Highland Street eastbound approach is a short block between this intersection and the upstream, unsignalized intersection with South Street and consists of an exclusive left-turn lane and a shared through/right-turn lane. There are three parallel-parking spaces on the south curb of this approach. The Elm Street westbound approach consists of an exclusive left-turn lane and a shared through/right-turn lane. There is a 7-foot wide raised center median on this leg of the intersection extending back approximately 25 feet. It should be noted that, until recently, the left lanes on the eastbound and westbound approaches were not designated exclusive left-turn lanes. Those approaches each had a shared left-turn/through lane and a shared through/right-turn lane, with only a single receiving lane on the opposite side for the through movements. This lane-use designation change occurred sometime in the latter half of 2016, after the Road Safety Audit was conducted.

The actuated, uncoordinated signal at this intersection operates with three phases. The first phase serves northbound and southbound Gorham Street movements and has a maximum green time of 40 seconds. The second phase is a pushbutton-actuated exclusive pedestrian phase with 7 seconds of walk time and 15 seconds of clearance. The third phase serves the eastbound and westbound movements with a maximum green time of 15 seconds.

Sidewalks are provided on both sides of the roadway along all approaches. Crosswalks, wheelchair ramps, and pedestrian pushbuttons and signal heads are provided across all approaches.

Gorham Street/South Street/Walnut Street is an unsignalized four-legged intersection with three approaches. The northbound and southbound Gorham Street approaches are free movements (no stop signs). They each have one lane, the northbound lane accommodating through and right-turn movements and the southbound lane accommodating left-turn and through movements. Both lanes are 16 to 18 feet wide, which allows southbound through-moving vehicles in particular to pass left-turning vehicles queued up on that approach.

The South Street southeast-bound approach is tightly skewed, forming a close angle with the north leg of Gorham Street. It is a one-way road with a single shared left-turn/through/right-turn lane that is yield-controlled at this intersection. The lane is wide, particularly at the skewed opening at the intersection, such that vehicles can form separate queues for separate turning movements. Parking is provided on both sides of South Street. Walnut Street forms this intersection's east leg. It is one-way eastbound, carrying traffic away from the intersection. It consists of one travel lane, with parking provided on both sides.

Sidewalks are provided on both sides of the roadway along all legs of the intersection. Crosswalks with wheelchair ramps are provided across Walnut Street and South Street. The South Street crosswalk is aligned perpendicular to the roadway, connecting from the northeast corner to a point on the southwest side of the street approximately 100 feet from the southwest corner.

As this intersection is located just over 100 feet to the south of the signalized intersection at Gorham Street/Highland Street/Elm Street, it is strongly influenced by that intersection's operations. Northbound queues at that intersection frequently spill back into this intersection and beyond, blocking vehicles on the southeast-bound and southbound approaches turning onto Walnut Street.

South Street/Highland Street is an unsignalized four-legged intersection with three approaches. The north leg of South Street is a stop-controlled two-way street with no centerline striping. The single approach lane accommodates left-turn, through, and right-turn movements. Parking is provided on the east side. The south leg of South Street is a one-lane, one-way (southeast-bound) road carrying traffic away from the intersection, with parking on both sides.

The Highland Street eastbound and westbound approaches are free movements. The west leg is a two-lane, two-way road, with parking on both sides of the road. The approach lane accommodates left-turn, through, and right-turn movements. The east leg is a short block that also serves as the west leg of the Gorham Street/Highland Street/Elm Street intersection. The single westbound approach lane on that leg serves left-turn, through, and right-turn movements.

Sidewalks are provided on both sides of the roadway along all legs. Crosswalks and wheelchair ramps are provided across the north, south, and west legs.

As this intersection is located less than 100 feet to the west of the signalized intersection at Gorham Street, it is strongly influenced by that intersection's operations. The South Street south leg is used by the majority of eastbound and southbound traffic heading to Gorham Street southbound in order to bypass the signalized intersection. This intersection is also abutted on the northwest by an elementary school, making safety a major priority.

EXISTING DEFICIENCIES

Safety

Several safety deficiencies have been identified through analysis of crash reports, as well as through the formal Road Safety Audit (RSA) of the project area that was conducted in June 2016. Details of the crash analysis and RSA are provided in the Safety Analysis section below, with the identified deficiencies summarized here.

The abrupt termination of the Lowell Connector freeway facility at this signalized intersection with a surface street leads to approach speeds that are excessive given that a significant proportion of traffic on this approach executes a nearly 60-degree left turn. This factor, combined with the forced merge through a turning movement, contributes to the high crash rate, as drivers may misjudge the maneuver and attempt to take the turn at too high a speed. Frequent rear-end and sideswipe crashes have been reported, as have vehicle impacts with signs, poles, and property walls on the east side of Gorham Street. Two homes on the east side of Gorham Street, opposite the Lowell Connector, have guardrails installed along the curblines, further supporting a past history of vehicle encroachments outside of the roadway. The brick property wall north of the guardrail installations has been struck multiple times in recent years.

The merge from the two-lane Lowell Connector while turning left into the single northbound lane on Gorham Street produces safety concerns. Five of the 26 reported crashes at that intersection occurred along that vehicle path. There is no advanced warning about the lane drop in the form of signs or pavement markings, which complicates matters further. Spillback on the northbound receiving lane for that same movement due to excessive queuing at the downstream intersection of Gorham Street at Highland and Elm Streets increases the likelihood of rear-end crashes. Blockage of the southbound right-turn slip lane onto the Lowell Connector by queued through-moving vehicles also creates higher potential for rear-end crashes.

The T-intersection of Gorham Street and South Highland Street is located very close to the Lowell Connector intersection, making it difficult to navigate. Merging traffic to the south coming from the Lowell Connector makes gaps difficult to recognize. Traffic turning onto South Highland Street from either direction on Gorham Street slow down or stop where other traffic might not expect it, which may well contribute to the high rate of rear-end and sideswipe crashes in the area. Also, there is insufficient sight distance to both the left and the right on the eastbound approach due to building placement and vegetation.

The skew of the South Street approach at its intersection with Gorham Street is severe. The geometry requires that motorists entering the intersection from South Street look at a difficult angle over the left shoulder for gaps in traffic.

At the intersection of Gorham Street/Highland Street/Elm Street, the median island on the Elm Street approach has a signal pole that has been the subject of multiple vehicle hits.

With the single lane approaches for both northbound and southbound Gorham Street at Highland and Elm Streets, left-turning vehicles waiting for gaps in opposing traffic exacerbate already long queues, at times leading to aggressive traffic moves like passing on the right without a designated travel lane.

Traffic signal hardware at both signalized intersections is deficient. The equipment is antiquated and in need of upgrades, including emergency pre-emption equipment and programming. It was also noted that signal head placement for some approaches at both signalized intersections is not ideal. Furthermore, a “Thru” arrow green signal face is used inappropriately on the northbound approach of Gorham Street at Highland and Elm Streets, implying that turning movements are not permitted when, in fact, they are.

Signs and pavement markings throughout the project area were noted to be missing or badly worn.

Pedestrian and bicycle accommodations are deficient. Sidewalks are in disrepair, and there is no signage to alert motorists of midblock crosswalks. Also, there is no designated space for bicycle travel throughout the project area.

Capacity

Some of the safety deficiencies identified previously appear to cause or be caused by associated capacity issues.

Field observations of traffic operations in the project area have indicated a few capacity-related issues affecting the intersection of Gorham Street at Lowell Connector. These issues include spillback in the northbound receiving lane from the downstream signalized intersection of Gorham Street/Highland Street/Elm Street, the intersection merge of the two Lowell Connector eastbound left-turn lanes into the one northbound receiving lane, and inefficient signal timing and phasing.

Spillback from the Gorham Street/Highland Street/Elm Street intersection occurs due to capacity issues at that intersection that cause lengthy queues on the northbound approach. The result is that eastbound left-turning and northbound through-moving vehicles at Gorham Street/Lowell Connector are sometimes prevented from making or completing their movement through the intersection on the green indication, blocking traffic behind them and wasting green time. Furthermore, eastbound left-turning vehicles stuck in the intersection sometimes block southbound through-moving vehicles when the phase changes, and when those vehicles get blocked it has the further effect of blocking southbound right-turning vehicles from entering the channelized turn lane to make what is otherwise a free-flowing movement.

The capacity issues at the Gorham Street/Highland Street/Elm Street intersection affect more than just the northbound approach. The westbound approach often forms long queues that do not clear in a single cycle. These effects were observed in both the AM and PM peak hours.

The two (2) Lowell Connector eastbound left-turn lanes merging into a single receiving lane has the effect of reducing capacity on that movement compared to having a matching number of receiving lanes. The merge slows vehicles down mid-turn, an effect that propagates upstream. The result is that fewer vehicles are served on that movement each signal cycle than if there were no lane reduction.

Current signal timing and phasing is not optimal for either peak period or for off-peak hours of the day. The recall at Gorham Street/Lowell Connector for both major phases (excluding the driveway approach) is supposed to be set to minimum; however, field observations indicate that the phase serving northbound and southbound Gorham Street is operating at maximum recall with a lengthy maximum-green time. The volumes of vehicles traveling northbound-through and southbound-through are far less than the capacity that the green time on that phase provides, resulting in significant wasted green time during the cycle and increased delay for the higher-volume eastbound movements.

Another issue with the signal timing is the long maximum green time for the eastbound phase. Though the phase is on minimum recall, it uses most if not all of the green time each cycle during the peak hour, which gives the southbound through-moving vehicles more time to queue up. When more than two or three vehicles are queued for the southbound through movement, southbound right-turning vehicles are blocked from the channelized turn lane and the queue in the southbound travel lane on Gorham Street quickly grows.

COMPLETE STREETS

This project does not fall within an area designated as a priority location in the City of Lowell's Tier II Prioritization Plan under its Complete Streets Program. Nonetheless, this project area's functionality extends beyond its vehicular safety and capacity. In keeping with MassDOT's Healthy Transportation Policy, the existing facilities have been evaluated for pedestrian- and bicycle-friendly elements, as well as its role in operations of community transit.

The preferred combination of design alternatives has been identified in part by its degree of compliance with the goals of MassDOT's Healthy Transportation Policy as well as the City of Lowell's Complete Streets Policy.

Sidewalks: The minimum sidewalk requirement for facilities such as this is to have two (2) 5-foot sidewalks on Gorham Street.

There are sidewalks on both sides of Gorham Street, although the western sidewalk is interrupted by the Lowell Connector. Existing sidewalks are in fair condition, and range from 6.5 to 10 feet wide. Poles and bollards along the sidewalk reduce the effective sidewalk width. Existing wheelchair ramps are inconsistent, and some need to be brought into ADA compliance.

There are no sidewalks on the Lowell Connector, as pedestrians are not permitted.

Bicycle Facilities: The pavement width on Gorham Street ranges from 32 to 37 feet. Existing pavement markings are generally limited to stop lines and a double-yellow centerline. The existing road widths are sufficient to provide for a two-lane section with 11- or 12-foot travel lanes, as well as a 5-foot shoulder that may serve as a bicycle lane.

There are two areas on Gorham Street where parking is permitted. In these places, parked cars displace the "shoulder," leaving it unavailable for bicycle use, and theoretically disrupting bicycle connectivity:

1. East side, between Walnut Street and Auburn Street, and
2. West side, between Central Street and the Lowell Connector.

Bicycles are prohibited on the Lowell Connector. Bicycle accommodations are not provided.

Transit: The LRTA Route 3 bus operates in both directions on Gorham Street, and the Route 9 bus passes through the intersection of Gorham Street at Elm Street and Highland Street (turns right from southbound Gorham Street onto westbound Highland Street). Transit mobility and accessibility are considerations in the analysis process.

TRAFFIC VOLUMES

DATA COLLECTION

Forty-eight hour traffic counts, including speed and classification data, were collected using automatic traffic recorder (ATR) devices on Wednesday, March 2 and Thursday, March 3, 2016 at the following locations along the project area roadways, as well as on other potentially impacted roadways in the vicinity:

- Lowell Connector, west (south) of Gorham Street [both directions],
- Gorham Street, north of the Lowell Connector [both directions],
- Gorham Street, south of the Lowell Connector [both directions],
- Thorndike Street (Route 3A), north of Central Street [both directions],
- Lowell Connector's Northbound Off-Ramp to Thorndike Street (Route 3A) Southbound, and
- Lowell Connector's Northbound Off-Ramp to Thorndike Street (Route 3A) Northbound.

Peak hour turning movement counts (TMCs) were performed on Thursday, March 3, 2016 at the four project-area intersections plus one other intersection that may be subjected to a temporary increase in traffic demand during construction: Thorndike Street (Route 3A)/Central Street/Gorham Street, a signalized intersection located approximately 600 feet south of the Gorham Street/Lowell Connector intersection. The counts were taken between 7:00 AM and 9:00 AM for the morning peak period and between 4:00 PM and 6:00 PM for the afternoon peak period.

The full ATR and TMC traffic count reports are presented in **Appendix A** and **Appendix B**, respectively.

The collected traffic counts were used as a basis for identifying peak hours, calculating peak hour factors (PHFs) and heavy vehicle percentages, developing base year traffic volumes, projecting future traffic volumes, calibrating the traffic model, and evaluating intersection operations under existing and future conditions.

BASE YEAR TRAFFIC VOLUMES

Due to monthly variations in local traffic, raw traffic counts are typically adjusted using seasonal factors so that they represent an average month during the collection year. Data from MassDOT's permanent counting stations in the area were analyzed to determine the appropriate seasonal factor to apply to

data collected in the month of March. Station 4080, located on the Lowell Connector south of Plain Street, was determined to be the closest station to the project area that had reliable, multi-year data. The seasonal factor for March was calculated from four years of data, from 2006 to 2009, and was determined to be 1.00. Since seasonal factors are applied by multiplying the raw data by the factor, a seasonal factor of exactly 1 means the raw data represents an average month’s traffic volumes as-is.

Existing Design Hourly Volumes (DHV) and Annual Average Daily Traffic (AADT) volumes for roadway segments are provided in **Table 1**. AM and PM peak-hour turning movement volumes at the study area intersections are provided in **Figure 2** and **Figure 3**, respectively.

Table 1 – Existing Roadway Segment Volumes

Location	DHV	AADT
Gorham Street, North of Lowell Connector	1,840	23,130
Gorham Street, South of Lowell Connector	410	4,920
Lowell Connector Eastbound, West of Gorham Street	850	10,020
Lowell Connector Westbound, West of Gorham Street	870	9,700
Thorndike Street Northbound, North of Central Street	780	9,440
Thorndike Street Southbound, North of Central Street	550	6,970
Lowell Connector Off-Ramp to Thorndike Street Northbound	940	10,620
Lowell Connector Off-Ramp to Thorndike Street Southbound	170	1,550

Figure 2 – Existing AM Peak Hour Volumes

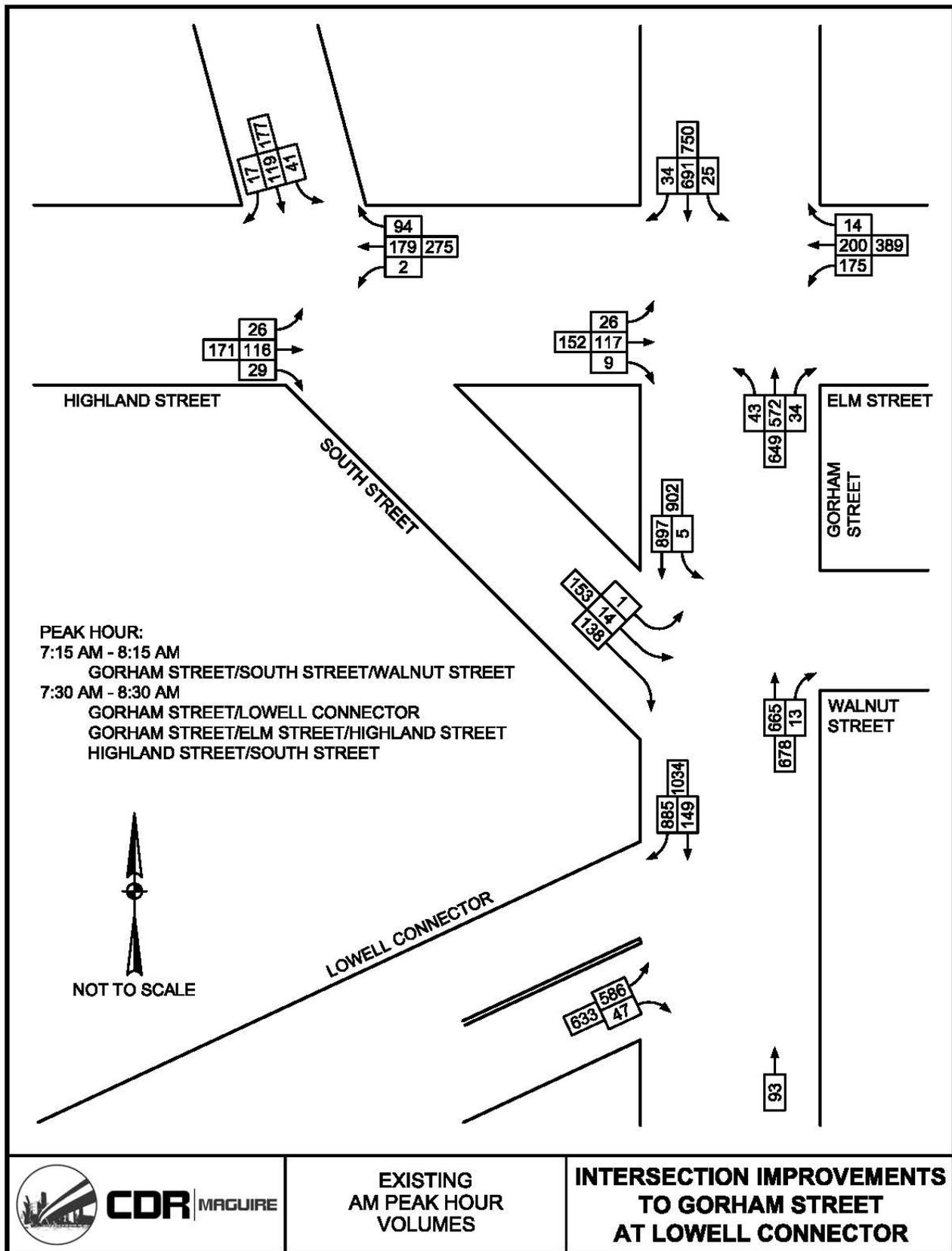
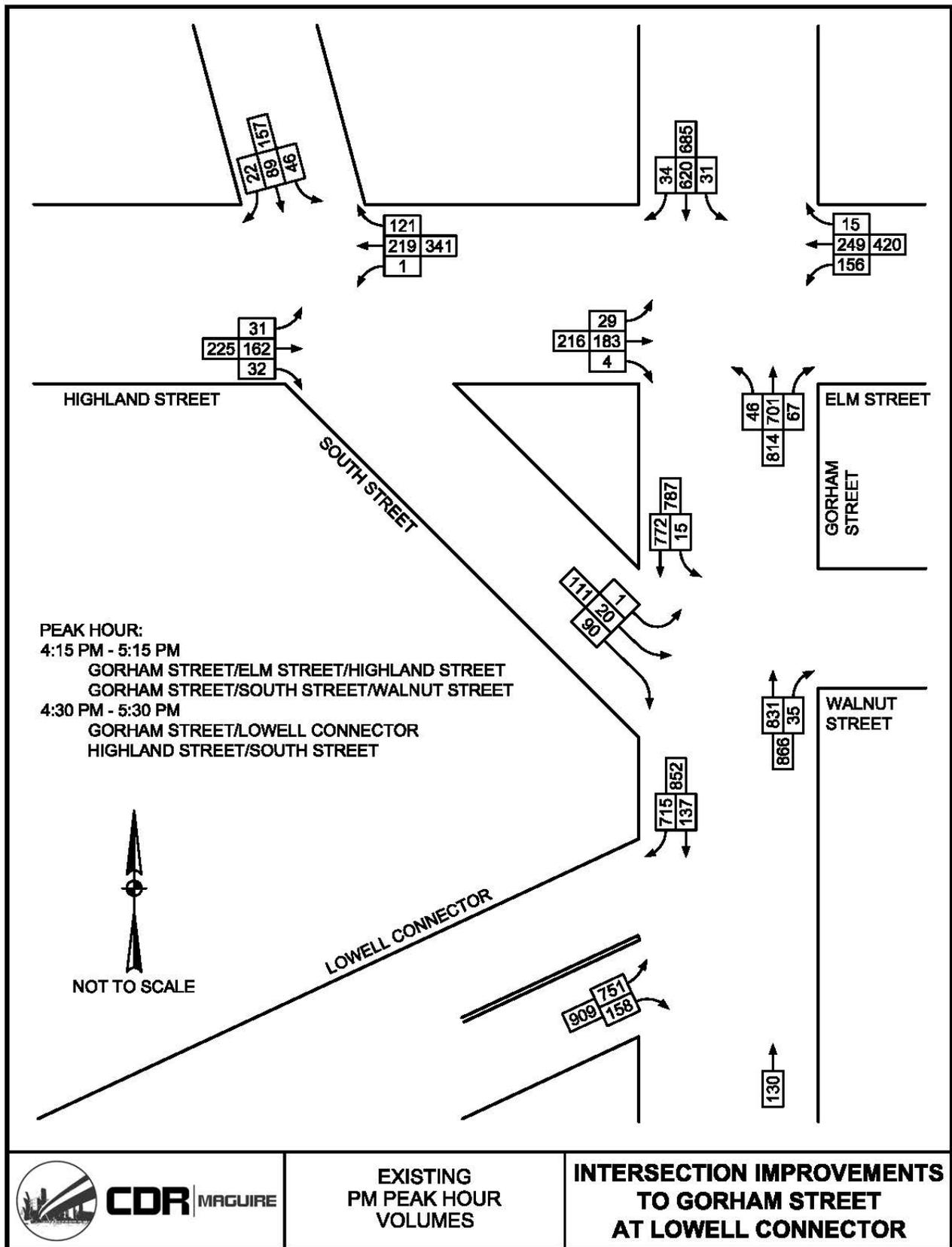


Figure 3 – Existing PM Peak Hour Volumes



FUTURE YEAR TRAFFIC VOLUMES

According to *Northern Middlesex Regional Traffic Volume Report: 2014* developed for the Northern Middlesex Council of Governments, the City of Lowell has not had significant traffic growth for the previous 12-year period. Lowell's growth rate was 0.09% annually for that period. In light of major development initiatives on Thorndike Street, a more robust annual traffic rate growth rate of 0.5% is recommended for this project, in order to conservatively assess transportation infrastructure performance for the design year 2026. This growth rate precludes the need to account for specific site developments in the area.

Table 2 below provides the roadway segment design volumes that are used to assess the performance of prospective traffic improvements explored in this Alternatives Analysis Report.

Table 2 – Future (2026) Roadway Segment Volumes

Location	DHV	AADT
Gorham Street, North of Lowell Connector	1,930	24,290
Gorham Street, South of Lowell Connector	430	5,170
Lowell Connector Eastbound, West of Gorham Street	895	10,530
Lowell Connector Westbound, West of Gorham Street	915	10,195
Thorndike Street Northbound, North of Central Street	820	9,925
Thorndike Street Southbound, North of Central Street	580	7,325
Lowell Connector Off-Ramp to Thorndike Street Northbound	990	11,165
Lowell Connector Off-Ramp to Thorndike Street Southbound	180	1,630

For intersection analysis under future (2026) conditions, the design turning-movement volumes are based on the same 0.5% annual growth rate applied to existing volumes, as shown in **Figure 4** and **Figure 5** for the AM and PM peak hours, respectively.

Figure 4 – Future (2026) AM Peak Hour Volumes

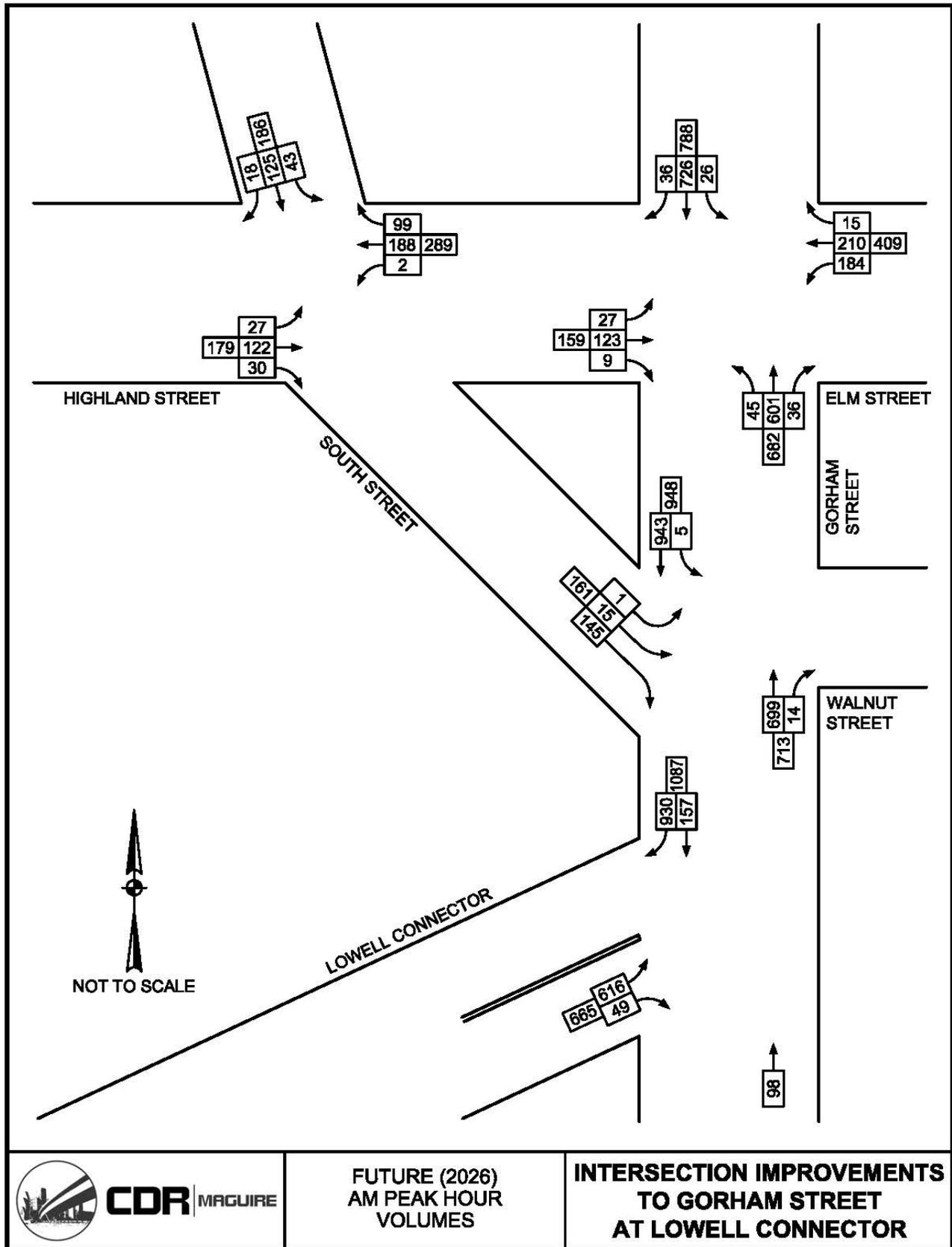
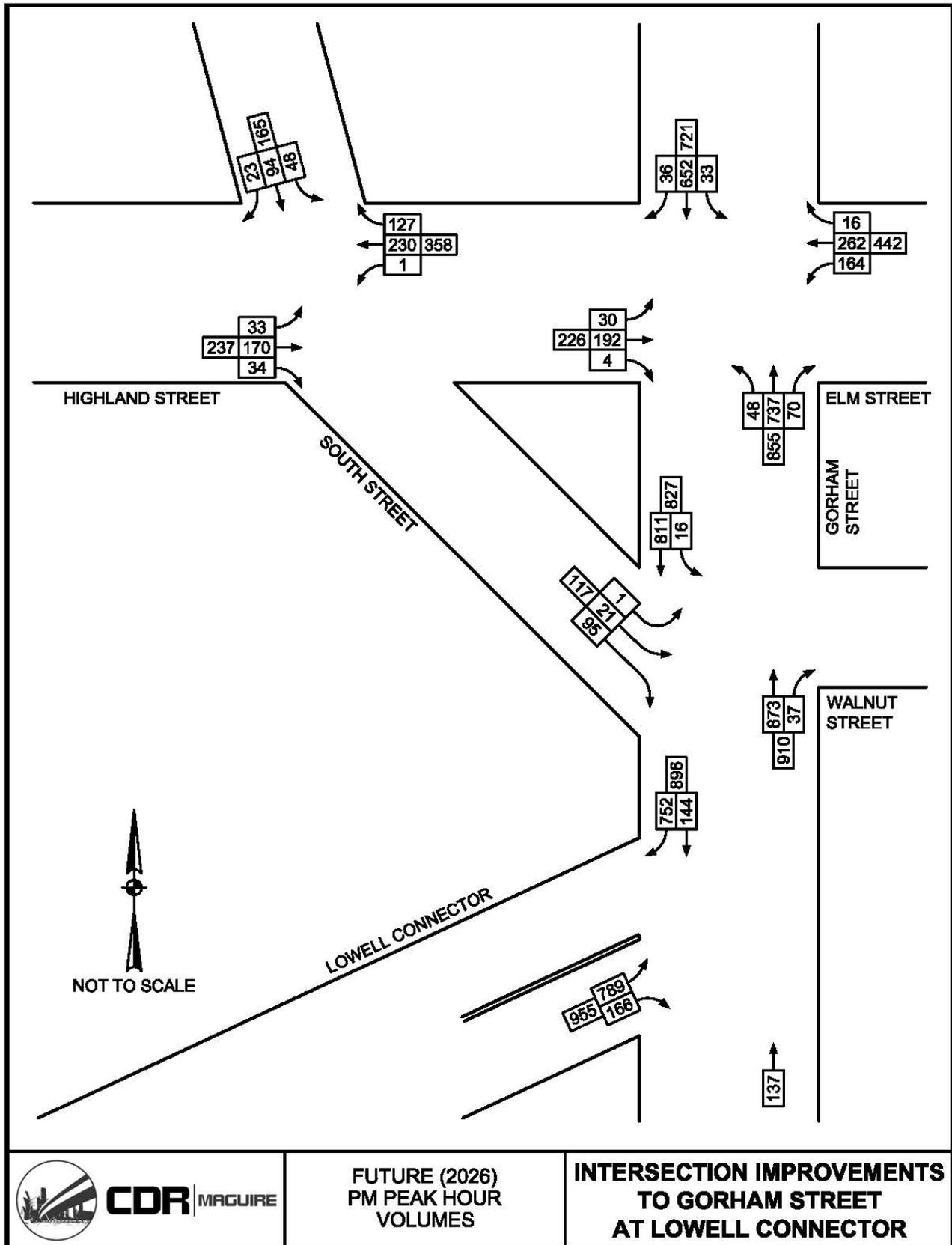


Figure 5 – Future (2026) PM Peak Hour Volumes



CDR MAGUIRE

FUTURE (2026)
PM PEAK HOUR
VOLUMES

**INTERSECTION IMPROVEMENTS
TO GORHAM STREET
AT LOWELL CONNECTOR**

SAFETY ANALYSIS

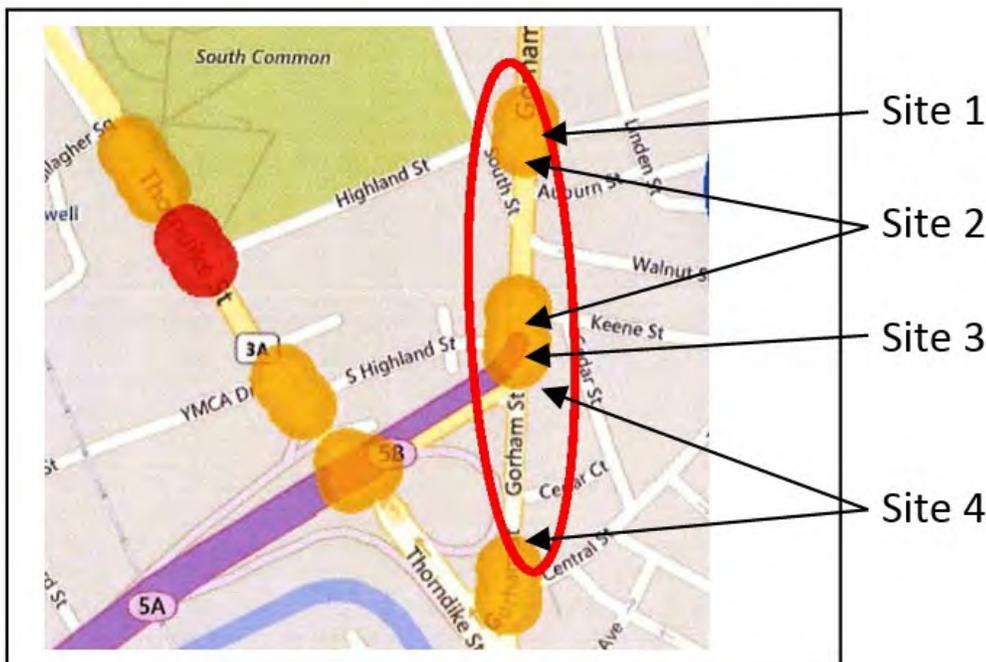
CRASH ANALYSIS

Crash reports for the period from 2011 through 2013 were obtained from MassDOT and individually reviewed and tabulated. A listing of the relevant crashes appears in **Appendix C**.

The areas covered by these crash reports are broken into 4 separate geographical sections, as shown in **Image 1**:

- Site 1: Intersection of Gorham Street with Highland and Elm Streets,
- Site 2: Gorham Street from Elm Street to Lowell Connector (~0.1 miles),
- Site 3: Intersection of Gorham Street with Lowell Connector (including South Highland Street intersection), and
- Site 4: Gorham Street from Lowell Connector to Central Street (~0.1 miles).

Image 1 – Crash Analysis Evaluation Sites



Within this overall quarter-mile segment of Gorham Street, there are roughly 20-30 crashes per year, totaling 74 crashes attributable to this segment, including intersections, during the 3-year study period. These crashes resulted in zero fatalities. In nineteen of these crashes (just over 25%), one or more injuries were reported.

Using the Site numbers above, the following table lists the general locations and the distribution of crash types in this study.

Table 3 – Crash Summary (2011-2013)

	Site 1	Site 2	Site 3	Site 4
Total Crashes	29	18	26	1
Injury Crashes	9 (31%)	4 (22%)	6 (23%)	0
Injuries	11	6	9	0
<i>Manner of Collision</i>				
Rear-end	11 (38%)	8 (44%)	8 (31%)	---
Angle	9 (31%)	8 (44%)	10 (38%)	---
Sideswipe Same Direction	---	1 (6%)	4 (15%)	1 (50%)
Single Vehicle	5 (17%)	1 (6%)	3 (12%)	---
Head-on	1 (4%)	---	---	---
Unknown	3 (10%)	---	1 (4%)	---

Site 1: Gorham Street at Elm and Highland Streets

The 29 crashes at this signalized intersection yield a crash rate of about 1.12 crashes per million entering vehicles (MEV), considerably higher than the 0.73 average for signalized intersections in MassDOT District 4. The high proportion of rear-end crashes is not surprising for a signalized intersection. The equally high proportion of angle crashes is more significant. However, it could be an indication of the previously existing east-west lane ambiguity (prior to designating exclusive left-turn lanes) or of capacity issues triggering more aggressive behaviors (e.g., “running the yellow”). There were 3 reported crashes into the Elm Street median, 2 involving the traffic signal pole.

Site 2: Gorham Street Segment from Elm Street to Lowell Connector

The 18 crashes on this short segment of road yield a crash rate of about 7.02 crashes per million vehicle-miles traveled (MVMT), more than double the 3.49 average for MassDOT District 4. The high proportion of rear-end crashes is probably a product of two site features:

- A fairly high number of turning movements causing abrupt braking, due to commercial land use and four intersecting streets (South Highland Street crash experience was included in Site 3 below), and
- While signal-related rear-end crashes were assigned to Sites 1 and 3 (signalized intersections), to the extent discernible in the crash reports, some of the remaining rear-end crash may well have been influenced by signal queuing.

Site 3: Gorham Street at Lowell Connector

This intersection crash tabulation includes South Highland Street, as it clearly shares an influence zone with the Lowell Connector.

The 26 crashes at this signalized intersection yield a crash rate of about 1.26 crashes per MEV, well above the 0.73 average for signalized intersections in MassDOT District 4. The high proportion of angle crashes and sideswipe-same direction crashes would seem to be greatly attributable to the geometry of the intersection for the Lowell Connector approach, where dual left-turn lanes feed into a single northbound receiving lane on Gorham Street.

There is a brick wall located on the east side of this intersection, opposite the Lowell Connector terminus. The wall has been hit several times, as reflected in the high number of single-vehicle crashes at this site. **Image 2** below shows the damage caused by one of these recent crashes.

Image 2 - Damage to Property Wall Located Opposite Lowell Connector Terminus



Site 4: Gorham Street Segment from Lowell Connector to Central Street

There was only one crash attributed to this short segment of road, indicative of the absence of intersecting streets or significant traffic generators, as well as reflecting traffic volumes that are far lower than the segment of Gorham Street to the north. The single crash event yields a crash rate of 1.85 crashes per MVMT, well below the MassDOT District 4 average of 3.49 crashes per MVMT. Due to the obviously low actual crash tally, though, the specific crash data at this location should not be considered statistically significant.

Conclusion: The three sections of Gorham Street from Elm Street to the Lowell Connector (Sites 1 through 3) analyzed in this study exceed district averages for such sites. On aggregate, this 1/8-mile, narrow street and its congested intersections average around 25 crashes per year.

HSIP Cluster

MassDOT's Highway Safety Improvement Program (HSIP) has identified HSIP-eligible "clusters" of crashes at both the Elm Street/Highland Street intersection (Site 1) and the Lowell Connector intersection (Site 3), based on crash data from 2012-2014. The orange highlighted areas in identify HSIP Cluster Sites from that study period. An HSIP cluster is a site at which the total number of "equivalent property damage only" crashes in the cluster is within the top 5% of all clusters in that region. This is not altogether surprising, given the elevated crash rates at these two sites. Therefore, these sites are worthy of closer crash history scrutiny.

Typically, for the site of an HSIP-eligible cluster, the actual report of each crash listed in the file records is reviewed. To the extent that such reports are available, these have been reviewed and their volumes and content have provided sufficient data for safety analysis.

Appendix C of this report contains copies of the original crash reports, as well as crash rate computation worksheets and collision diagrams for the four sites discussed herein.

ROAD SAFETY AUDIT

A Road Safety Audit (RSA) was conducted in June 2016, with representatives from design, public safety, and planning communities. The process and conclusions of the Audit are available in report form on the MassDOT website at:

http://www.massdot.state.ma.us/Portals/8/docs/traffic/SafetyAudit/District4/Lowell_GorhamSt_from_LowellConnector_to_ElmSt_RSA.pdf.

Table 4 on the following pages represents a summary of the improvements recommended during the RSA. Note that some of the recommended improvements have already been implemented in the field since the RSA was conducted.

Table 4 – Potential Safety Enhancement Summary from Road Safety Audit

I.D.	SAFETY ISSUE	POTENTIAL SAFETY ENHANCEMENT	SAFETY BENEFIT	TIME FRAME	COST	RESPONSIBLE AGENCY
South Street at Highland Street						
1	Signing and Pavement Marking	Move the southbound stop sign closer to the intersection.	Low	Short	Low	City of Lowell
Gorham Street at Elm Street and Highland Street						
2	Signal Equipment & Operations	All signal equipment should be replaced, with new signals being mastarm-mounted.	Medium	Medium	High	MassDOT
3	Signal Equipment & Operations	Replace green “thru” arrow on northbound signal head.	Medium	Short	Low	City of Lowell
4	Signal Equipment & Operations	Replace all incandescent traffic signals with L.E.D. heads.	Low	Short	Medium	City of Lowell
5	Road Geometry	Reconfigure Elm Street median island, to provide pedestrian refuge and better protect signal pole.	Medium	Medium	Medium	MassDOT
6	Signing and Pavement Marking	Stripe and sign the left lanes of the Elm Street and Highland Street approaches to be exclusive left turn lanes, regardless of signal phasing. ¹	Low	Short	Low	City of Lowell
Gorham Street at South Street						
7	Signing and Pavement Marking	Replace missing Yield sign near Gorham Street intersection with a stop bar and stop sign. ²	Low	Short	Low	City of Lowell
8	Signing and Pavement Marking	Place crosswalk signs with plaques at the crosswalk across South Street. Also place no-parking signs near the west end of the crosswalk.	Low	Short	Low	City of Lowell
9	Road Geometry	Realign the South Street approach to Gorham Street.	Low	Medium	Medium	MassDOT

I.D.	SAFETY ISSUE	POTENTIAL SAFETY ENHANCEMENT	SAFETY BENEFIT	TIME FRAME	COST	RESPONSIBLE AGENCY
Gorham Street at South Highland Street						
10	Pedestrian Accommodations	Provide signs to alert motorists of the presence of a crosswalk at Keene Street / South Highland Street.	Medium	Short	Low	City of Lowell
11	Intersection Operations	Consider prohibiting eastbound left turns from South Highland Street.	High	Short	Low	City of Lowell
12	Intersection Operations	Clear vegetation on west side of Gorham Street, between South Highland Street and the Lowell Connector.	Low	Short	Low	MassDOT
Gorham Street at Lowell Connector						
<i>Comprehensive Intersection Improvement Alternatives</i>						
13	Road Geometry	Construct an exclusive right-turn lane for the southbound approach to the Lowell Connector intersection.	Medium	Medium	High	MassDOT
14	Road Geometry	Reconfigure Lowell Connector intersection as a roundabout.	High	Long	High	MassDOT
15	Road Geometry	Reconfigure Lowell Connector intersection to establish north and west legs as “thru” movement.	High	Long	High	MassDOT
16	Road Geometry	Realign Lowell Connector intersection to eliminate skew.	Medium	Long	High	MassDOT
<i>Improvements to Individual Elements in the Intersection</i>						
17	Signal Equipment & Operations	All signal equipment should be replaced, with new signals being mastarm-mounted.	Medium	Medium	High	MassDOT
18	Signal Equipment & Operations	Replace all incandescent traffic signals with L.E.D. heads.	Low	Short	Medium	MassDOT
19	Intersection Operations	Restripe the northbound lane of Gorham Street north of the Lowell Connector to better facilitate the merge.	Medium	Short	Low	MassDOT

I.D.	SAFETY ISSUE	POTENTIAL SAFETY ENHANCEMENT	SAFETY BENEFIT	TIME FRAME	COST	RESPONSIBLE AGENCY
20	Intersection Operations	Extend the guardrail segments along the curblines opposite the Lowell Connector northward.	Low	Short	Low	MassDOT
21	Intersection Operations	Resurface the northbound Lowell Connector approach.	Medium	Medium	Medium	MassDOT
22	Intersection Operations	Improve signing on the Lowell Connector approach to establish more positive driver expectancy for the signalized intersection.	Medium	Medium	Low	MassDOT
23	Intersection Operations	Implement positive pedestrian barriers to eliminate pedestrian encroachment on the Lowell Connector.	Low	Medium	Low	MassDOT
Project-wide						
24	Pedestrian Accommodations	Reconstruct all sidewalks to ADA requirements.	Low	Medium	High	MassDOT
25	Bicycle Accommodations	Restripe Gorham Street to provide a 5-foot shoulder on both sides.	Medium	Short	Low	City of Lowell
26	Bicycle Accommodations	Use “share the road” between Central Street and Lowell Connector.	Low	Short	Low	City of Lowell
27	Signing and Pavement Marking	All signs in the project area should be replaced.	Medium	Medium	Low	MassDOT
28	Signing and Pavement Marking	Replace the missing Stop signs at Keene Street and at Auburn Street.	Low	Short	Low	City of Lowell

¹ The eastbound and westbound approaches to the Gorham Street/Elm Street/Highland Street intersection have since been restriped to designate the left approach lanes as exclusive left-turn lanes.

² The Yield sign has since been replaced.

ALTERNATIVES CONSIDERED

Alternatives for improvements were considered at three locations within the project area: the intersection of the Lowell Connector with Gorham Street (Site 3), the intersection of Gorham Street with Elm Street and Highland Street (Site 1), and the Gorham Street roadway segment between those intersections (Site 2). The sets of alternatives are explored below in that order, as the choice of alternatives for Site 2 is directed by the choice of alternatives at each of the two intersections.

Alternatives for the intersection of Gorham Street with the Lowell Connector have single-digit numerical designations with alphabetic suffixes. Those at the Gorham Street/Elm Street/Highland Street intersection have numbers in the 20s, and alternatives for the roadway segment in between have numbers in the 10s.

INTERSECTION OF GORHAM STREET AND LOWELL CONNECTOR (SITE 3)

This intersection serves as a terminus for the Lowell Connector at Gorham Street. This is a signalized three-legged intersection, experiencing both congestion and safety issues. It has been identified as a crash “cluster” by the Department’s Highway Safety Improvement Program (HSIP).

The primary traffic flow is between the Lowell Connector and the north segment of Gorham Street. Gorham Street appears to lack the capacity to accommodate “inbound” traffic from the Lowell Connector, or to deliver the “outbound” traffic onto the Lowell Connector.

In addition to the No-Build scenario, 11 different design alternatives for geometric improvements were developed and evaluated for safety and efficiency based on a combination of four intersection realignment options given by single-digit numbers and three different lane configuration variations given by alphabetic suffixes.

The lane configuration variations are as follows:

- “A” suffix: No changes to the number of approach or departure lanes: Two eastbound approach lanes on the Lowell Connector and one northbound departure lane on Gorham Street,
- “B” suffix: Widening the northbound Gorham Street departure to two lanes, such that any northbound lane merge would occur farther downstream from this intersection (see Alternatives 12 and 13), and
- “C” suffix: Reducing the Lowell Connector approach to one left-turn lane by dropping a lane upstream in the vicinity of the Thorndike Street interchange.

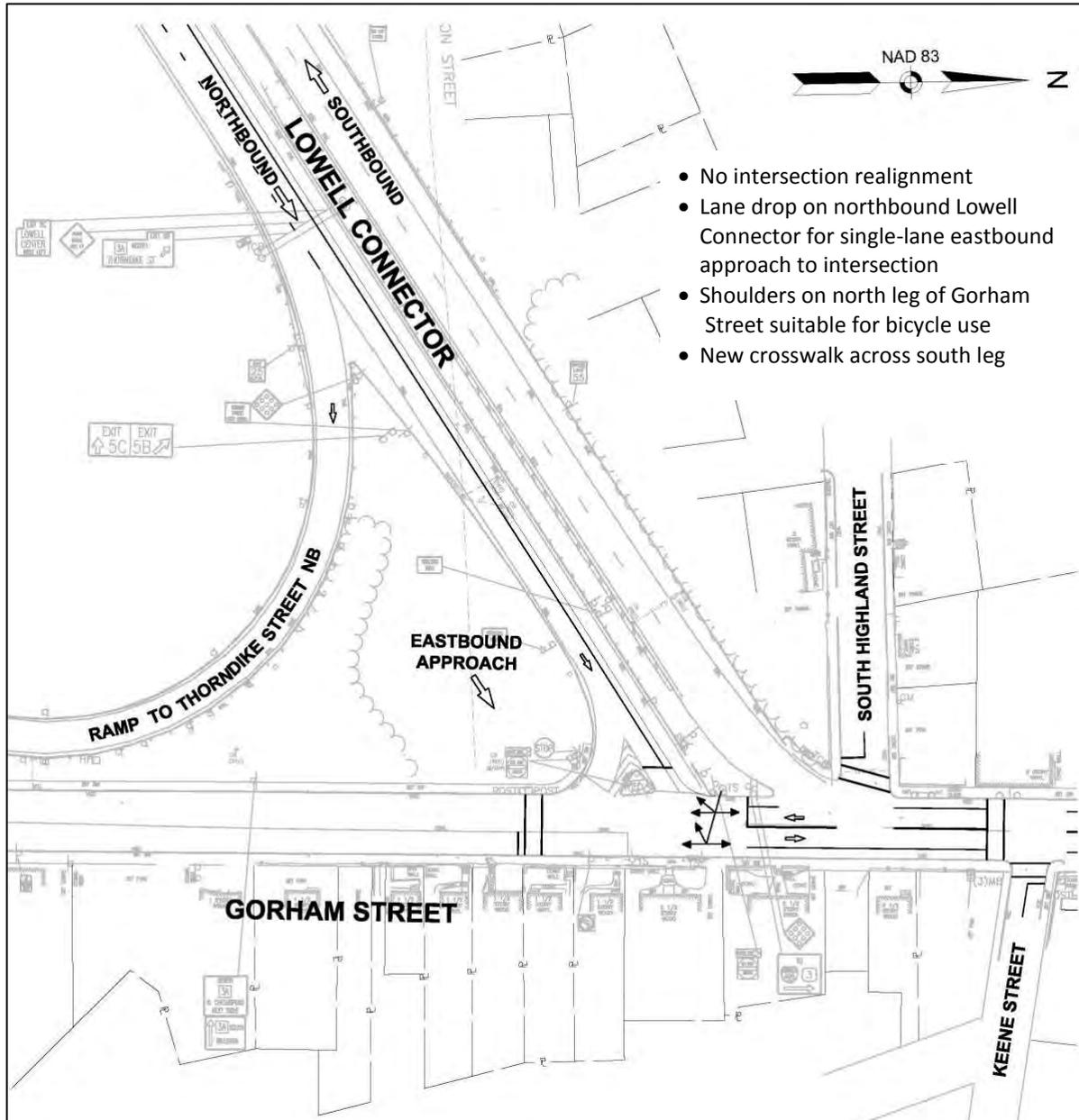
The following four sets of alternatives represent the intersection realignment options and are depicted with their lane configuration variations (A, B, and C suffixes). Note that Alternative Set 3 merged with Alternative Set 4 early in the study process, so Alternative 3 is skipped.

Alternative Set 1: No Intersection Realignment: Under this alternative, the intersection would continue to operate in its current three-legged configuration in its current orientation.

Alternative 1A represents the No-Build scenario, with no intersection realignment and no changes to the number of approach or departure lanes. However, Alternative 1A, like all future alternatives considered, would still allow for signal timing optimization and minor striping revisions to enhance existing operations. There would be no change in signal phasing, though coordination with the traffic signal at the Elm Street/Highland Street intersection could be considered. This set of alternatives would also include vegetative clearing between South Highland Street and the Lowell Connector on-ramp. Pedestrian traffic cannot be accommodated on the west side of this intersection, and all variations of Alternative 1 should include signage or positive redirection of pedestrians to the sidewalk along the east side of Gorham Street.

The proposed geometric layouts of Alternatives 1B and 1C are shown in **Figure 6** and **Figure 7**, respectively.

Figure 7 – Lowell Connector Alternative 1C



- No intersection realignment
- Lane drop on northbound Lowell Connector for single-lane eastbound approach to intersection
- Shoulders on north leg of Gorham Street suitable for bicycle use
- New crosswalk across south leg

Alternative Set 2: Realign Lowell Connector Approach to “Tee” Intersection: This set of alternatives calls for moving the intersection some 175 feet to the south, creating a perpendicular intersection approach for the Lowell Connector. This realignment would increase the distance between the Lowell Connector intersection and the South Highland Street intersection, reducing the safety issues caused by their existing close proximity. It also would potentially offer the opportunity to improve other aspects of vehicular, bicycle, and pedestrian safety. As the intersection would no longer align with a driveway on the east side of Gorham Street, the signal phase and equipment serving that driveway would be eliminated.

The proposed geometric layouts of Alternatives 2A, 2B, and 2C are shown in **Figure 8** through **Figure 10**.

Figure 8 – Lowell Connector Alternative 2A

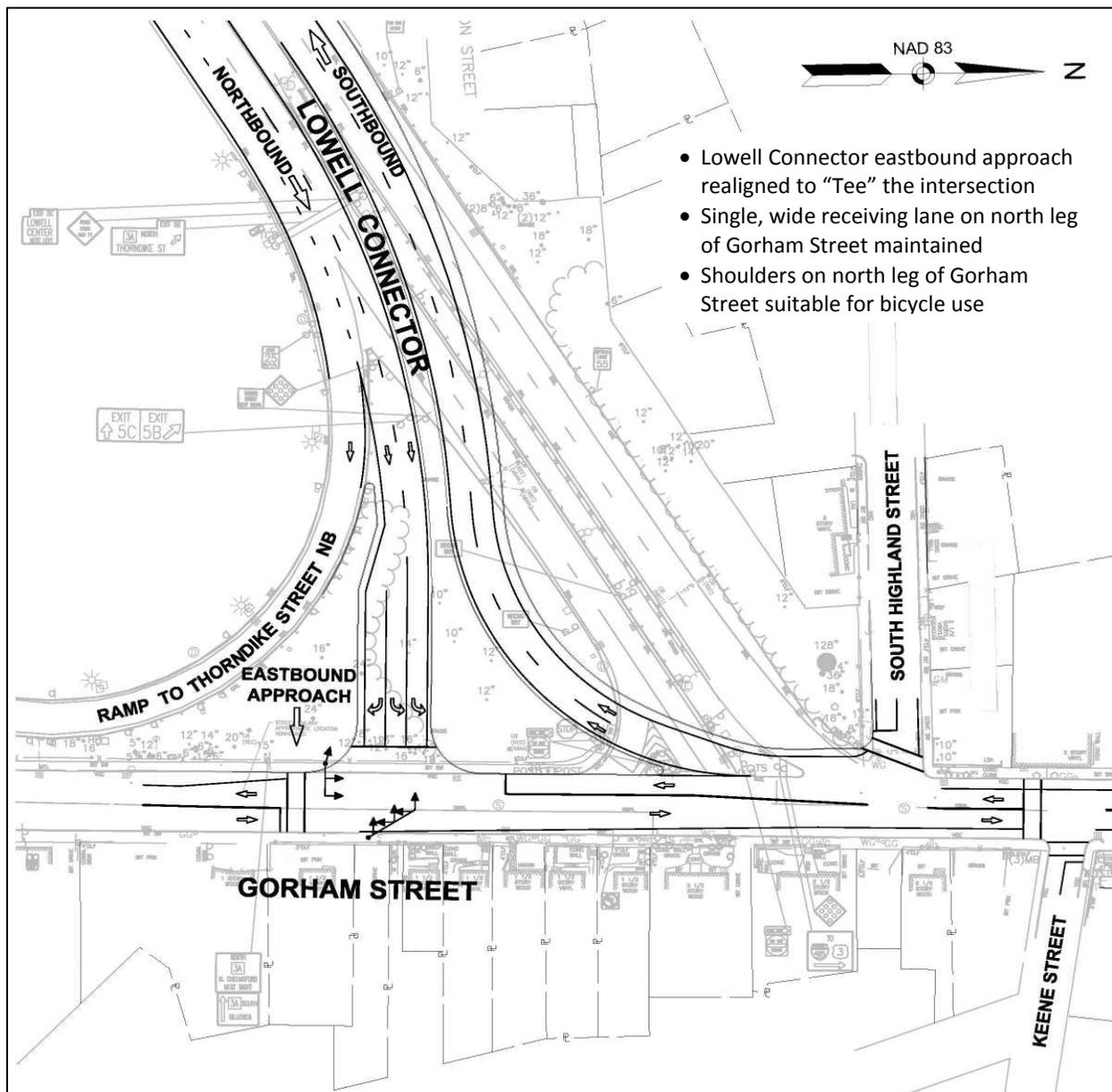
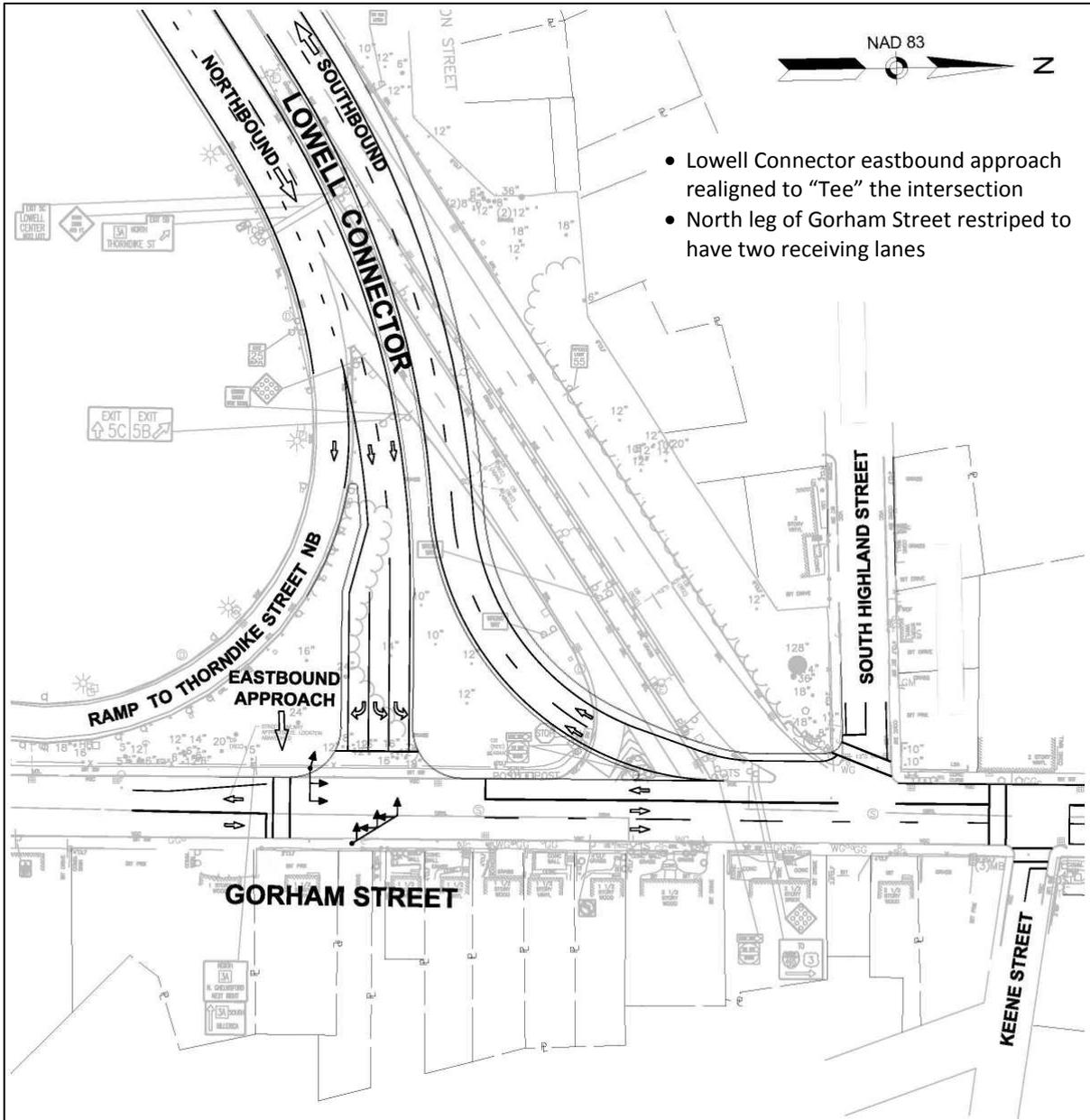
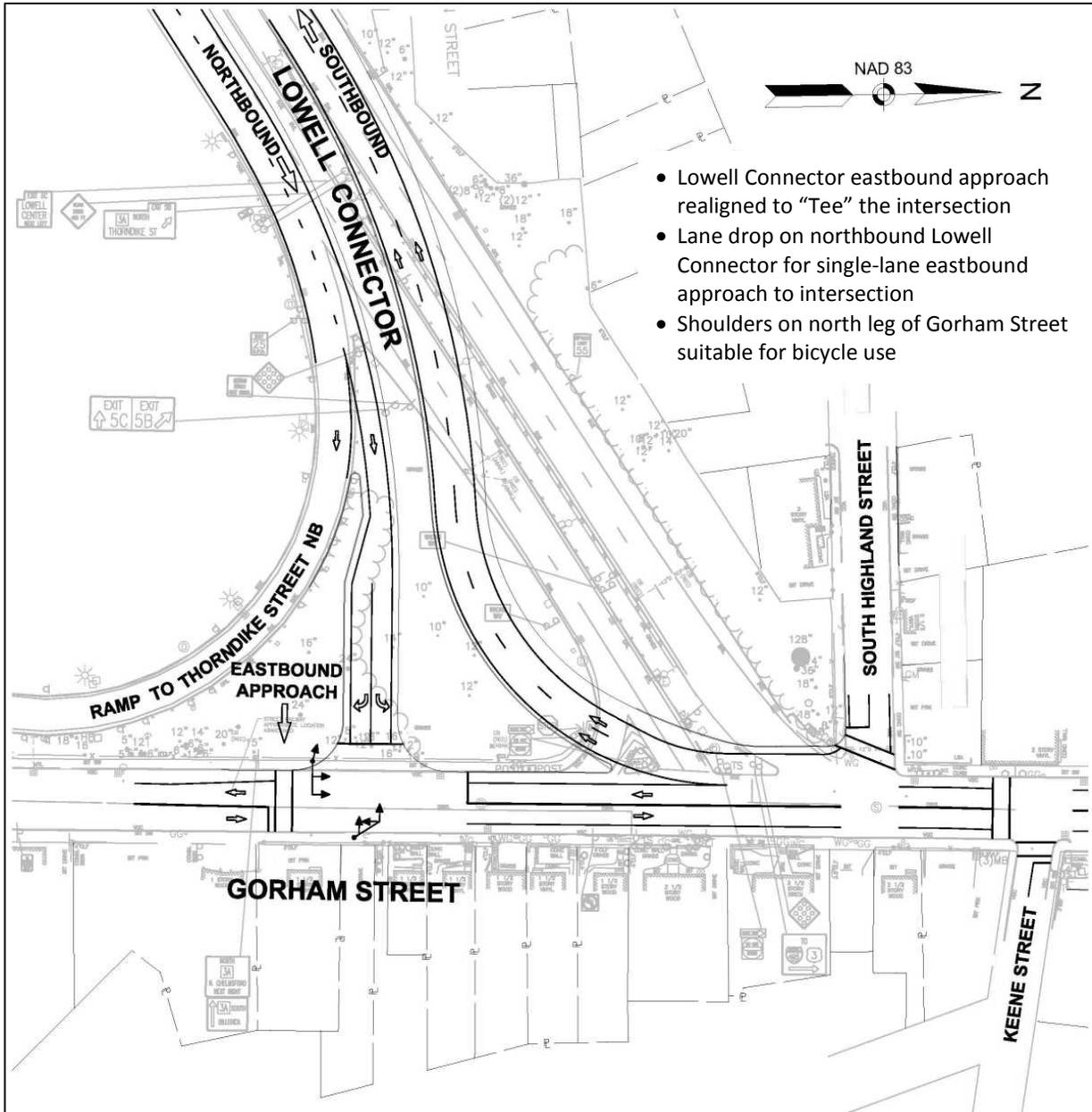


Figure 9 – Lowell Connector Alternative 2B



- Lowell Connector eastbound approach realigned to “Tee” the intersection
- North leg of Gorham Street restriped to have two receiving lanes

Figure 10 – Lowell Connector Alternative 2C



- Lowell Connector eastbound approach realigned to “Tee” the intersection
- Lane drop on northbound Lowell Connector for single-lane eastbound approach to intersection
- Shoulders on north leg of Gorham Street suitable for bicycle use

Alternative Set 3 has been merged with Alternative Set 4.

Alternative Set 4: Replace Signalized Intersection with Roundabout: This set of alternatives would utilize the infield on the west side of Gorham Street at the existing intersection to install a roundabout. The land is within the MassDOT right-of-way and would not require any land acquisition. A notable feature of a roundabout at this location is that the northbound left-turn movement from Gorham Street onto the Lowell Connector becomes a viable movement. Alternatives 4A and 4B, shown in **Figure 11** and **Figure 12**, consist of a 2-lane roundabout. Alternative 4C, shown in **Figure 13**, consists of a single-lane roundabout. All three alternatives in this set preserve the free movement for the southbound right turn. Alternatives 4A and 4B accomplish this with an entry lane that has no conflicting movements, and Alternative 4C employs a bypass lane.

Figure 11 – Lowell Connector Alternative 4A

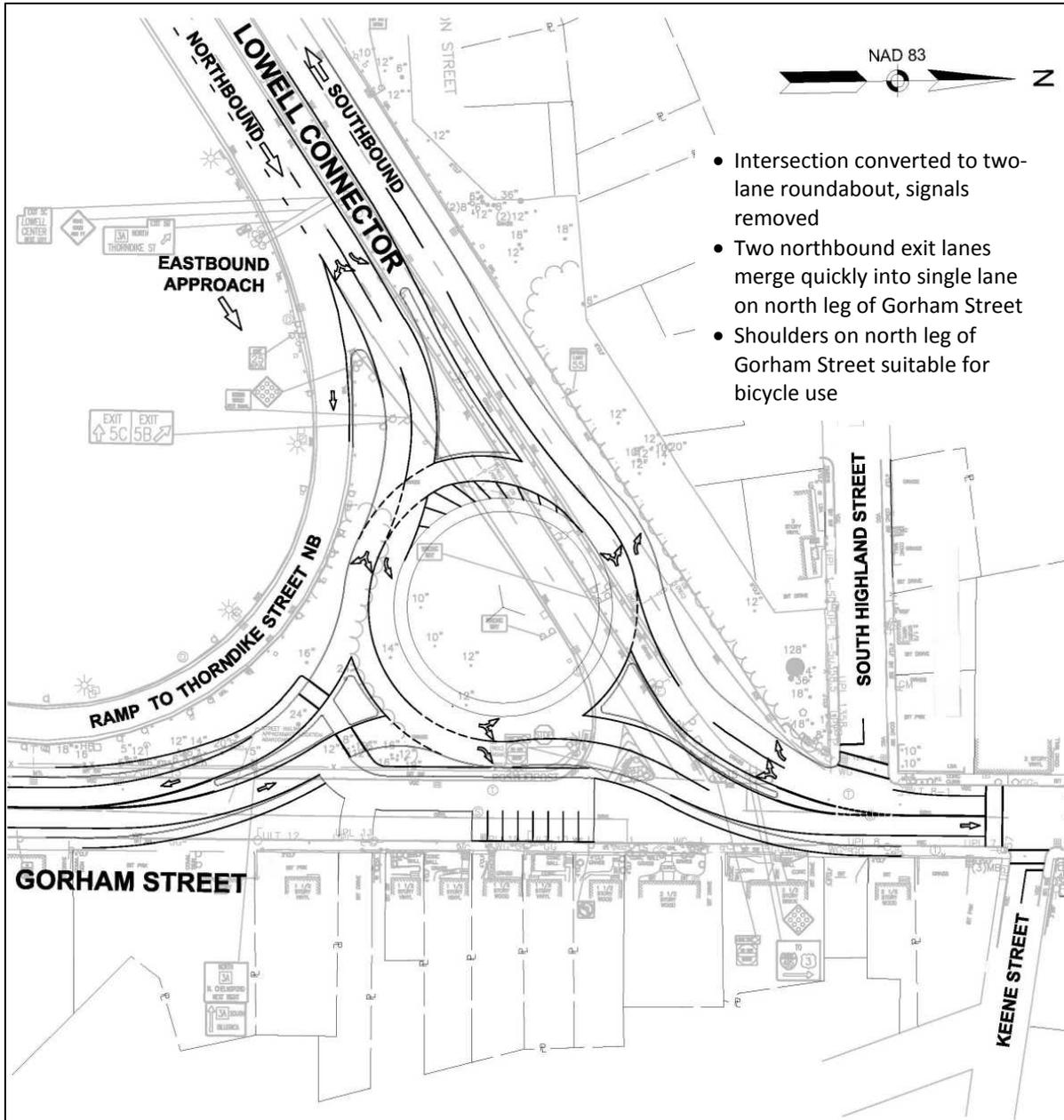


Figure 12 – Lowell Connector Alternative 4B

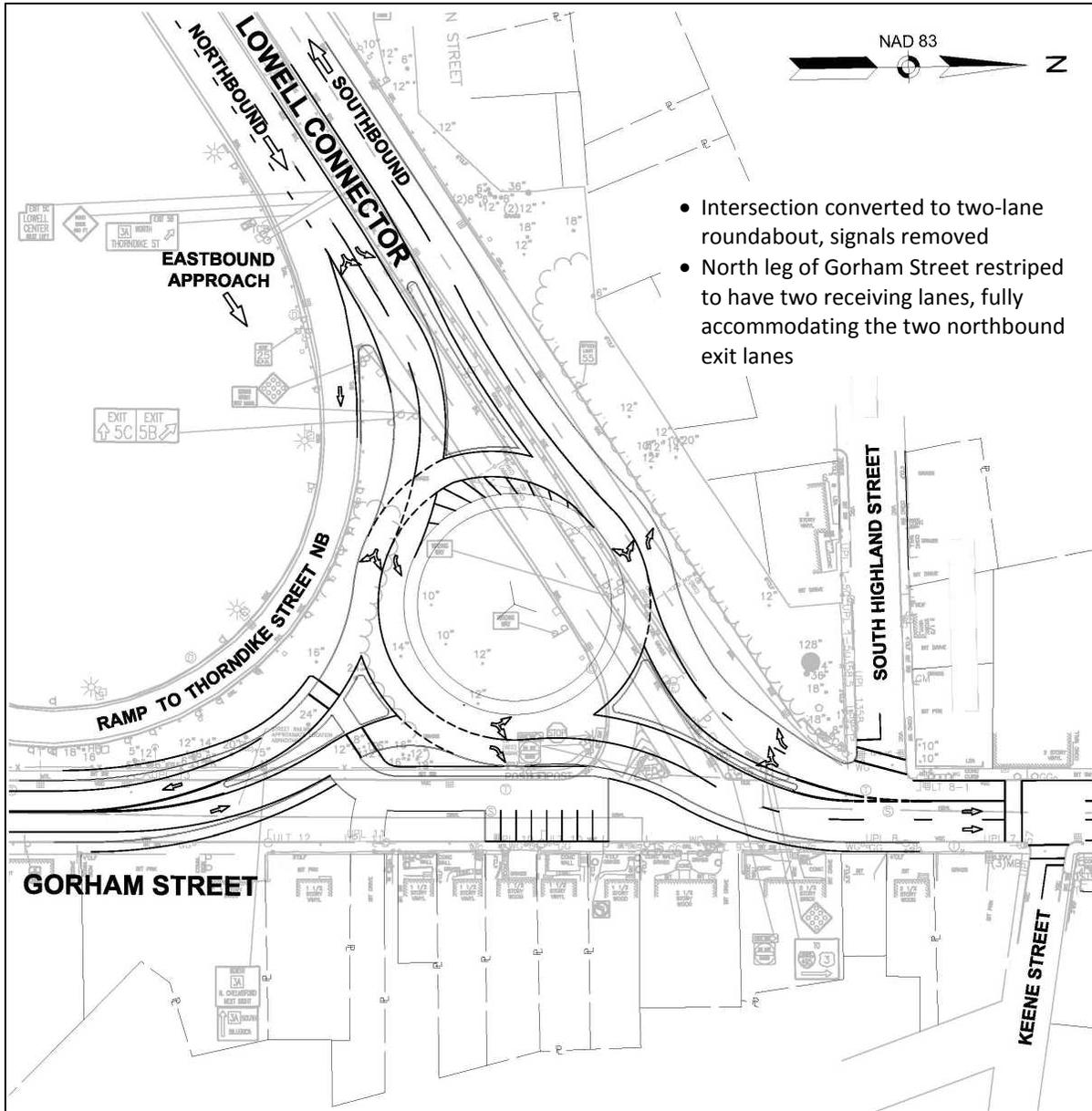
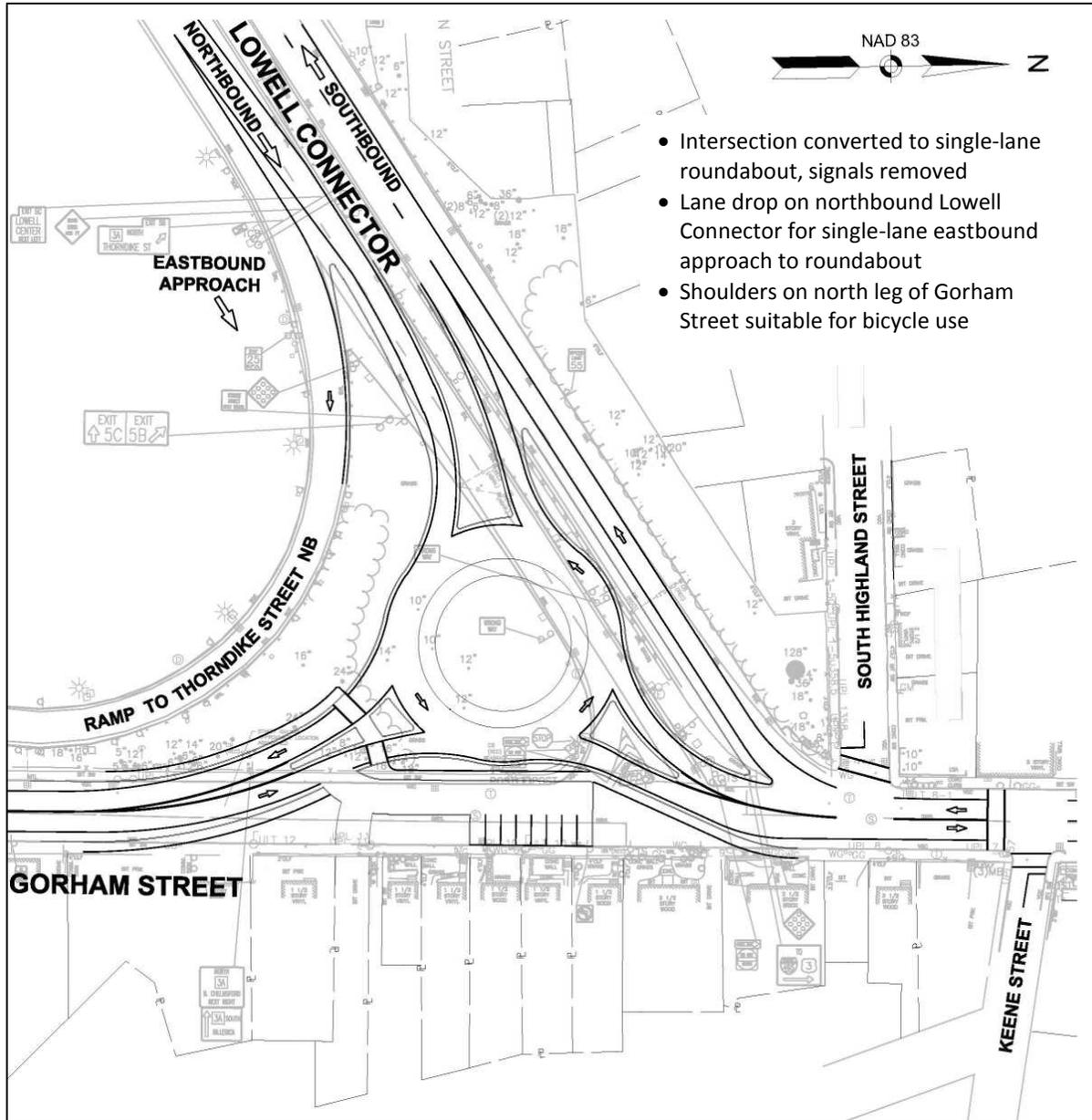


Figure 13 – Lowell Connector Alternative 4C



- Intersection converted to single-lane roundabout, signals removed
- Lane drop on northbound Lowell Connector for single-lane eastbound approach to roundabout
- Shoulders on north leg of Gorham Street suitable for bicycle use

Alternative Set 5: Realign Intersection to Change through Movements: This option involves realigning the three approaches to the intersection such that the movements between the north leg (Gorham Street) and the west leg (Lowell Connector) are the predominant movements. The south (Gorham Street) leg becomes the minor leg, requiring turning movements onto and off of the main flow of traffic. The intersection would continue to be signal-controlled, but as the intersection would no longer align with a driveway on the east side of Gorham Street, the signal phase and equipment serving that driveway would be eliminated. The primary benefit of this option is to improve the intersection's capacity for the high volume movement of traffic from the eastbound approach on the Lowell Connector to northbound Gorham Street. The left turn from northbound Gorham Street onto the Lowell Connector would remain a prohibited movement and would be blocked by the island extending across the intersection that also assists in preserving the free movement from southbound Gorham Street onto the Lowell Connector.

The proposed geometric layouts of Alternatives 5A, 5B, and 5C are shown in **Figure 14** through **Figure 16**.

Figure 14 – Lowell Connector Alternative 5A

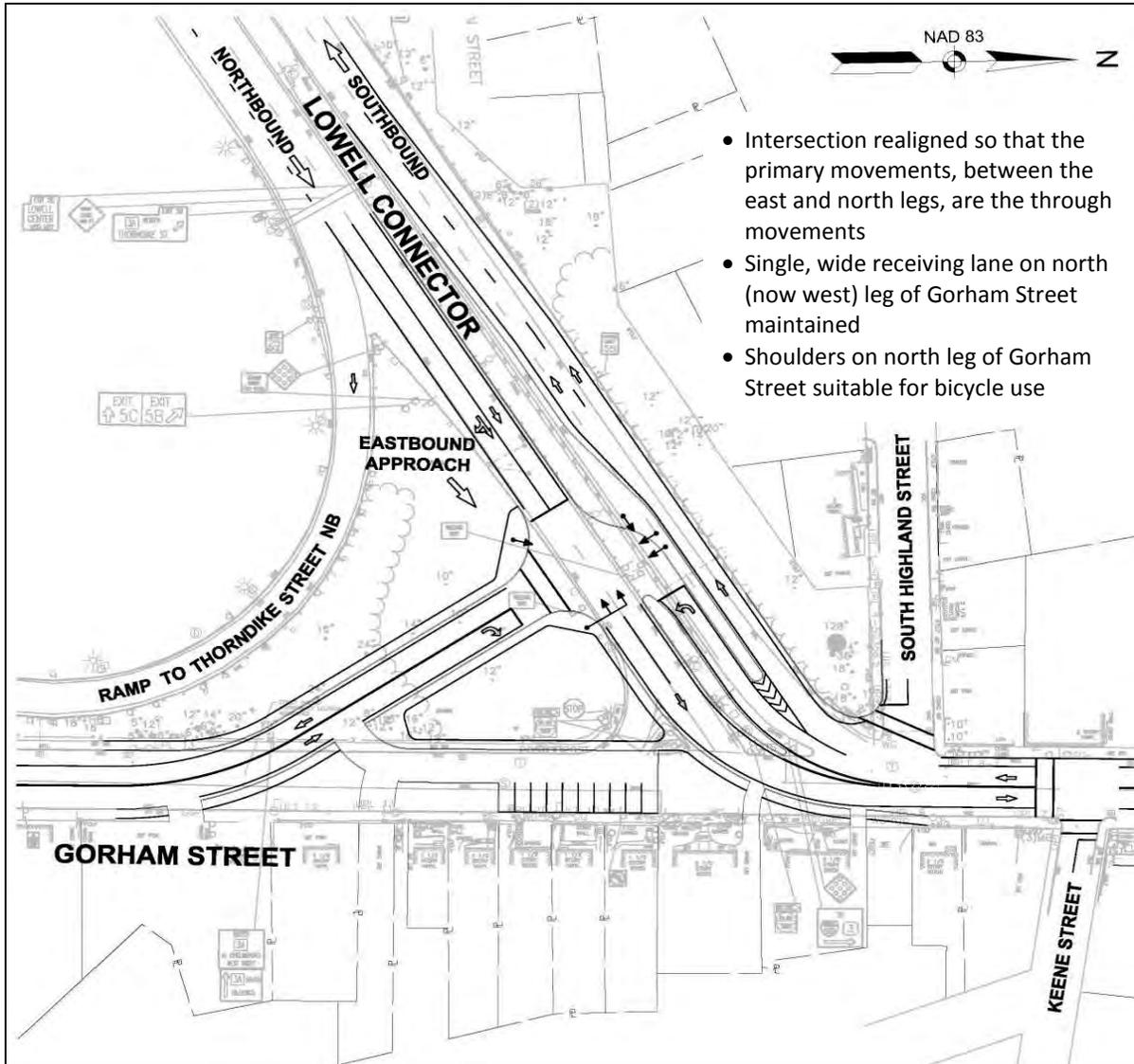
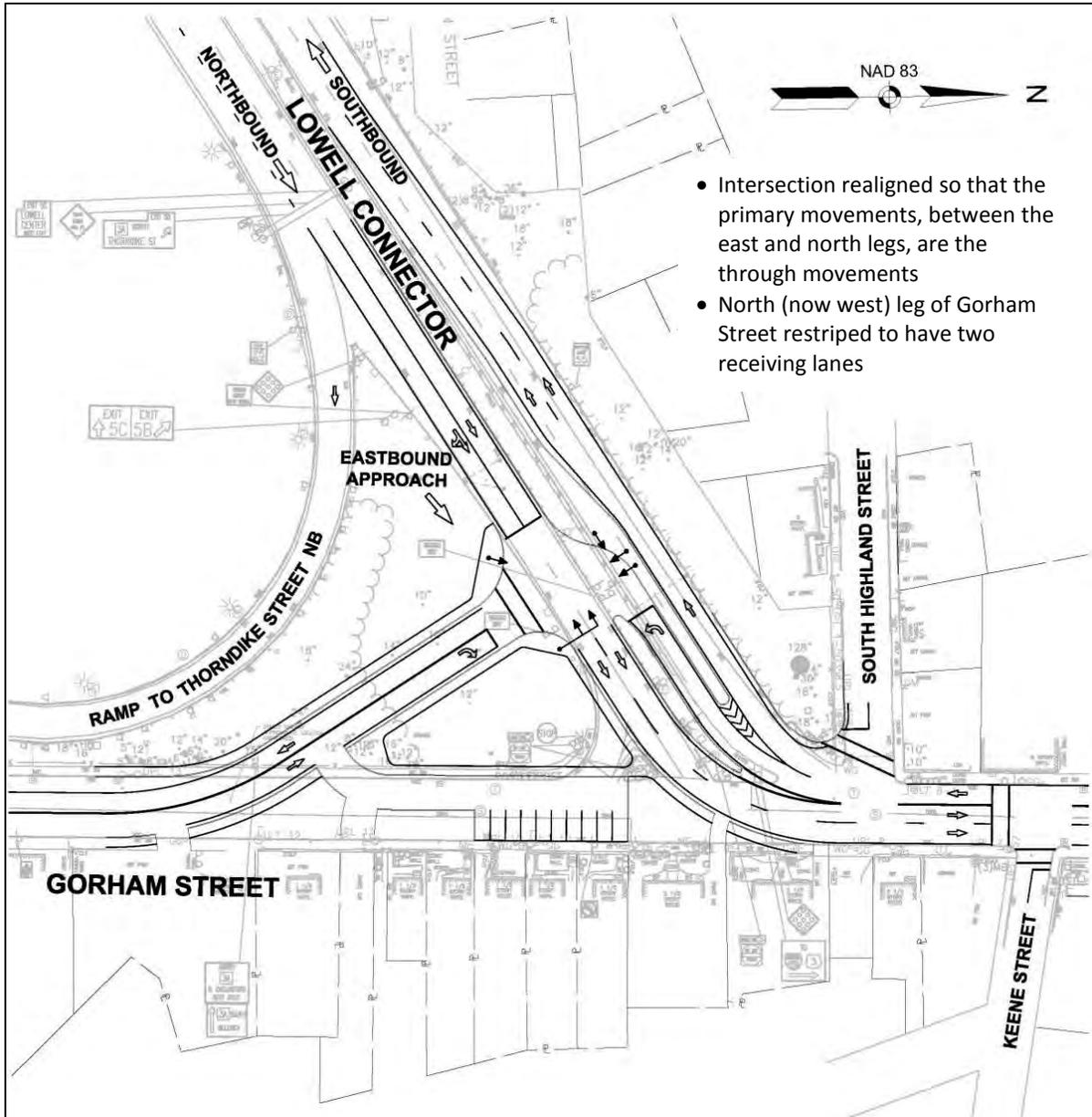
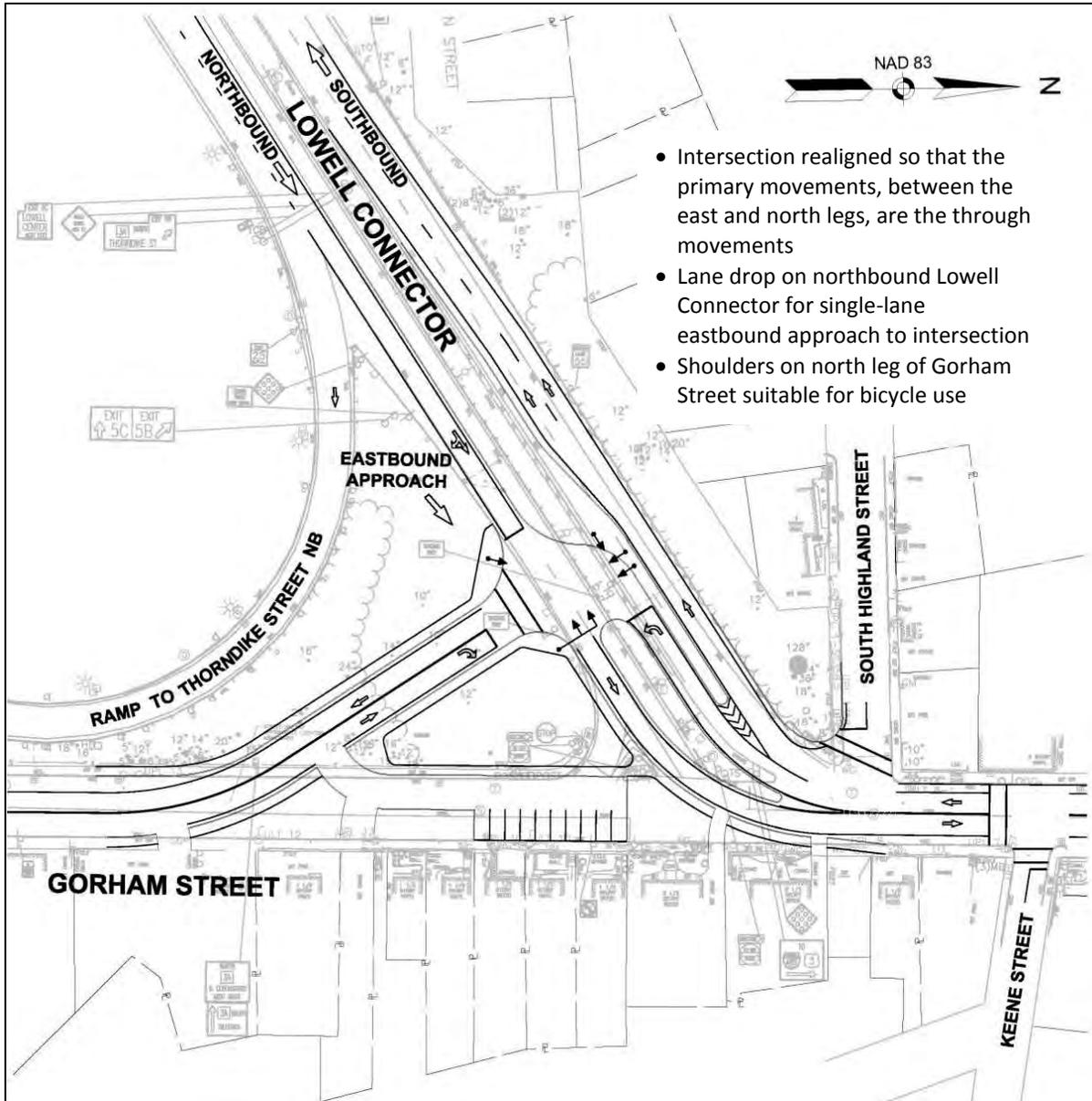


Figure 15 – Lowell Connector Alternative 5B



- Intersection realigned so that the primary movements, between the east and north legs, are the through movements
- North (now west) leg of Gorham Street restriped to have two receiving lanes

Figure 16 – Lowell Connector Alternative 5C



- Intersection realigned so that the primary movements, between the east and north legs, are the through movements
- Lane drop on northbound Lowell Connector for single-lane eastbound approach to intersection
- Shoulders on north leg of Gorham Street suitable for bicycle use

INTERSECTION OF GORHAM STREET AND ELM/HIGHLAND STREETS (SITE 1)

This is a signalized, four-legged intersection, experiencing both congestion and safety issues. It has been identified as a crash “cluster” by the Department’s Highway Safety Improvement Program (HSIP).

The primary traffic demand is a north-south movement between the Lowell Connector to the south and the employment centers of Downtown Lowell to the north. These heavy northbound and southbound movements currently have single approach lanes.

The Elm Street westbound approach and Highland Street eastbound approach to this intersection have two lanes each which, until recently, were not assigned specific lane-use designations. The result of this configuration was a merge across the intersection for through movements from two lanes to a single receiving lane on the other side of the intersection. Both approaches were restriped in recent months to designate the left approach lane as an exclusive left-turn lane, removing the merge condition.

A fairly high level of pedestrian activity results in many calls for the exclusive pedestrian signal phase, limiting the available times for the vehicular phases.

The No-Build scenario and three improvement alternatives were assessed for potential implementation at this intersection.

Alternative 20: No-Build: Under this scenario, minor replacement of curb and road surface would be completed. Although no geometrical changes to the intersection affecting lane use would occur, the removal of the existing signal pole from the median Island on the Elm Street approach, and perhaps removal of the island itself, should be considered. Furthermore, signal timing would be optimized (with no phasing changes), with consideration of coordination with the traffic signal at the Lowell Connector intersection.

Alternative 21 was removed from consideration as it proposed reassignment of the approach lanes for Elm Street and Highland Street, which has already been implemented in the field.

Alternative 22: Northbound Left-Turn Lane: This option involves providing a 3-lane roadway within the existing curb width of the Gorham Street south leg of the intersection. An exclusive left-turn lane here would allow for northbound through-moving traffic to proceed with the green signal, unimpeded by left-turning traffic waiting for a gap in the opposing southbound flow. This option could be applied in concert with Gorham Street Alternative 12 below, which calls for a second northbound lane from the Lowell Connector continuous to this intersection, where the left travel lane would become the exclusive left-turn lane. The critical merge point for northbound through traffic would occur in the region where the left northbound lane transitions into the exclusive turn lane. It could also be implemented in conjunction with Alternative 11, the Gorham Street No-Build alternative, where striping modifications are applied only on the approach to this intersection.

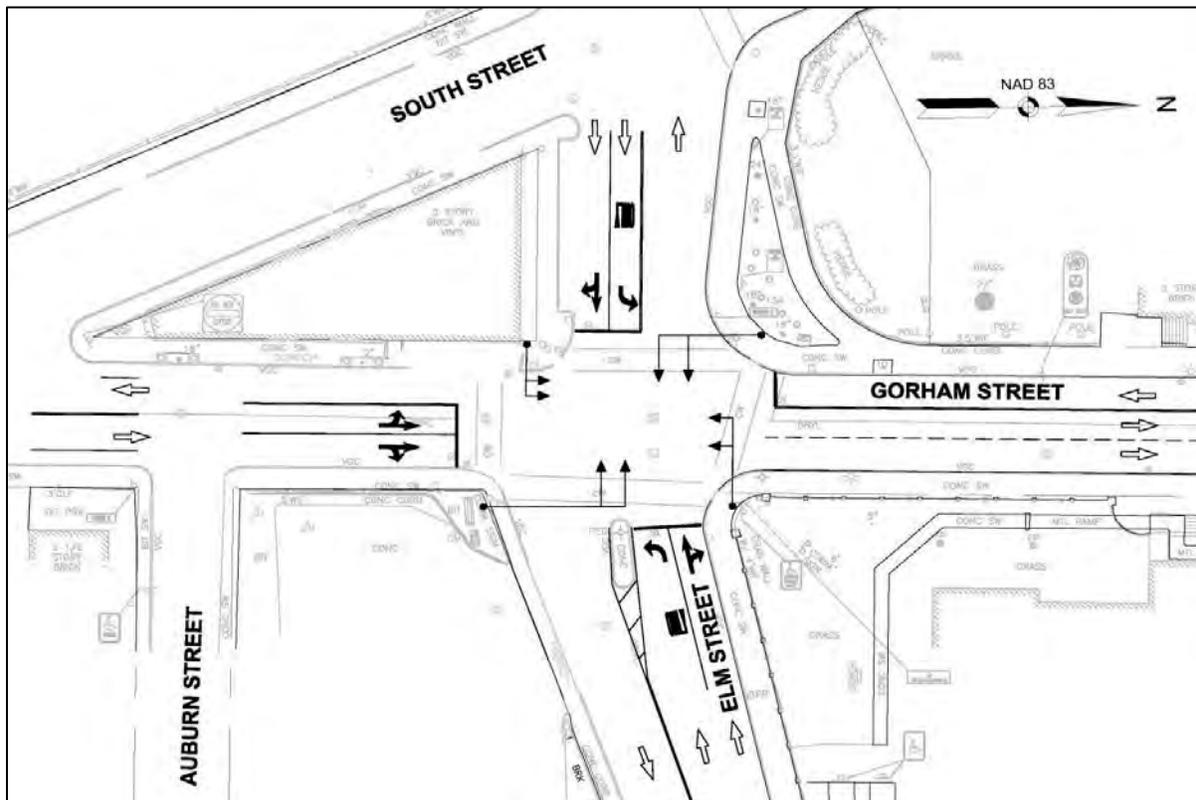
The minor improvements proposed under the No-Build scenario could be implemented under this alternative as well.

Alternative 23: Two Northbound Through Lanes: This option involves restriping of the south leg of the intersection and minor widening of the northern leg to provide two general-use lanes on the northbound Gorham Street approach with a matching number of receiving lanes for the through movement. Like some other options previously described, this would address the congestion relating to a northbound merge at the Lowell Connector intersection by shifting the merge condition further to the north, in this case to a more favorable segment just north of Elm Street.

The minor improvements proposed under the No-Build scenario could be implemented under this alternative as well.

The proposed geometric layout of Alternative 23 is shown in **Figure 18**.

Figure 18 – Elm Street/Highland Street Alternative 23



Alternative 24: Re-Phase the Existing Signal: At this intersection, congestion is a key issue. Alternatives to the current three-phase signal operation must be considered, with an eye toward making this intersection operate efficiently and effectively. Phasing options to be considered include (but are not limited to):

- Create eastbound and westbound protected left-turn phases, with leading greens for these left-turn movements,
- Split the east-west phasing, allowing each approach its own phase, and
- Remove exclusive pedestrian phase in favor of concurrent phasing.

This alternative does not propose any geometric changes. Also, it is not exclusive of the other alternatives in this section and can be implemented in conjunction with any of them.

GORHAM STREET FROM LOWELL CONNECTOR TO ELM/HIGHLAND STREETS (SITE 2)

Gorham Street is a two-way, two-lane road, 32-37 feet in width, with several parking prohibitions. This segment is generally striped approximately in the middle of the street, seemingly independent of parking restrictions.

The single northbound lane restricts the functionality of the Lowell Connector intersection upstream, where two lanes of traffic exiting the Lowell Connector to the north are throttled by the single receiving lane on Gorham Street.

The single southbound lane approaching the Lowell Connector causes the signal-controlled through-moving traffic to queue up at times, obstructing the free flow of right-turning traffic.

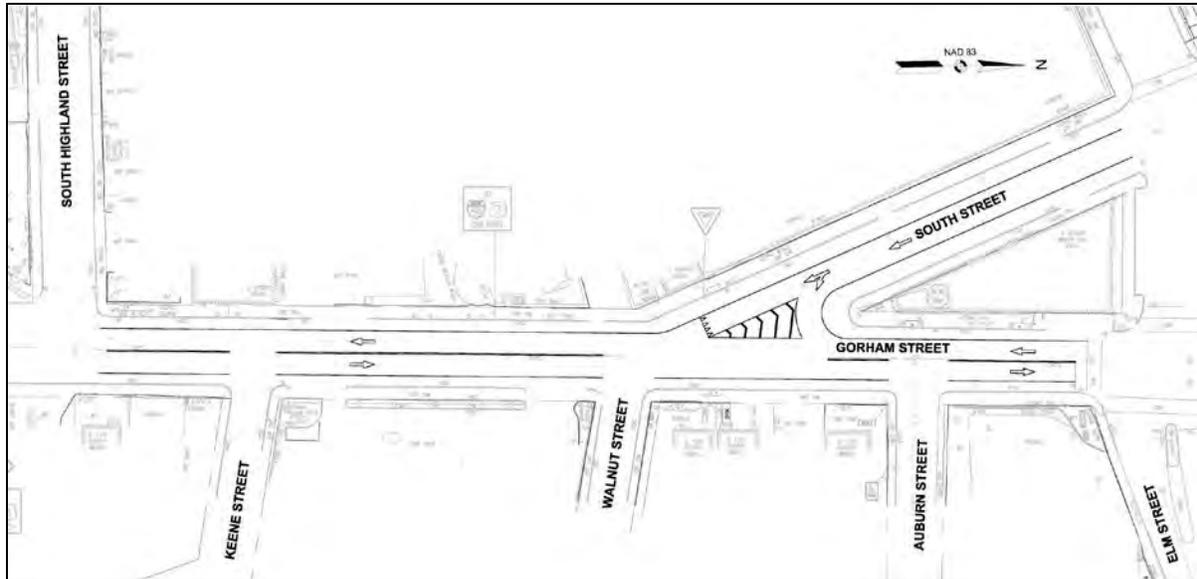
Three design options are presented for this segment of the road. The preferred alternative at this location is likely to be driven by the preferred alternatives at the two signalized intersection at either end. The segment alternative will depend on the number of northbound departure lanes at the Lowell Connector intersection and the number of northbound approach lanes at the intersection at Elm Street and Highland Street.

Alternative 11: No-Build: Under this scenario, this entire section of Gorham Street would remain a two-lane road, not addressing the impacts on the Lowell Connector intersection as discussed above. This alternative lends itself to more opportunity to delineate curb offsets or shoulders that are suitable for bicycle use.

The critical merge point for the northbound lanes would remain within the Lowell Connector intersection.

The proposed geometric layout of Alternative 11 is shown in **Figure 19**.

Figure 19 – Gorham Street Alternative 11



One relatively minor geometric improvement is included under this alternative. South Street’s southeast-bound approach to Gorham Street would have a striped island to separate out left-turning traffic and to better delineate the lane for the other streams of traffic. This option is intended to be compatible with the Lowell Connector Alternatives 1A (No-Build), 2A, 4A, and 5A. It is also compatible with the Elm Street/Highland Street Alternatives 20 (No-Build) and 24, and with some modifications on the northern end only it could be compatible with Alternative 22.

Alternative 12: Additional Northbound Lane: As discussed among the options for the two intersections above, the single northbound lane on Gorham Street causes congestion problems at those intersections and safety issues at the Lowell Connector intersection.

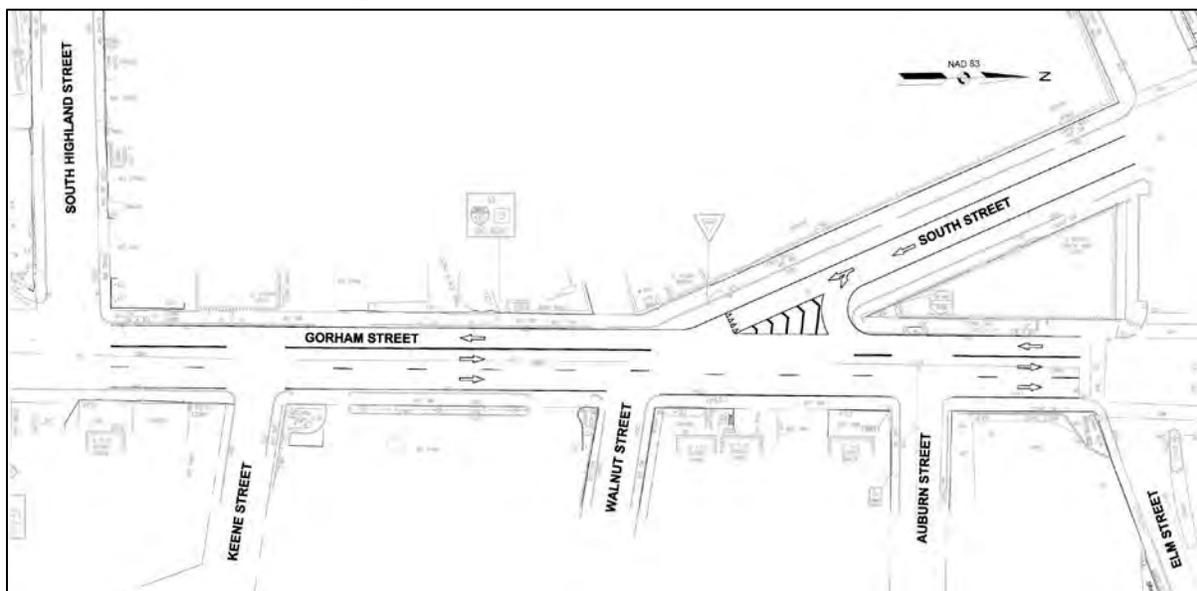
Under this option, Gorham Street would be restriped at essentially its current width (with minor widening near Elm Street) to provide two northbound lanes extending continuously from the Lowell Connector to Elm Street/Highland Street. This would require three 11-foot lanes (two northbound and one southbound) and one-foot curb offsets.

This option is compatible with Lowell Connector Alternatives 1B, 2B, 4B, and 5B. It is also compatible with Elm Street/Highland Street Alternatives 22 and 23.

The critical merge point for the northbound lanes would depend on which of the Elm Street/Highland Street alternatives is implemented. The minor improvements to the South Street approach to Gorham Street proposed under the No-Build scenario could be implemented under this alternative as well.

The proposed geometric layout of Alternative 12 is shown in **Figure 20**.

Figure 20 – Gorham Street Alternative 12



Alternative 13: Two Northbound Lanes Merging to One near Walnut Street: As discussed among the options for the Lowell Connector intersection, the single northbound lane on Gorham Street causes congestion and safety problems at that intersection.

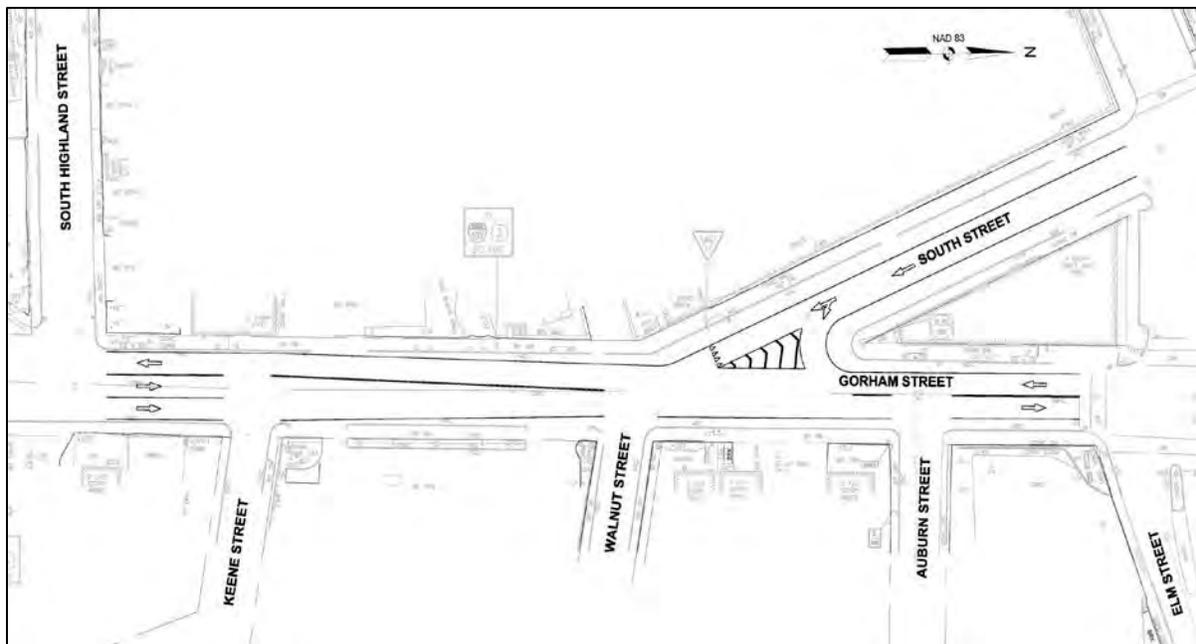
Under this option, Gorham Street would be restriped to provide two northbound lanes departing the Lowell Connector intersection but would be reduced to one lane prior to the approach to the Elm Street/Highland Street intersection.

The critical merge point for the northbound lanes would occur between Keene Street and Walnut Street.

This option is compatible with Lowell Connector Alternatives 1B, 2B, 4B, and 5B. It is also compatible with Elm Street/Highland Street Alternative 20 (No-Build) and Alternative 24. The minor improvements to the South Street approach to Gorham Street proposed under the No-Build scenario (Alternative 11) could be implemented under this alternative as well.

The proposed geometric layout of Alternative 13 is shown in **Figure 21**.

Figure 21 – Gorham Street Alternative 13



ALTERNATIVES ANALYSIS

ALTERNATIVE EVALUATION CRITERIA

Given the wide variety of geometric and operational changes considered, the various alternatives were assessed in light of a number of defined goals and objectives. The primary considerations in evaluating the alternatives were vehicular, pedestrian, and bicycle safety, as well as improvements to intersection capacity. Also considered were accommodation of trucks and transit buses, abutters' accessibility and property, consistency with community circulation and planning goals, environmental effects, and probable costs.

Preliminary vehicle capacity analyses were conducted using Trafficware's Synchro/SimTraffic (version 9) software. Upon identifying the more effective alternatives, the capacity analyses for the selected Lowell Connector alternatives were re-analyzed in combination with the preferred alternative at Elm Street/Highland Street, because each intersection's operations can be greatly influenced by the other. Analyses of these alternatives were conducted in SIDRA software, which is more capable of evaluating roundabouts than Synchro/SimTraffic. Capacity analysis reports for both SimTraffic and SIDRA are provided in **Appendix D**.

The primary criterion for evaluating traffic operations is level of service (LOS), which is determined by assessing average delay experienced by vehicles at intersections.

Table 5 below displays intersection LOS criteria from the *Highway Capacity Manual* for both signalized and unsignalized intersections. LOS A indicates the most favorable condition, with minimum traffic delay. Levels of service D and E are progressively worse operating conditions, and LOS F conditions represents the worst condition where demand exceeds the capacity and/or there is significant traffic delay. Most urban communities set level of service D as the minimum acceptable level of service for peak hour operation.

Table 5 – Vehicle Level of Service Criteria

Level of Service (LOS)	Average Delay (sec/veh)	
	Signalized Intersections	Unsignalized Intersections
A	0-10	0-10
B	>10-20	>10-15
C	>20-35	>15-25
D	>35-55	>25-35
E	>55-80	>35-50
F	>80*	>50*

*Or volume exceeding capacity (v/c ratio > 1)

Other key measures of operational efficiency are the volume-to-capacity (v/c) ratio, which is a measure of congestion, and the queue length, which is evaluated at 50th and 90th percentile levels.

INTERSECTION OF GORHAM STREET AND LOWELL CONNECTOR (SITE 3)

Preliminary Screening: With eleven improvement alternatives identified for the Lowell Connector intersection, three at Elm Street/Highland Street, and two on the Gorham Street roadway segment in between, plus the No-Build alternatives for each of those, the number of combinations of alternatives to compare and contrast could be daunting. It is noted only certain combinations of alternatives are compatible, but the total number of combinations is still large. Rather than advancing the detailed analysis of all compatible combinations of these alternatives, an objective rating process was used to “score” the various alternatives at the Lowell Connector intersection based on their comparative benefit to the community in eleven key areas, as shown in **Table 6**.

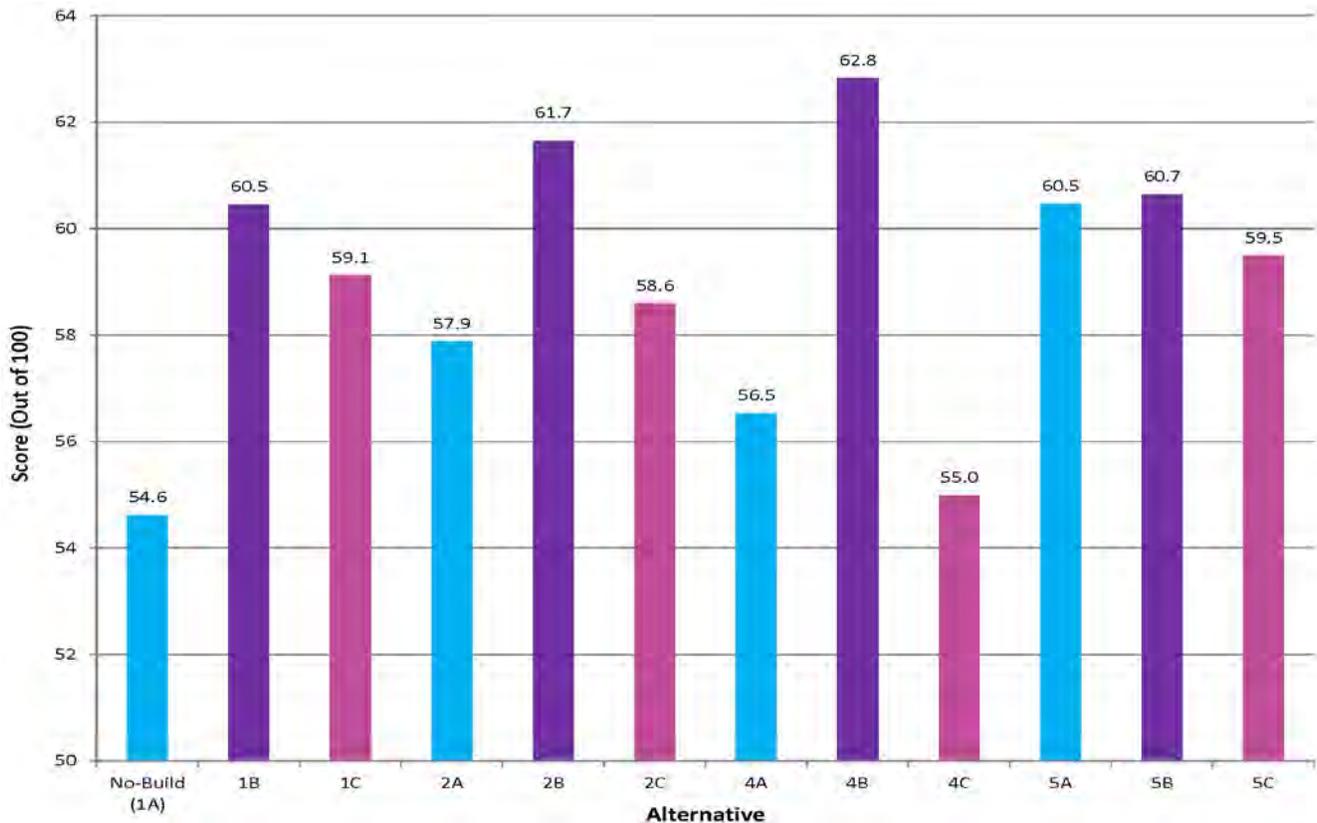
Table 6 – Evaluation Criteria Score Definitions

Criterion	Score Definitions		
	0	5	10
Vehicle Capacity (Delay)*	Severely degraded	Essentially unchanged Delays	Large reduction in delays
Vehicle Safety	Severely degraded Safety	Essentially unchanged Safety	Greatly improved Safety
Bicycle Accommodation / Safety	Severely degraded Safety	Essentially unchanged Safety	Greatly improved Safety
Pedestrian Accommodation / Safety	Severely degraded Safety	Essentially unchanged Safety	Greatly improved Safety
Construction Cost	More than \$2 mil.	\$1-2 mil.	Less than \$1 mil.
Abutter Impact, Accessibility	Significant loss of access	No significant change	Improved access
Abutter Impact, ROW	Significant Property acquisition	Temporary easements with minor takings	No ROW Actions
Impact on Other Streets	Significant increase in congestion and delays	Minor increase in congestion and delays	No change or slight improvement
Ability to Accommodate Trucks and Transit Buses	Severely Degraded Accommodation	Essentially Unchanged Accommodation	Greatly Improved Accommodation
Environmental Impact (Air/Noise Quality, Water Quality, Cultural, etc.)	Significant Negative Impacts	Essentially Unchanged Impacts	Significant Positive Impacts
Aesthetics, Public Perception, Alignment with City Policies/Goals	Poor Appeal	Neutral Appeal	Strong Appeal

*For traffic operations (vehicle capacity/delay), in order to capture and compare the effects of the in-intersection lane merge from the Lowell Connector to northbound Gorham Street and potential spillback from the intersection at Elm/Highland Streets, the Lowell Connector alternatives were evaluated using the SimTraffic microsimulation tool within the Synchro suite of software. These alternatives were analyzed in the context of the full study area network, including the other signalized intersection plus the two unsignalized intersections. The preferred alternative for the intersection at Elm/Highland Streets was assumed. The output for each alternative and peak period (AM or PM) is an average of five microsimulation runs. The full output reports from SimTraffic are provided in **Appendix D**.

Each alternative was given a score for each of the evaluation criteria, and total scores (out of a possible 100 points) were generated using weighted sums, as shown in **Figure 22**. The highest-scoring alternatives were selected to advance in the process.

Figure 22 – Preliminary Analysis Scores for Lowell Connector Alternatives



The preliminary evaluation indicated that the “B” alternatives, providing two full departure lanes for Gorham Street northbound, consistently outscored their “A” and “C” counterparts. The “A” alternatives, which maintained the single northbound departure lane, failed to address the operational and safety issues of the in-intersection merge. While “C” the alternatives addressed those issues, they resulted in increased capacity problems at the intersections. One drawback to the “B” alternatives however, is that bicycle accommodations on Gorham Street throughout the section are precluded by the two northbound lanes, as there is no spare width for bicycle lanes.

Alternative 1B (**Figure 6**) was discarded as it did not adequately address the operational and safety deficiencies at the southbound entrance to the Lowell Connector and South Highland Street, and did not enhance pedestrian safety.

Alternative 5B (**Figure 15**) was discarded because of similar operational problems at South Highland Street, and the possibility of excessive speeds on the Lowell Connector approach operating under a green light.

Therefore, the following Lowell Connector intersection alternatives were selected for further consideration and evaluation:

- Alternative 2B (**Figure 9**): Realign Lowell Connector Approach to “Tee” Intersection, Two Northbound Departure Lanes
- Alternative 4B (**Figure 12**): Replace Signalized Intersection with Two-Lane Roundabout, Two Northbound Departure Lanes

Selected Alternatives Analysis: The two selected Lowell Connector alternatives, 2B and 4B, were evaluated for traffic operations in the context of Alternatives 23 and 12 (**Figure 18** and **Figure 20**, respectively), the likely preferred alternatives for the Highland Street intersection and the adjacent segment of Gorham Street. For Alternative 2B, in which the Lowell Connector intersection remains signalized, the traffic signals at the two intersections would be coordinated, with the cycle offset set to minimize the possibility of northbound spillback from the downstream intersection that would affect operations at this intersection upstream. The Synchro/SimTraffic analysis indicates that it is possible to apply a half-cycle length to the Lowell Connector intersection (a cycle length half of that at the other intersection) and not only have good throughput with minimal delays, but also reduce the possibility of southbound through-moving vehicles queuing up such that southbound right-turning vehicles are blocked from entering their channelized turn lane, inhibiting their otherwise free movement. In Alternative 4B, this intersection is converted to a roundabout and is no longer signalized. The signal at the Elm Street/Highland would be optimized for north-south movements such that the spillback issue is eliminated to the extent possible.

As Alternative 4B employs a multi-lane roundabout, a formal operational analysis for this alternative was conducted using SIDRA software. Alternative 2B was also analyzed in SIDRA to enable a proper comparison between the two alternatives. Capacity analysis reports for the analyses conducted in SIDRA, both network and Lowell Connector intersection-specific, are provided in **Appendix D**. The intersection-specific output is summarized in **Table 7** and **Table 8** for the AM and PM peak hours, respectively.

Table 7 - SIDRA Capacity Analysis Summary, AM Peak Hour

Lane Group	LOS	Delay (sec)	v/c Ratio	50th Percentile Queue (ft)	95th Percentile Queue (ft)
Alternative 2B – “Teed” Intersection					
Lowell Connector EB Left	C	27.5	0.608	178.5	291.4
Lowell Connector EB Right	A	0.7	0.049	3.8	6.2
Gorham Street NB Thru	B	11.4	0.133	36.0	58.7
Gorham Street SB Thru/Right	A	9.9	0.812	198.4	323.8
<i>Intersection</i>	<i>B</i>	<i>15.6</i>	<i>0.812</i>	<i>198.4</i>	<i>323.8</i>
Alternative 4B – Two-Lane Roundabout					
Lowell Connector EB Left/Right	A	5.8	0.303	15.4	38.4
Gorham Street NB Left/Thru	A	6.8	0.186	6.9	17.3
Gorham Street SB Thru	A	3.9	0.132	5.7	14.3
Gorham Street SB Right	A	0.0	0.604	0.0	0.0
<i>Intersection</i>	<i>A</i>	<i>2.9</i>	<i>0.604</i>	<i>15.4</i>	<i>38.4</i>

Table 8 – SIDRA Capacity Analysis Summary, PM Peak Hour

Lane Group	LOS	Delay (sec)	v/c Ratio	50th Percentile Queue (ft)	95th Percentile Queue (ft)
Alternative 2B – “Teed” Intersection					
Lowell Connector EB Left	B	12.2	0.576	108.3	176.8
Lowell Connector EB Right	A	1.4	0.165	11.9	19.4
Gorham Street NB Thru	B	16.3	0.351	43.1	70.4
Gorham Street SB Thru/Right	A	5.5	0.686	71.7	117.0
<i>Intersection</i>	<i>A</i>	<i>8.6</i>	<i>0.686</i>	<i>108.3</i>	<i>176.8</i>
Alternative 4B – Two-Lane Roundabout					
Lowell Connector EB Left/Right	A	7.3	0.429	25.7	64.0
Gorham Street NB Left/Thru	A	9.1	0.280	10.6	26.4
Gorham Street SB Thru	A	3.8	0.121	5.2	12.9
Gorham Street SB Right	A	0.0	0.493	0.0	0.0
<i>Intersection</i>	<i>A</i>	<i>4.5</i>	<i>0.493</i>	<i>25.7</i>	<i>64.0</i>

The SIDRA analysis indicates that, under Alternative 2B (the “Teed” intersection), the Lowell Connector intersection would operate above minimum-acceptable levels of service for all lane groups, at LOS C or better in the AM peak hour and at LOS B or better in the PM peak hour. Furthermore, the queues for the key eastbound left-turn movement (from the Lowell Connector to northbound Gorham Street) would be reasonable. Assuming 25 feet per vehicle, the 50th percentile queue would be approximately 7 vehicles in the AM peak hour and 4 vehicles in the PM peak hour. The 95th percentile queues would be approximately 12 vehicles in the AM peak hour and 7 vehicles in the PM peak hour. In addition to these capacity and delay improvements, safety benefits could be realized under this alternative. The ability to more clearly delineate travel paths through the intersection, coupled with the provision of two northbound departure lanes on Gorham Street, is expected to lead to a significant and measurable

reduction in crash rates at this location, where sideswipe and angle accidents comprise over half of the analyzed crashes on this site. Alternative 2B has the ability to accommodate pedestrians in a similar manner as the existing conditions but with improved signage and a crosswalk added across the south leg of the intersection. As a “B” alternative, it would not provide explicit bicycle facilities on Gorham Street. Accommodation of buses through the intersection would be unchanged under this alternative relative to existing.

Alternative 4B (the two-lane roundabout) would perform very well, based on the SIDRA analysis. All lane groups would operate at LOS A in both peak hours. The queues for the eastbound left-turn movement would be minimal. The 50th percentile queues would be less than one vehicle in the AM peak hour and approximately 1 vehicle in the PM peak hour, and 95th percentile queues would be roughly 1.5 vehicles and 2.5 vehicles in the AM and PM peak hours, respectively. The indication is that a multi-lane roundabout at this location would operate exceptionally well and would result in minimal delay for all entering vehicles. Safety benefits could be realized under Alternative 4B similar to what was discussed for Alternative 2B, as vehicles would be able to more clearly delineate travel paths through the intersection, and there would be a second northbound departure lane on Gorham Street to eliminate the merge condition. These features are expected to lead to a significant and measurable reduction in crash rates at this location. Alternative 4B would provide for somewhat improved pedestrian safety over existing conditions by moving the vehicular traffic turning movements to the west, away from pedestrian traffic on the east sidewalk. Like Alternative 2B, as a “B” alternative, this alternative would not provide explicit bicycle facilities on Gorham Street, but as a roundabout, it would be the more difficult of the two intersection configurations for bicyclists to navigate. Buses traveling through the intersection would need to make some slight turning movements to enter and exit the roundabout where they currently travel straight through the intersection, which is a minor degradation to bus accommodations.

Based on the overall results of this analysis, Alternative 4B (the two-lane roundabout) has been selected as the preferred alternative for the Lowell Connector intersection. The installation of the roundabout is expected to result in minimal queueing of traffic on all approaches, reducing rear-end crashes, which comprise about 30% of the crashes at this site. The roundabout would provide efficient operations for anticipated future traffic demands and can fit within the available space. It even enables the northbound left-turn movement onto the Lowell Connector, which is currently prohibited. The software analyses accounted for a reasonable number of vehicles performing that turning movement and still yielded exceptional operational results for all lane groups entering the roundabout.

In consideration of the other evaluation criteria, one notable impact to the abutting properties was identified for this alternative: Direct access to the properties on the east side of Gorham Street in the vicinity of the intersection was eliminated. A new parking area is proposed to accommodate those properties, and access is proposed from the northbound approach to the roundabout. Vehicles exiting the parking area can use the roundabout to access Gorham Street in either direction or turn onto the Lowell Connector, entering from the south leg of the roundabout. There is a similar issue for a driveway on the north end of the roundabout, in that vehicular access to the west and south from the driveway is achieved indirectly by exiting to the north on Gorham Street, then turning left onto Highland Street, left onto South Street, and right onto southbound Gorham Street to the roundabout at the Lowell Connector. These are inconvenient maneuvers, but access to these abutting properties is still possible.

INTERSECTION OF GORHAM STREET AND ELM/HIGHLAND STREETS (SITE 1)

This intersection currently experiences operational failure in both the AM and PM peaks hours, primarily due to high volumes for northbound, southbound, and westbound vehicles. The northbound and southbound congestion causes numerous rear-end collisions and even affects the operation of the Lowell Connector intersection to the south due to northbound spillback. Safety improvements are important to this intersection. Further degradation of the north-south traffic capacity should be avoided, as it can contribute to the rear-end collisions.

Alternatives 20 (No-Build) and 22 (**Figure 17**: northbound left-turn lane) were both found to have minimal effect on the safety and capacity of the intersection.

Alternative 21 was removed from consideration as it proposed reassignment of the approach lanes for Elm Street and Highland Street, which has already been implemented in the field.

Alternative 23 (**Figure 18**) provides two northbound through lanes, at first seems to replicate the existing condition with a single northbound lane south of the intersection. This is addressed in Alternative 12 below. A proposed merge just north of Elm Street provides a much more favorable alignment, without turning movements and under slower speeds. This alternative was evaluated in conjunction with Gorham Street Alternative 12 and with signal timing that has been optimized for north-south movements and coordinated with the Lowell Connector intersection's signal (for Alternative 2B). The capacity analysis in Synchro/SimTraffic indicates that this alternative will greatly reduce the spillback of northbound traffic into the Lowell Connector intersection located upstream.

Alternative 24, which removes the existing exclusive pedestrian phase, would appear to provide more green light time for traffic demands, but fails to do so. This is because the pedestrian traffic would continue to exercise their right-of-way in the crosswalks, greatly reducing the impact of the additional green time while compromising pedestrian safety, including students of the nearby Rogers public school.

For the above reasons, Alternative 23 (Figure 18) is the sole alternative to be advanced in the study and is therefore the preferred alternative for the intersection of Gorham Street with Elm Street and Highland Street.

Its potential to reduce northbound spillback into the Lowell Connector intersection is key to realizing operational improvements at that intersection no matter which alternative is selected there.

GORHAM STREET FROM LOWELL CONNECTOR TO ELM/HIGHLAND STREETS (SITE 2)

As noted earlier in the "Alternatives Considered" section, the preferred alternative for the road segment between the Lowell Connector (Site 3) and the intersection at Elm/Highland Streets (Site 1) will be determined by the lane configurations dictated by the preferred alternatives at the intersections on either end.

The analysis of the Lowell Connector intersection above indicates that the intersection would operate best with two receiving lanes on the north leg of the intersection. Both of the two selected alternatives

for the Lowell Connector intersection have this configuration. No matter which of those two alternatives is ultimately designated the preferred alternative, either Alternative 12 or 13 on the Gorham Street road segment is called for. Both Alternatives 12 and 13 have a two-lane northbound section on the south end of the road segment.

The analysis of the intersection of Highland/Elm Streets indicates that it would operate best with a two-lane northbound approach. The preferred alternative at that site (Alternative 23) was selected for that configuration. The only alternative for this roadway segment that accommodates the required two lanes for through movements at that intersection is Alternative 12, which provides a lane configuration that supports the optimal improvements at the intersections at both ends.

Thus, Alternative 12 (Figure 20), calling for two northbound lanes throughout the length of this segment, is the sole alternative to be advanced in the study and is therefore the preferred alternative for this link.

PREFERRED ALTERNATIVES AND RECOMMENDATIONS

The preferred combination of alternatives that is recommended for design and construction are:

- Lowell Connector Intersection: A two-lane roundabout with two full exit lanes for northbound traffic (Alternative 4B). It is further recommended that more aggressive signage be implemented on northbound Lowell Connector approaching the terminus at Gorham Street to provide warning of the end of the freeway facility.
- Elm Street/Highland Street Intersection: An additional general-purpose lane on the northbound approach to the intersection with minor widening of the northern leg to provide a matching number of receiving lanes (Alternative 23).
- Gorham Street, Between Intersections: An additional northbound travel lane (Alternative 12). It is further suggested that all of Gorham Street within the project limits be reconstructed to extend roadway life and improve vehicular operations. The addition of “Sharrow” pavement markings in the southbound lane and the outside northbound lane and/or “Share the Road” signage is recommended for Gorham Street to assist in accommodating bicyclists.

While Lowell Connector Alternative 2B (the “Tee” intersection) was also identified as a good option for improvements at that location, the roundabout alternative (Alternative 4B) was selected due to its long-term benefits of significantly superior levels of service, shorter delays, and shorter traffic queues.

Alternative 4B would have challenges during construction. Public safety and maintenance of traffic would need to be addressed, and access to abutting residential and retail properties on the east side of Gorham Street would need to be maintained. A significant portion of the eastbound approach for each of the two alternatives is located in the existing infield between the ramp to northbound Thorndike Street and the final approach to Gorham Street. The construction of this alternative would require more comprehensive and detailed temporary traffic control plans. Details of the traffic patterns necessary during construction might include possible detours involving Thorndike Street or Highland Street, and temporary connections to existing and interim stage alignments to maintain various traffic movements. The construction effort to complete Alternative 4B can be considered moderate-to-complex.

Construction of this combination of alternatives is not expected to have a major impact on existing utilities in the project area. All existing utility infrastructure could be maintained during and after the construction process.

A 40-scale plan showing the preferred combination of alternatives is provided in the sleeve at the back of this report.

The preliminary estimated construction cost of this set of preferred alternatives is approximately \$1.425 million.