BOSTON REGION METROPOLITAN PLANNING ORGANIZATION

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MEMORANDUM

DATE: **June 5, 2014**

TO: **Boston Region Metropolitan Planning Organization (MPO)**

FROM: **Chen-Yuan Wang, MPO Staff**

RE: **Safety and Operations Analyses at Selected Boston Region MPO Intersections, FFY 2013: Lexington Street at Beaver Street in Waltham**

1 INTRODUCTION

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersection of Lexington Street at Beaver Street in Waltham.

The location was approved for study by the Boston Region MPO following a selection process[1] for four locations from a short list of 21 intersections based on a series of criteria including 1) high equivalent property damage only (EDPO) crash ratings, 2) the number of pedestrian and bicycle crashes, 3) transit significance, 4) regional significance, and 5) implementation potential.

The four locations approved for study are:

- North/South Franklin Street (Route 37) at Union Street/Plymouth Street (Route 139) in Holbrook
- Western Avenue (Route 107) at Washington Street (Route 129) in Lynn
- Lexington Street at Beaver Street in Waltham
- Franklin Street (Route 37) at West Street in Braintree

The Waltham intersection is ranked 107 in MassDOT's 2008–10 statewide top-200 intersection crash list. The city of Waltham expressed a strong interest in studying the location for safety and operational improvements.

This memorandum contains the following sections:

- Existing conditions
- Issues and concerns for all users, including pedestrians, bicyclists, trucks, buses, and automobiles
- Crash data analysis
- Intersection capacity analysis
- Traffic signal improvement alternatives

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[1] Memorandum to Boston Region MPO, *Safety and Operations Analyses at Selected Intersections—FFY 2013, Task 1: Intersection Selection Procedure*, Mark Abbot and Chen-Yuan Wang, November 1, 2012.

- Modern roundabout alternative
- Improvement recommendations

This memorandum also includes technical appendices that contain methods and data applied in the study and detailed reports of the intersection capacity analyses.

2 EXISTING CONDITIONS

This "T" intersection is at the geographic center of the city of Waltham, about one-half mile north of the city hall and Main Street (Route 20) and about one mile west of Interstate 95 (I-95)/Route 128. This location carries a large amount of commuting traffic and is congested in both the AM and PM peak periods, especially in the PM peak period.

Lexington Street, running north-south, is the major street of the intersection. It is a principal arterial that stretches from Main Street north to the City's border with the Town of Lexington. It then continues as Waltham Street in Lexington, connects Route 2 in both directions, and terminates at Lexington Center. About 1,000 feet north of this intersection, Lexington Street intersects with Totten Pond Road and Bacon Street. Totten Pond Road is a major roadway that connects I-95/Route 128 at Exit 27 and reaches to the office parks and commercial developments in the Route 128 vicinity.

Beaver Street is the minor street of the intersection. It is classified as an urban minor arterial that stretches from this intersection eastward, intersecting Forest Street and Waverley Oak Road (Route 60), to Warren Street near the City's border with Watertown and Belmont.

Figure 1 shows the existing intersection layout and adjacent developments. The adjacent areas are mainly residential, along with a private school, Chapel Hill-Chauncy Hall School, which occupies the area northeast of the intersection. South of the intersection, commercial developments exist on both sides of Lexington Street. Lexington Street in the study area primarily contains three lanes, with a center lane for two-way left turns to adjacent commercial developments. North of the intersection, Lexington Street widens to four lanes until Totten Pond Road. All of the lanes on Lexington Street appear to be narrow.[2] Beaver Street is primarily a two-lane roadway (one lane in each direction) with sufficient width in the intersection vicinity.

[2] The lanes probably were divided from an original two-lane roadway in order to accommodate increasing traffic over the years. Because of the adjacent residential and commercial developments, there is limited room for expansion to multiple standard 12-foot lanes.

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FIGURE 1
Existing Conditions at the Intersection

Safety and Operations Analyses at Selected Intersections

Approaching the intersection, Lexington Street northbound runs slightly uphill and has two through lanes with a channelized turnoff to Beaver Street. Lexington Street southbound, slightly downhill, contains one through lane and one left-turn-only lane. Beaver Street widens from one lane to two lanes at the intersection: one for left turns only and one for right turns only. The two lanes are separated by a triangular traffic island.

The intersection is signalized. Its traffic signal operates in three phases: 1) a concurrent phase for Lexington Street, both approaches with left turns permitted, 2) an exclusive phase for the Lexington Street southbound approach, with left turns protected (a lagging left-turn protected phase), and 3) an exclusive phase for the Beaver Street approach.

All of the approaches are indicated by three signal faces. All signal faces have the regular three-section red/yellow/green circular indication, except the one above the southbound left-turn lane, which is a four-section signal face with the bottom section indicating a green or yellow arrow. It would indicate a circular green in the concurrent northbound/southbound phase and a circular green and a green arrow simultaneously in the lagging protected left-turn phase. A “left turn yield on circular green” sign is installed next to the four-section signal head on the mast arm (Figure 2).

Right turns on red are allowed at the intersection. Right turns on the westbound approach (Beaver Street) are actually controlled by a pair of yield signs, not by the intersection’s traffic signal (Figure 3).

Sidewalks, which are about five feet wide in most sections, exist on both sides of Lexington Street and Beaver Street. Crosswalks are installed across Beaver Street and the southbound approach of Lexington Street. Push buttons and pedestrian signal heads are installed on the posts at the two traffic islands on Beaver Street and on the west side of Lexington Street.

Pedestrian signals operate concurrently with traffic signal phases that have no, or minimal, conflict with the crossings. The crossing of Beaver Street is concurrent with the northbound/southbound traffic signal and the crossing of the Lexington Street southbound approach is concurrent with the Beaver Street traffic signal. The crossing of Lexington Street has no conflicts with prevailing traffic. However, the crossing of Beaver Street conflicts with the left turns from Lexington Street. In order to alert the left-turning drivers to yield to pedestrians, a “yield to pedestrians in crosswalk“ sign is facing Lexington Street southbound at the corner of the traffic island on Beaver Street. Viewed from the southbound stop line, the sign appeared to be small.[3]

[3] During a return site visit in August 2013, staff did not observe the sign. The pedestrian signal for crossing Beaver Street was operational.

FIGURE 2
Lexington Street Southbound Approach

FIGURE 3
View from Beaver Street Approaching the Intersection

Currently, the pavement markings for the crosswalk across the Lexington Street southbound approach are completely faded (or covered by new pavement). There are no curb cuts at either end of the crosswalk (Figure 4). The pedestrian signals and push buttons for crossing the approach are operational.

Staff observed that a utility pole is located very close to Lexington Street and could be hazardous to northbound drivers, especially for right-turning vehicles. Also, a fence of the adjacent house extends to the right-turn corner, obstructing drivers' view of the pedestrian crossings (Figure 5).

A utility pole, located on the traffic island just south of the westbound right-turn lane, also is potentially obstructive. It could hinder drivers' view of northbound traffic when they are at the yield location.

This intersection carries a number of bicyclists during the day. In the recent traffic count on November 15, 2012, staff observed about ten bicycles in each of the two-hour peak traffic periods; most of them traveling on Lexington Street. Cyclists need to use the traffic lanes, as there are essentially no shoulders on either side of Lexington Street.

Based on the counts, heavy vehicles (trucks and buses) comprised about 3% and 2%, respectively, of the intersection's total entry traffic in both the AM and PM peak hours, which is considered normal. The movement from Beaver Street to Lexington Street southbound had the highest share—nearly 6% in the AM and 5% in the PM peak hours. The approach lane is relatively wide, and large trucks usually have no problem turning left unless one of the northbound vehicles stops beyond the stop line.

MBTA Massachusetts Bay Transportation Authority (MBTA) Bus Route 554 goes through the intersection about four times during each of the AM and PM peak hours; but there are no bus stops in the immediate vicinity of the intersection.

3 ISSUES AND CONCERNS

Staff met with Waltham city engineers on January 16, 2013, to discuss the study area's issues and concerns. A field reconnaissance to survey the existing facilities and observe the PM peak-period traffic conditions was performed after the meeting.

The primary concern is the high number of crashes, and their severity, at the intersection. This intersection has a higher-than-average crash rate compared with other locations in MassDOT Highway District 4. Crash data analysis identified a high proportion (nearly 30%) of left-turn crashes; and police crash reports indicate that some of these accidents have to do with drivers

FIGURE 4
Pedestrian Push Button and Signal on Lexington Street

FIGURE 5
View from Lexington Street Northbound

misinterpreting the signal indication for southbound left turns on Lexington Street.

Currently, the southbound left turns are operated in a permissive/protected mode. It is a lagging left-turn protected mode, but some drivers can mistake it as being protected at the beginning of the circular green indication. It is well known that drivers turning left on a permissive circular green indication may inadvertently mistake that indication as implying the left turn has the right of way over opposing traffic.

Another major concern is the traffic congestion in the evening peak period. During the period, traffic frequently backs up on the southbound and the westbound approaches. Field observations indicate that the southbound queues sometimes extend almost to Totten Pond Road but seldom spill through it.[4] The westbound queue is not as extensive but usually extends pass the driveway of Chapel Hill-Chauncy Hall School. The queue is usually caused by the high volume of right turns from Beaver Street under a limited storage length of about 200 feet. The right turns are currently under yield control. Intersection collision analysis (see next section) indicates that some rear-end collisions at the yield location likely are a result of traffic congestion.

Based on discussions with City engineers, staff field observations, and the available crash and traffic data, the issues and concerns for the study intersection can be summarized as:

- High number of crashes, crash rate, and severity of crashes
- High proportion of left-turn crashes
- Southbound left-turn operation and signal indication potentially confusing to drivers
- Traffic congestion in the PM peak period
- Faded crosswalk across Lexington Street, with no accessible ramps (curb cuts) at both ends
- Pedestrians crossing on Beaver Street conflicting with left-turn traffic from Lexington Street
- Pedestrian signals not accessible to blind or low-vision individuals
- Improper locations of utility poles at the intersection
- No bicycle travel accommodation on either street

[4] Lexington Street is an alternative route to Route 128. According to the City engineers, from time to time the intersection congestion is exacerbated by additional traffic, when an incident occurs on Route 128 in the vicinity.

4 CRASH DATA ANALYSIS

MPO staff collected two sets of the most recent available crash data: 1) MassDOT's Registry of Motor Vehicles (RMV) 2006–2010 crash data, and 2) crash reports for the latest four years, 2009–2012, provided by the Waltham Police Department. Table 1 summarizes the crash statistics at the intersection based on the MassDOT RMV 2006–2010 crash data. On average, approximately 18 crashes occurred at the intersection each year. About 27% of the total crashes resulted in personal injuries. Crash types consist of 42% rear-end collisions, 26% angle collisions, 11% single-vehicle collisions, 8% head-on collisions, 8% sideswipe collisions, and 5% unknown.

No crashes involved pedestrians. Three crashes involved a bicycle within in the five-year period. About 46% of the total crashes occurred during peak periods, which indicates that many of the crashes are potentially related to stop-and-go traffic conditions at the intersection.

Crash rate[5] is effective tool for examining the relative safety of a location. Based on the crash data and the turning movement counts collected recently by staff, the crash rate for this intersection was calculated as 1.34 (see Appendix A). This is much higher than the average crash rate for signalized locations in MassDOT's Highway Division District 4, which is estimated at 0.77.[6]

Based on the Waltham Police Department crash reports, MPO staff constructed a collision diagram for the intersection (see Figure 6). The diagram shows that the majority of crashes occurred on Lexington Street, with a noticeably high number of crashes involving a southbound left-turn vehicle and a northbound through vehicle. There were 11 such crashes in the past four years, with six of them causing personal injuries.

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[5] Crash rates are estimated based on crash frequency (crashes per year) and vehicle exposure (traffic volumes or miles traveled). Per MassDOT guidance, crash rates are expressed as "crashes per million entering vehicles" for intersection locations and as "crashes per million miles traveled" for roadway segments.

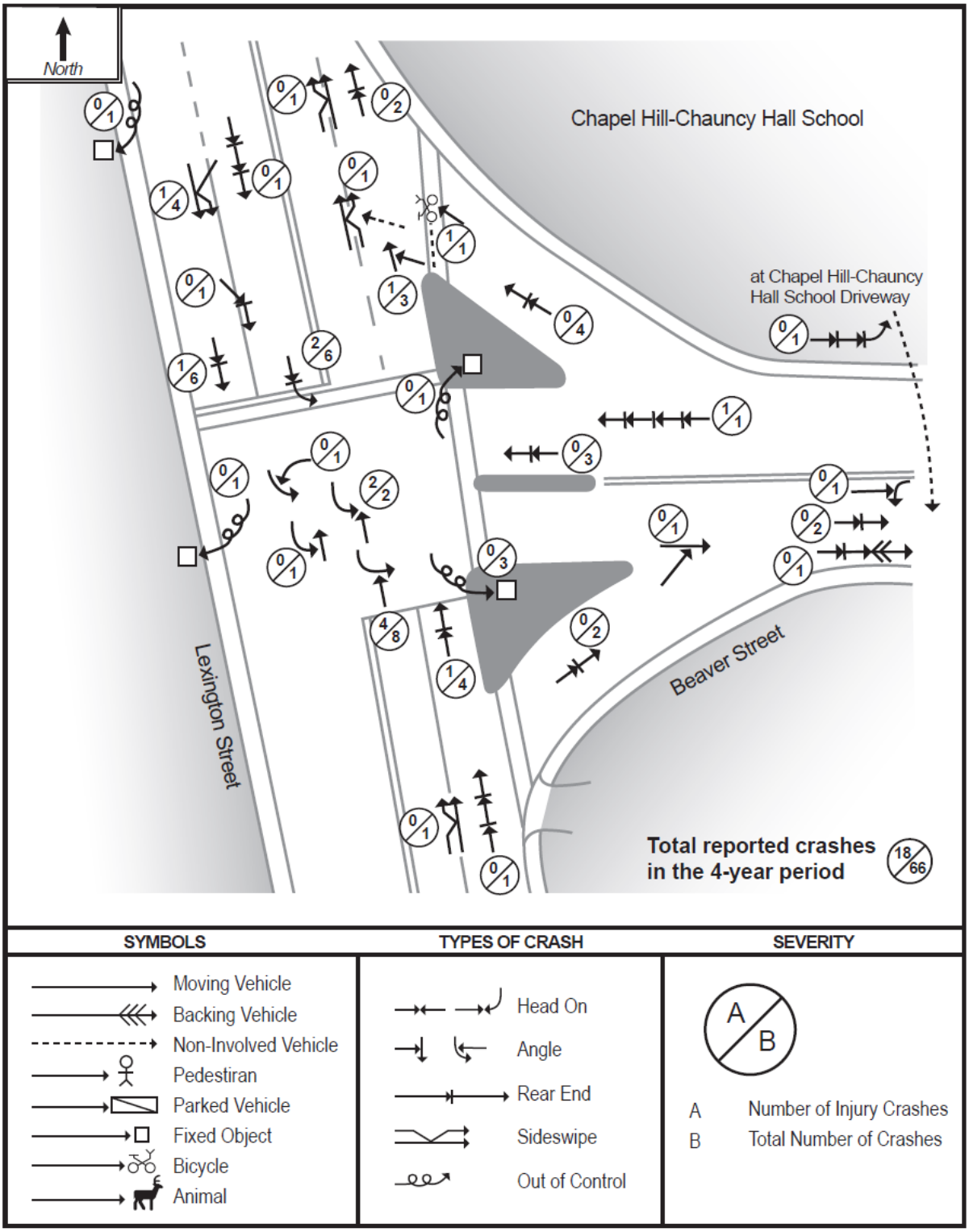
[6] The average crash rates estimated by the MassDOT Highway Division (as of January 23, 2013) are based on a database that contains intersection crash rates submitted to MassDOT as part of the review process for an Environmental Impact Report or Functional Design Report.

TABLE 1
Intersection Crash Statistics
MassDOT Crash Data 2006–10

Statistics Period	2006	2007	2008	2009	2010	5-Year Total	Annual Average
Total number of crashes	**21**	**12**	**22**	**16**	**20**	**91**	**18.2**
Crash Severity:							
Property damage only	12	9	14	7	15	57	11.4
Non-fatal injury	5	2	6	7	5	25	5.0
Fatality	0	0	0	0	0	0	0.0
Not reported/unknown	4	1	2	2	0	9	1.8
Collision type:							
Rear-end	8	2	11	7	10	38	7.6
Angle	6	6	3	6	3	24	4.8
Single vehicle	2	1	2	1	4	10	2.0
Head-on	4	0	2	0	1	7	1.4
Sideswipe	1	2	1	1	2	7	1.4
Not reported/unknown	0	1	3	1	0	5	1.0
Involved pedestrian(s)	0	0	0	0	0	0	0.0
Involved cyclist(s)	1	0	1	0	1	3	0.6
Occurred during weekday peak periods*	10	5	10	7	10	42	8.4
Wet or icy pavement conditions	11	7	10	5	4	37	7.4
Dark conditions (lit or unlit)	5	6	6	7	7	31	6.2

* Peak periods are defined as 7:00–10:00 AM and 3:30–6:30 PM.
Source: MassDOT.

FIGURE 6
Collision Diagram
Waltham Police Crash Reports 2009–12



Currently, the southbound left turns operate in a permissive/protected mode (also referred as a lagging left-turn mode), which is indicated first by a circular green ball followed by a green arrow in addition to the circular green. Drivers may mistake the circular green-only indication as being protected and proceed to enter the intersection. When traffic is congested, drivers also may behave aggressively and proceed to make risky left turns under the permissive mode. These movements could potentially cause conflicts with the northbound through movements that actually have the right-of-way priority. Police reports for crashes involving southbound left-turning vehicles did indicate these two possible causes. In addition, two of the six rear-end crashes in the southbound left-turn lane were also caused by drivers following too closely, thinking that they could proceed under the permissive mode.

The other crashes on Lexington Street are mostly rear-end collisions occurring on the northbound and southbound entry approaches, and mostly during the peak traffic periods under congested conditions. There also were a high number of angle crashes occurring on the northbound departure approach, where it is joined by the right-turn lane from Beaver Street. The right-turn lane is under yield control and carries high traffic volume during peak periods. Most of the angle crashes are caused by right-turn vehicles failing to yield to through vehicles. The congested condition is also indicated by the four rear-end collisions occurring at the yield control.

Another noticeable crash location is where three out-of-control single vehicles collided with the signal post on the south side of Beaver Street. These all occurred under snow or ice weather conditions. However, it appears that the left turn from Lexington Street is somewhat tight and there is space for an adjustment at the corner. The locations and sizes of the traffic island, the signal post, and the existing controller box should be reexamined, if the intersection is to be reconstructed.

5 INTERSECTION CAPACITY ANALYSIS

Staff collected turning movement counts at the intersection on Thursday, November 15, 2012, when the weather was cloudy and chilly with no rain. The data were recorded in 15-minute intervals during peak traffic periods in the morning, from 7:00 to 9:00 AM, and in the evening, from 4:00 to 6:00 PM.

Peak traffic hours in each of the two periods were then identified and the associated turning movements and pedestrian crossings were used for the intersection's capacity analysis.

Figure 7 shows the observed vehicular turning movement counts in the AM and PM peak hours. The intersection carried about 2,650 vehicles in the AM peak hour from 7:45 to 8:45, and about 3,350 vehicles in the PM peak hour from 5:00 to 6:00 (see Appendix B for detailed 15-minute breakdowns for passenger vehicles, various heavy vehicles, pedestrians, and bicycles in the peak periods and the peak hours).

There were three and four pedestrians, respectively, crossing the intersection (mostly across Beaver Street) during the two-hour AM and PM peak periods. There were eight and eleven bicyclists, respectively, passing through the intersection (mostly traveling on Lexington Street) during the two-hour AM and PM peak periods.

Heavy vehicles comprised about 3% of the total entry traffic in the AM peak hour and about 2% in the PM peak hour. The movement from Beaver Street to Lexington Street southbound had the highest share of heavy vehicles —nearly 6% in the AM and 5% in the PM peak hour. The percentages at individual approaches were used for the intersection capacity analysis.

Based on the collected data, the intersection was modeled as a fully actuated isolated intersection. Table 2 summarizes analysis results from Synchro[7] for existing conditions in the AM and PM peak hours. Analysis indicates that the intersection operates at acceptable level of service (LOS) C in the AM peak hour with an average delay of about 32 seconds per vehicle. In the PM peak hour, the intersection is estimated to operate at LOS E with an average delay of nearly 80 seconds per vehicle. Specifically, the southbound left-turn group is estimated to operate at LOS F with an average extensive delay of nearly two minutes. Both the right- and left-turn lane groups on Beaver Street are evaluated to operate at LOS F with an average delay of more than one minute. Detailed analysis parameters and results for the AM and PM peak hours are included in Appendix C.

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[7] Synchro Version 8 is a computer application developed and distributed by Trafficware Ltd. The software can perform capacity analysis and traffic simulation (when combined with SimTraffic) for an individual intersection or a series of intersections.

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FIGURE 7
AM/PM Peak-Hour Traffic Volumes

Safety and Operations Analyses at Selected Intersections

TABLE 2
Intersection Capacity Analysis of Existing Conditions

Street Name	Approach/Movement	LOS[1]	Delay per Vehicle
Lexington Street	NB – Through/right	C (D)	31 (55)
Lexington Street	SB – Left	D (F)	41 (159)
Lexington Street	SB – Through/right	B (B)	11 (12)
Beaver Street	WB – Left	D (F)	42 (96)
Beaver Street	WB – Right	D (F)	40 (82)
Overall		**C (E)**	**32 (77)**

[1] LOS = level of service. The LOS for the AM peak hour is the first letter. The LOS for the PM peak hour is in parentheses.

6 TRAFFIC SIGNAL IMPROVEMENT ALTERNATIVES

Using Synchro's signal optimization function, staff tested a number of traffic signal improvement alternatives with no major layout modifications considering the adjacent residential land use and the limited availability of right of way. Among the alternatives examined, three are considered feasible; they are listed below from the *least to the most expensive* improvement option:

- Alternative 1: Simply change the southbound left-turn operation from the lagging (permissive/protected) to the leading (protected/permissive) mode, with the existing signal timing setting.
- Alternative 2: Retime the traffic signal based on the Alternative 1 phasing sequence.
- Alternative 3: Install traffic signal indication for the westbound right-turn lane group and operate it in an overlapping (with the southbound protected phase)/permissive (in other signal phases) mode; retime the signal based on the same phasing sequence as in Alternatives 1 and 2.

Tables 3 and 4 summarize the capacity analyses for the proposed improvement alternatives in both the AM and PM peak hours. All the alternatives maintain the existing cycle length of 105 seconds and the concurrent pedestrian signal operations.

Alternative 1, changing the southbound left-turn from the lagging to the leading mode, would maintain about the same level of service in the AM and PM peak hours with a slight increase of one to two seconds of average delay. However, the leading left-turn phase potentially could reduce left-turn crashes somewhat.[8]

[8] The leading left-turn mode meets drivers' expectations better than the lagging mode, especially for the drivers who have been waiting for traffic light changes at the intersection.

Alternative 2, adjusting signal timing with the same sequence as Alternative 1, would maintain the same level of service and average delay as the existing conditions in both peak hours. In addition, it potentially could reduce the southbound left-turn crashes.

Alternative 3, installing signal indication for the westbound right-turn lane group and overlapping its operation with the southbound left-turn protected phase, would further reduce the average delay by five seconds in the AM peak hour and by eight seconds in the PM peak hour. Moreover, the signal potentially could reduce the angle collisions at the right-turn merging location.

Further analyses indicate that increasing the southbound left-turn lane from one to two would significantly improve the intersection's level service and reduce delays. However, the surrounding areas do not have room for such an expansion alternative.

Detailed signal timing settings and analysis results for the three proposed alternatives in the both the AM and PM peak hours are shown in Figure 8, Table 5, and Appendix D.

TABLE 3
Intersection Capacity Analysis of the Level of Service for Existing Conditions and Alternatives

		Existing Conditions	Alternative 1	Alternative 2	Alternative 3
Street Name	**Approach**	**LOS[1]**	**LOS**	**LOS**	**LOS**
Lexington Street	NB – Through/right	C (D)	C (D)	C(E)	C(E)
Lexington Street	SB – Left	D (F)	D (F)	D(F)	C(F)
Lexington Street	SB – Through/right	B (B)	B (B)	B(B)	A(B)
Beaver Street	WB – Left	D (F)	D (F)	D(E)	D(E)
Beaver Street	WB – Right	D (F)	D (E)	D(E)	C(D)
Overall		**C (E)**	**C (E)**	**C (E)**	**C(E)**

[1] LOS = level of service. The LOS for the AM peak hour is the first letter. The LOS for the PM peak hour is in parentheses.

The majority of intersections in the region, if running with a protected/permissive left-turn phase, operate in a leading mode, which generally is considered somewhat safer than a lagging mode. However, some intersections do operate left turns in a lagging mode because of the consideration of signal coordination, traffic pattern, or capacity concerns.

TABLE 4
Intersection Capacity Analysis of Delay for Existing Conditions and Alternatives

		Existing Conditions	Alternative 1	Alternative 2	Alternative 3
Street Name	**Approach**	**Delay[1]**	**Delay**	**Delay**	**Delay**
Lexington Street	NB – Through/right	31 (55)	32 (55)	35 (79)	35 (76)
Lexington Street	SB – Left	41 (159)	40 (165)	38 (154)	29 (149)
Lexington Street	SB – Through/right	11 (12)	10 (12)	10 (14)	9 (14)
Beaver Street	WB – Left	42 (96)	44 (96)	45 (73)	54 (78)
Beaver Street	WB – Right	40 (82)	43 (82)	37 (64)	26 (36)
Overall		**32 (77)**	**33 (79)**	**31 (77)**	**27 (69)**

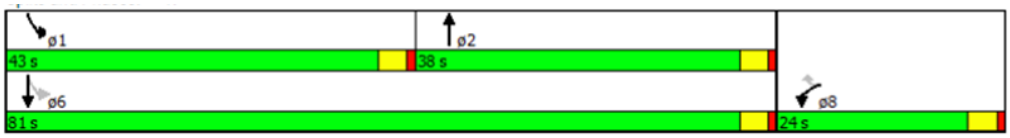
[1] The delay for the AM peak hour is the first number. The delay for the PM peak hour is in parentheses.

FIGURE 8

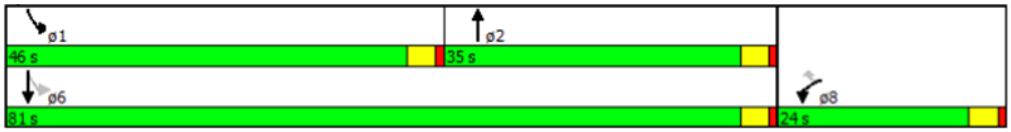
Intersection Signal Timings and Phasing for Existing Conditions and Alternatives

AM Peak Hour - Existing

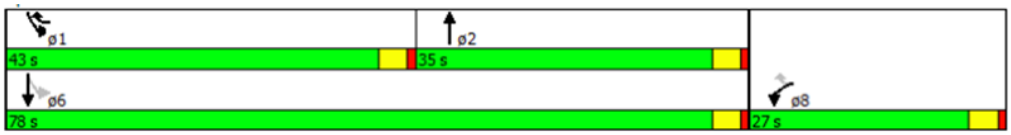
AM Peak Hour – Alternative 1



AM Peak Hour – Alternative 2

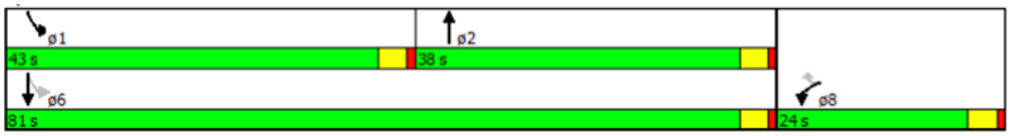


AM Peak Hour – Alternative 3

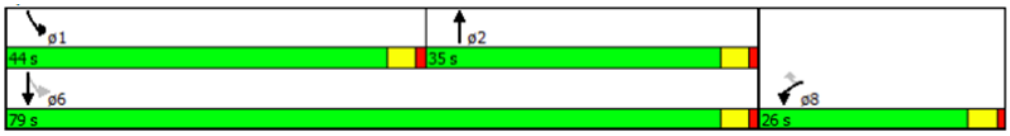


PM Peak Hour – Existing

PM Peak Hour – Alternative 1



PM Peak Hour – Alternative 2



PM Peak Hour – Alternative 3

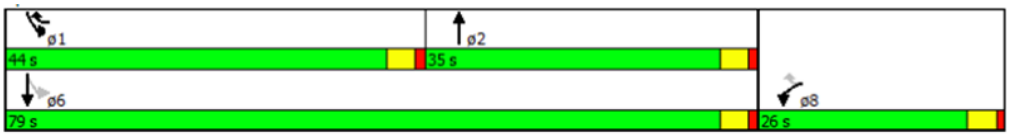


TABLE 5
Intersection Signal Phasing for
Existing Conditions and Alternatives

		Existing Conditions	Alternative 1	Alternative 2	Alternative 3
Street Name	**Approach**	**Phases**	**Phases**	**Phases**	**Phases**
Lexington Street	NB – Through/right	2	2	2	2
Lexington Street	SB – Left	1, 6	1, 6	1, 6	1, 6
Lexington Street	SB – Through/right	6	6	6	6
Beaver Street	WB – Left	8	8	8	8
Beaver Street	WB – Right	8	8	8	8

7 MODERN ROUNDABOUT ALTERNATIVE

Another improvement alternative considered for this intersection is to install a modern roundabout. This section examines if and how a modern roundabout would work at this intersection.

Synchro tests of a single-lane roundabout under the existing traffic conditions indicate that a modern roundabout would fail in both the AM and PM peak hours. In the AM peak hour, the southbound approach would operate at a volume-to-capacity (V/C) ratio of 1.07, which is more than 85% of the estimated capacity.[9] The approach would operate at an unacceptable level of service and endure extensive delays. In the PM peak hour, both the southbound and northbound approaches would operate at an unacceptable level of service. The southbound approach would endure an extremely extensive delay. Detailed analyses of individual approaches for both peak hours are shown in Appendix E.

The analysis confirms that an intersection that carries unbalanced traffic flows usually is not favorable for modern roundabout operations, especially with a high percentage of left turns.

Staff further tested another roundabout alternative with the southbound through movements and the westbound right-turn movements separated from the roundabout operation (see Appendix F for a draft diagram of the conceptual design). This alternative would operate acceptably in the AM peak hour. However, in the PM peak hour, the northbound traffic still would queue up and endure delays as the extensive southbound left-turn traffic would occupy the roundabout most of the time. In addition, this alternative would require some land takings on the west side of Lexington Street and a major land taking at the northeast corner of the intersection.

The above analysis shows that a modern roundabout is not feasible at this location.

8 IMPROVEMENT RECOMMENDATIONS

The study intersection has a high number of crashes with a large proportion of left-turn crashes and is congested during the PM peak hour. The crash data analysis indicates that the left-turn crashes likely are related to the permissive/protected left-turn operation and signal indication. The intersection

[9] For any of the approaches in a modern roundabout, a V/C ratio of 0.85 is regarded as the threshold of an acceptable level of service. All the approaches should operate under the threshold to ensure the roundabout's smooth operation.

capacity analysis indicates that the southbound left-turn and the Beaver Street left- and right-turn approaches endure extensive delays.

Staff examined the following three traffic signal improvement alternatives (cited on page 16, above):

- Alternative 1: Change the southbound left-turn operation from lagging (permissive/protected) to leading (protected/permissive) mode, with the existing signal timing setting.
- Alternative 2: Retime the traffic signal based on the Alternative 1 phasing change.
- Alternative 3: Install traffic signal indication for the westbound right-turn lane group and operate it in an overlapping (with the southbound protected phase)/permissive; retime the signal based on the same phasing sequence as Alternatives 1 and 2.

The analyses for the alternatives show that Alternative 3 could reduce the average delay by five to eight seconds in both the AM and PM peak hours. More importantly, this alternative potentially could reduce the southbound left-turn crashes and the westbound right-turn crashes.

Staff also explored the feasibility of a modern roundabout alternative. It was found to be unfavorable in terms of operations and land-taking requirements.

Hence, staff recommends a comprehensive approach to improve the intersection's safety and operations based on Alternative 3, with an upgrade of the signal system and a number of modifications within the existing intersection layout.

The signal system upgrade should include the following items:

- Install flashing left-turn yellow arrow for the southbound protected/permissive left turns.[10] Figure 9 shows the proposed position and arrangement of signal faces with flashing yellow arrows for the southbound left-turn protected/permissive operation. In addition to the overhead signal face, a supplemental signal face for the left turns should be placed on the existing pedestrian signal post.
- Install traffic signals for the westbound right turns. There should be two signal faces, one on each side of the right-turn lane, replacing the existing yield signs. Figure 10 shows the proposed three-section signal faces. It is intended that a right turn on red after stop be permitted. A right turn on red after stop sign (MUTCD[11] R10-17a) should be placed on the curb side about 50 feet before the signals.
- Modify the current traffic phase to completely shut down the southbound left turns and allow only through movements on Lexington Street when the pedestrian crossing Beaver Street is actuated.[12] This modification would eliminate the conflict between the crossing pedestrians and the southbound left turners.
- Install accessible pedestrian signals at the intersection.
- Maintain the existing emergency vehicle preemption capacity.
- Equip the system with communication capability between this and the traffic signal at the intersection of Lexington Street at Totten Pond Road/Bacon Street for future signal coordination or for being included in an adaptive traffic signal control system[13].

---

[10] For many years, engineers have had concerns that drivers turning left on a permissive circular green indication might inadvertently mistake it as the left turns having the right of way over the opposing traffic. Recent national researches assert that Flashing Yellow Arrow (FYA) is the best overall alternative to the circular green as permissive signal display for left turns. MassDOT now plans to upgrade all state highway intersections that have a separate left-turn lane under a protected/permissive left-turn phasing to incorporate FYA indication. It will be accomplished by a systematic review of such state-owned intersections.

[11] *Manual for Uniform Traffic Control Devices*, Federal Highway Administration, U.S. Department of Transportation, 2009 Edition with Revision Numbers 1 and 2 incorporated, May 2012.

[12] With the installation of the four-section FYA indication, left turns will be prohibited by the indication of a red arrow.

[13] Advanced traffic signal control technology that can adapt to serve demand by adjusting the cycle lengths, splits, and/or offsets of traffic signals in a corridor based on volume or occupancy data collected in real time.

FIGURE 9
Proposed Arrangement of Signal Faces with Flashing Yellow Arrow for the Southbound Left-Turn Protected/Permissive Operation

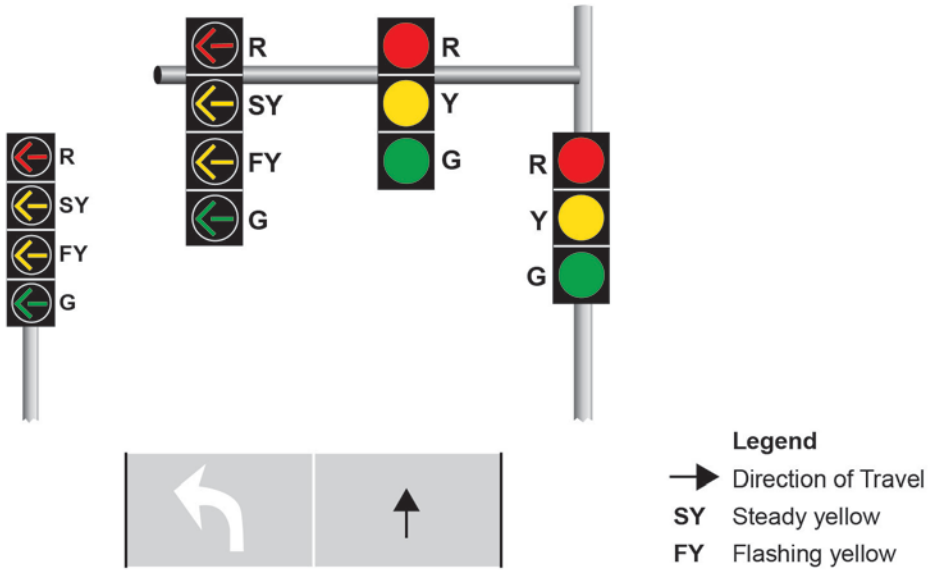
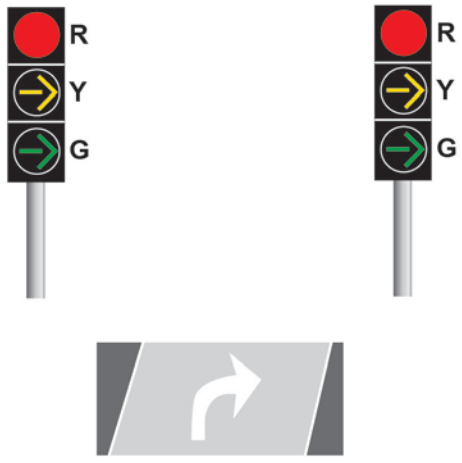


FIGURE 10
Proposed Signal Faces for the Westbound Right-Turn Operation



The intersection modifications should include the following items:

- Redesign the traffic islands on Beaver Street to better accommodate the pedestrian crossings and vehicles' turning movements without increasing the prevailing vehicle speeds. One major modification would be to move the entrance of the northbound right-turn lane about 15 to 20 feet north of the existing location (away from the utility pole) and realign the right-turn lane accordingly (by reducing the size of the adjacent traffic island). This would greatly improve the right-turning drivers' view of the crossing pedestrians and improve pedestrian safety.
- A comprehensive review of the locations of the signal control box, mast arms, the signal posts, control box, and the adjacent utility poles, fire hydrants, and other apparatus. Relocation of the signal control box and the utility pole at the southeast corner should be considered in the comprehensive plan.
- Install ADA (Americans with Disabilities Act) curb ramps at both ends of the crosswalk across Lexington Street, with detectable warning pads on the ramps.
- Install the MUTCD "turning vehicle yield to pedestrians" sign (R10-15, see Figure 11) at about 50 feet before the right-turn turnoff on Beaver Street and on Lexington Street northbound.

FIGURE 11
MUTCD Sign R10-15: Turning Vehicles Yield to Pedestrians

At this preliminary planning stage, staff estimates the total cost of the above proposed improvements at approximately $750,000 to $1,000,000. Both streets and the intersection are under the jurisdiction of the city of Waltham. The City can seek funding from the state by working closely with MassDOT Highway District 4 through a project implementation process.

In the short term, the following improvements should be considered:

- Increase the size of the two yield signs on Beaver Street (see Figure 3) to 48”x48”x48”.
- Install the MUTCD “turning vehicles yield to pedestrians” sign at the right-turn locations mentioned above.
- Consider reinstalling a larger “turning vehicles yield to pedestrians” sign on the signal post facing the southbound left-turn vehicles.[14]
- Install sharrow markings on the outside lane of Lexington Street to remind drivers to share the road with cyclists.[15]

CW/cw

[14] Staff does not have a suggestion for the format of the sign, as currently there is no MUTCD standard sign for regulating left turning vehicles yielding to pedestrians on crosswalks.

[15] A five-foot shoulder on each side of Lexington Street would be desirable for bicycle accommodation at this intersection. Its feasibility should be examined during the intersection’s functional design stage.

APPENDIX A

Intersection Crash Rate

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Waltham | COUNT DATE : 11/15/2012

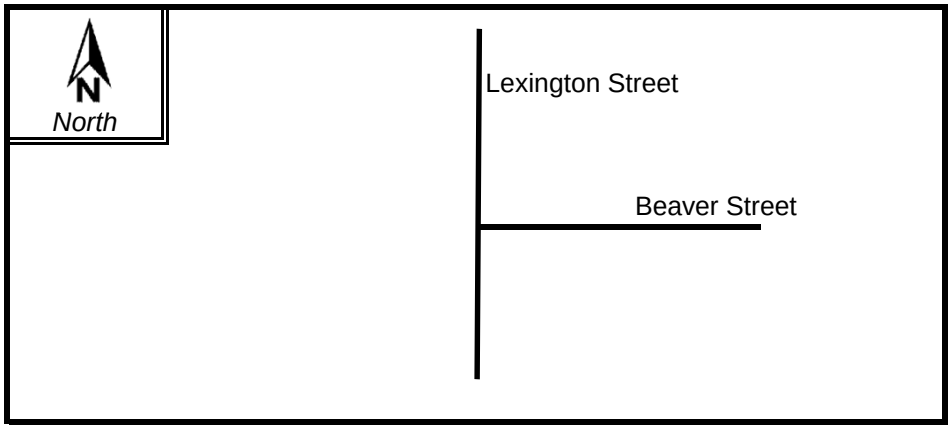
DISTRICT : 4 | UNSIGNALIZED : | SIGNALIZED : X

~ INTERSECTION DATA ~

MAJOR STREET : Lexington Street

MINOR STREET(S) : Beaver Street

INTERSECTION DIAGRAM (Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	NB	SB	EB	WB		
PEAK HOURLY VOLUMES (AM/**PM**) :	809	1,493		1,052		**3,354**

" K " FACTOR : **0.090**

INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **37,267**

TOTAL # OF CRASHES : 91

OF YEARS : 5

AVERAGE # OF CRASHES PER YEAR (**A**) : **18.20**

CRASH RATE CALCULATION : **1.34**

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

Comments : District 4 Signalized Ave = 0.77 crashes per million entering vehilces

Project Title & Date: Safety and Operations Analyses at Selected Intersections - Waltham

APPENDIX B

Intersection Traffic, Pedestrian, and Bicycle Counts
November 15, 2012

Lexington Street at Beaver Street, Waltham

Start Date: 11/15/2012
Start Time: 7:00:00 AM
Site Code: 11151211

AM Peak Period
All Vehicles

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
07:00 AM	0	102	46	0	0	111	104	0	0	1	0	0	0	0	0	21	0	103	0	0	**487**
07:15 AM	0	107	64	0	0	136	137	0	0	0	0	0	0	0	0	40	0	150	1	1	**634**
07:30 AM	0	99	50	0	0	131	165	0	0	1	0	0	0	0	0	41	0	153	1	0	**639**
07:45 AM	0	112	53	0	1	115	130	0	0	0	0	0	0	0	0	49	0	180	0	2	**639**
08:00 AM	0	81	62	0	0	107	147	0	0	0	0	0	0	0	0	58	0	193	0	0	**648**
08:15 AM	0	73	62	0	2	128	167	0	0	1	0	0	0	0	0	54	0	205	0	1	**689**
08:30 AM	0	85	59	1	0	142	142	0	0	0	0	0	0	0	0	47	0	214	0	0	**689**
08:45 AM	0	82	46	0	0	118	124	0	0	0	0	0	0	0	0	53	0	198	0	1	**621**
Total:	**0**	**741**	**442**	**1**	**3**	**988**	**1116**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**363**	**0**	**1396**	**2**	**5**	**5046**

AM Peak Period
Cars

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
07:00 AM	0	92	42	0	0	109	99	0	0	1	0	0	0	0	0	19	0	99	0	0	**460**
07:15 AM	0	93	62	0	0	134	129	0	0	0	0	0	0	0	0	38	0	144	1	1	**600**
07:30 AM	0	89	48	0	0	127	160	0	0	1	0	0	0	0	0	40	0	147	1	0	**611**
07:45 AM	0	108	48	0	1	113	125	0	0	0	0	0	0	0	0	46	0	177	0	2	**617**
08:00 AM	0	76	61	0	0	102	142	0	0	0	0	0	0	0	0	53	0	191	0	0	**625**
08:15 AM	0	70	59	0	2	126	161	0	0	1	0	0	0	0	0	52	0	204	0	1	**672**
08:30 AM	0	83	57	1	0	140	132	0	0	0	0	0	0	0	0	44	0	209	0	0	**665**
08:45 AM	0	76	41	0	0	113	116	0	0	0	0	0	0	0	0	50	0	194	0	1	**590**
Total:	**0**	**687**	**418**	**1**	**3**	**964**	**1064**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**342**	**0**	**1365**	**2**	**5**	**4840**

AM Peak Period
MBTA Buses

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
07:00 AM	0	0	0		0	0	0	0		0	0	0	0		0	1	0	0		0	**1**
07:15 AM	0	0	1		0	0	1	0		0	0	0	0		0	0	0	0		0	**2**
07:30 AM	0	0	0		0	0	0	0		0	0	0	0		0	1	0	0		0	**1**
07:45 AM	0	0	0		0	0	0	0		0	0	0	0		0	0	0	1		0	**1**
08:00 AM	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	**0**
08:15 AM	0	0	0		0	0	0	0		0	0	0	0		0	1	0	0		0	**1**
08:30 AM	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	**0**
08:45 AM	0	0	1		0	0	1	0		0	0	0	0		0	0	0	0		0	**2**
Total:	**0**	**0**	**2**		**0**	**0**	**2**	**0**		**0**	**0**	**0**	**0**		**0**	**3**	**0**	**1**		**0**	**8**

AM Peak Period
Trucks

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
07:00 AM	0	10	4		0	2	5	0		0	0	0	0		0	1	0	2		0	**24**
07:15 AM	0	14	1		0	2	5	0		0	0	0	0		0	2	0	4		0	**28**
07:30 AM	0	10	2		0	4	3	0		0	0	0	0		0	0	0	5		0	**24**
07:45 AM	0	4	5		0	2	5	0		0	0	0	0		0	3	0	2		0	**21**
08:00 AM	0	5	1		0	4	4	0		0	0	0	0		0	5	0	1		0	**20**
08:15 AM	0	3	3		0	1	6	0		0	0	0	0		0	1	0	1		0	**15**
08:30 AM	0	2	2		0	2	8	0		0	0	0	0		0	3	0	5		0	**22**
08:45 AM	0	6	3		0	5	5	0		0	0	0	0		0	3	0	2		0	**24**
Total:	**0**	**54**	**21**		**0**	**22**	**41**	**0**		**0**	**0**	**0**	**0**		**0**	**18**	**0**	**22**		**0**	**178**

AM Peak Period
Large Trucks (Freight)

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
07:00 AM	0	0	0		0	0	0	0		0	0	0	0		0	0	0	2		0	**2**
07:15 AM	0	0	0		0	0	2	0		0	0	0	0		0	0	0	2		0	**4**
07:30 AM	0	0	0		0	0	2	0		0	0	0	0		0	0	0	1		0	**3**
07:45 AM	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	**0**
08:00 AM	0	0	0		0	1	1	0		0	0	0	0		0	0	0	1		0	**3**
08:15 AM	0	0	0		0	1	0	0		0	0	0	0		0	0	0	0		0	**1**
08:30 AM	0	0	0		0	0	2	0		0	0	0	0		0	0	0	0		0	**2**
08:45 AM	0	0	1		0	0	2	0		0	0	0	0		0	0	0	2		0	**5**
Total:	**0**	**0**	**1**		**0**	**2**	**9**	**0**		**0**	**0**	**0**	**0**		**0**	**0**	**0**	**8**		**0**	**20**

Lexington Street at Beaver Street, WalthPM

Start Date: 11/15/2012
Start Time: 4:00:00 PM
Site Code: 11151211

PM Peak Period
All Vehicles

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
4:00 PM	0	151	41	0	0	137	149	0	0	1	0	0	0	0	0	55	0	147	1	0	680
4:15 PM	0	140	48	0	0	159	152	0	0	0	0	0	0	0	0	61	0	157	2	0	717
4:30 PM	0	163	48	0	2	172	155	0	0	1	0	0	0	0	0	41	0	171	1	0	750
4:45 PM	0	131	74	0	0	180	152	0	0	0	0	0	0	0	0	58	0	147	0	0	742
5:00 PM	0	129	56	0	0	173	173	0	0	0	0	0	0	0	0	49	0	199	0	0	779
5:15 PM	0	162	57	0	1	189	165	0	0	0	0	0	0	0	0	73	0	216	0	0	862
5:30 PM	0	140	73	0	0	185	214	0	0	1	0	0	0	0	0	66	0	201	0	0	879
5:45 PM	0	131	61	0	2	207	187	0	0	0	0	0	0	0	0	61	0	187	0	0	834
Total:	0	1147	458	0	5	1402	1347	0	0	3	0	0	0	0	0	464	0	1425	4	0	6243

PM Peak Period
Cars

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
4:00 PM	0	141	35	0	0	134	141	0	0	1	0	0	0	0	0	52	0	141	1	0	644
4:15 PM	0	123	45	0	0	157	148	0	0	0	0	0	0	0	0	56	0	156	2	0	685
4:30 PM	0	150	45	0	2	171	149	0	0	1	0	0	0	0	0	41	0	167	1	0	723
4:45 PM	0	123	69	0	0	180	152	0	0	0	0	0	0	0	0	54	0	142	0	0	720
5:00 PM	0	120	55	0	0	171	170	0	0	0	0	0	0	0	0	43	0	197	0	0	756
5:15 PM	0	156	53	0	1	188	164	0	0	0	0	0	0	0	0	71	0	216	0	0	848
5:30 PM	0	136	70	0	0	183	206	0	0	1	0	0	0	0	0	63	0	200	0	0	858
5:45 PM	0	125	58	0	2	206	187	0	0	0	0	0	0	0	0	58	0	186	0	0	820
Total:	0	1074	430	0	5	1390	1317	0	0	3	0	0	0	0	0	438	0	1405	4	0	6054

PM Peak Period
MBTA Buses

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
4:00 PM	0	0	2		0	0	0	0		0	0	0	0		0	2	0	0		0	4
4:15 PM	0	2	1		0	0	0	0		0	0	0	0		0	2	0	0		0	5
4:30 PM	0	2	1		0	0	0	0		0	0	0	0		0	0	0	0		0	3
4:45 PM	0	3	0		0	0	0	0		0	0	0	0		0	1	0	0		0	4
5:00 PM	0	2	0		0	0	0	0		0	0	0	0		0	1	0	0		0	3
5:15 PM	0	2	1		0	0	0	0		0	0	0	0		0	0	0	0		0	3
5:30 PM	0	1	0		0	0	0	0		0	0	0	0		0	0	0	0		0	1
5:45 PM	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	0
Total:	0	12	5		0	0	0	0		0	0	0	0		0	6	0	0		0	23

PM Peak Period
Trucks

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
4:00 PM	0	10	4		0	2	7	0		0	0	0	0		0	1	0	5		0	29
4:15 PM	0	14	1		0	2	3	0		0	0	0	0		0	2	0	1		0	23
4:30 PM	0	10	2		0	1	5	0		0	0	0	0		0	0	0	3		0	21
4:45 PM	0	4	5		0	0	0	0		0	0	0	0		0	3	0	5		0	17
5:00 PM	0	5	1		0	2	3	0		0	0	0	0		0	5	0	2		0	18
5:15 PM	0	3	3		0	1	0	0		0	0	0	0		0	1	0	0		0	8
5:30 PM	0	2	2		0	2	6	0		0	0	0	0		0	3	0	1		0	16
5:45 PM	0	6	3		0	1	0	0		0	0	0	0		0	3	0	1		0	14
Total:	0	54	21		0	11	24	0		0	0	0	0		0	18	0	18		0	146

PM Peak Period
Large Trucks (Freight)

	Lexington Street Northbound					Lexington Street Southbound										Beaver Street Westbound					
Start Time	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Left	Thru	Right	Peds	Bikes	Vehicle Total
4:00 PM	0	0	0		0	1	1	0		0	0	0	0		0	0	0	1		0	3
4:15 PM	0	1	1		0	0	1	0		0	0	0	0		0	1	0	0		0	4
4:30 PM	0	1	0		0	0	1	0		0	0	0	0		0	0	0	1		0	3
4:45 PM	0	1	0		0	0	0	0		0	0	0	0		0	0	0	0		0	1
5:00 PM	0	2	0		0	0	0	0		0	0	0	0		0	0	0	0		0	2
5:15 PM	0	1	0		0	0	1	0		0	0	0	0		0	1	0	0		0	3
5:30 PM	0	1	1		0	0	2	0		0	0	0	0		0	0	0	0		0	4
5:45 PM	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		0	0
Total:	0	7	2		0	1	6	0		0	0	0	0		0	2	0	2		0	20

Lexington Street at Beaver Street, Waltham

Start Date: 11/15/2012
Start Time: 7:00:00 AM
Site Code: 11151211

AM Peak Hour
All Vehicles

	Lexington Street Northbound				Lexington Street Southbound								Beaver Street Westbound				
Start Time	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Vehicle Total
07:45 AM	0	112	53	0	115	130	0	0	0	0	0	0	49	0	180	0	**639**
08:00 AM	0	81	62	0	107	147	0	0	0	0	0	0	58	0	193	0	**648**
08:15 AM	0	73	62	0	128	167	0	0	0	0	0	0	54	0	205	0	**689**
08:30 AM	0	85	59	1	142	142	0	0	0	0	0	0	47	0	214	0	**689**
Total:	**0**	**351**	**236**	**1**	**492**	**586**	**0**	**0**	**0**	**0**	**0**	**0**	**208**	**0**	**792**	**0**	**2665**
PHF:		**0.78**	**0.95**		**0.87**	**0.88**							**0.90**		**0.93**		**0.97**
Truck%:		**3.99%**	**4.66%**		**2.24%**	**4.44%**							**5.77%**		**1.26%**		**3.15%**

AM Peak Period
All Vehicles

	Lexington Street Northbound				Lexington Street Southbound								Beaver Street Westbound				
Start Time	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Vehicle Total
07:00 AM	0	102	46	0	111	104	0	0	0	0	0	0	21	0	103	0	**487**
07:15 AM	0	107	64	0	136	137	0	0	0	0	0	0	40	0	150	1	**634**
07:30 AM	0	99	50	0	131	165	0	0	0	0	0	0	41	0	153	1	**639**
07:45 AM	0	112	53	0	115	130	0	0	0	0	0	0	49	0	180	0	**639**
08:00 AM	0	81	62	0	107	147	0	0	0	0	0	0	58	0	193	0	**648**
08:15 AM	0	73	62	0	128	167	0	0	0	0	0	0	54	0	205	0	**689**
08:30 AM	0	85	59	1	142	142	0	0	0	0	0	0	47	0	214	0	**689**
08:45 AM	0	82	46	0	118	124	0	0	0	0	0	0	53	0	198	0	**621**
Total:	**0**	**741**	**442**	**1**	**988**	**1116**	**0**	**0**	**0**	**0**	**0**	**0**	**363**	**0**	**1396**	**2**	**5046**

Lexington Street at Beaver Street, Waltham

Start Date: 11/15/2013
Start Time: 4:00:00 PM
Site Code: 11151211

PM Peak Hour
All Vehicles

	Lexington Street Northbound				Lexington Street Southbound								Beaver Street Westbound				
Start Time	**Left**	**Thru**	**Right**	**Peds**	**Left**	**Thru**	**Right**	**Peds**	**Left**	**Thru**	**Right**	**Peds**	**Left**	**Thru**	**Right**	**Peds**	**Vehicle Total**
5:00 PM	0	129	56	0	173	173	0	0	0	0	0	0	49	0	199	0	**779**
5:15 PM	0	162	57	0	189	165	0	0	0	0	0	0	73	0	216	0	**862**
5:30 PM	0	140	73	0	185	214	0	0	0	0	0	0	66	0	201	0	**879**
5:45 PM	0	131	61	0	207	187	0	0	0	0	0	0	61	0	187	0	**834**
Total:	**0**	**562**	**247**	**0**	**754**	**739**	**0**	**0**	**0**	**0**	**0**	**0**	**249**	**0**	**803**	**0**	**3354**
PHF:		**0.87**	**0.85**		**0.91**	**0.86**							**0.85**		**0.93**		**0.95**
Truck%:		**3.56%**	**4.05%**		**0.80%**	**1.62%**							**5.22%**		**0.50%**		**1.94%**

PM Peak Period
All Vehicles

	Lexington Street Northbound				Lexington Street Southbound								Beaver Street Westbound				
Start Time	**Left**	**Thru**	**Right**	**Peds**	**Left**	**Thru**	**Right**	**Peds**	**Left**	**Thru**	**Right**	**Peds**	**Left**	**Thru**	**Right**	**Peds**	**Vehicle Total**
4:00 PM	0	151	41	0	137	149	0	0	0	0	0	0	55	0	147	1	**680**
4:15 PM	0	140	48	0	159	152	0	0	0	0	0	0	61	0	157	2	**717**
4:30 PM	0	163	48	0	172	155	0	0	0	0	0	0	41	0	171	1	**750**
4:45 PM	0	131	74	0	180	152	0	0	0	0	0	0	58	0	147	0	**742**
5:00 PM	0	129	56	0	173	173	0	0	0	0	0	0	49	0	199	0	**779**
5:15 PM	0	162	57	0	189	165	0	0	0	0	0	0	73	0	216	0	**862**
5:30 PM	0	140	73	0	185	214	0	0	0	0	0	0	66	0	201	0	**879**
5:45 PM	0	131	61	0	207	187	0	0	0	0	0	0	61	0	187	0	**834**
Total:	**0**	**1147**	**458**	**0**	**1402**	**1347**	**0**	**0**	**0**	**0**	**0**	**0**	**464**	**0**	**1425**	**4**	**6243**

APPENDIX C

AM/PM Peak-Hour Intersection Capacity Analysis
Existing Conditions

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Volume (vph)	208	792	351	236	492	586
Satd. Flow (prot)	1533	1439	2822	0	1555	1605
Flt Permitted	0.950				0.231	
Satd. Flow (perm)	1533	1439	2822	0	378	1605
Satd. Flow (RTOR)		665	106			
Confl. Peds. (#/hr)						
Confl. Bikes (#/hr)						
Peak Hour Factor	0.90	0.93	0.78	0.95	0.87	0.88
Growth Factor	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	6%	1%	4%	5%	2%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0
Parking (#/hr)						
Mid-Block Traffic (%)	0%		0%			0%
Shared Lane Traffic (%)						
Lane Group Flow (vph)	231	852	698	0	566	666
Turn Type	NA	Perm	NA		pm+pt	NA
Protected Phases	8		2		1	6
Permitted Phases		8			6	
Detector Phase	8	8	2		1	6
Switch Phase						
Minimum Initial (s)	3.0	3.0	8.0		2.0	8.0
Minimum Split (s)	21.0	21.0	21.0		6.0	21.0
Total Split (s)	24.0	24.0	38.0		43.0	81.0
Total Split (%)	22.9%	22.9%	36.2%		41.0%	77.1%
Yellow Time (s)	3.0	3.0	3.0		3.0	3.0
All-Red Time (s)	1.0	1.0	1.0		1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0		0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0		4.0	4.0
Lead/Lag			Lead		Lag	
Lead-Lag Optimize?			Yes		Yes	
Recall Mode	None	None	Min		None	Min
Act Effct Green (s)	20.8	20.8	24.6		56.0	56.0
Actuated g/C Ratio	0.24	0.24	0.29		0.66	0.66
v/c Ratio	0.62	1.00	0.78		0.90	0.63
Control Delay	41.9	40.9	30.9		40.9	10.8
Queue Delay	0.0	0.0	0.0		0.0	0.0
Total Delay	41.9	40.9	30.9		40.9	10.8
LOS	D	D	C		D	B
Approach Delay	41.1		30.9			24.6
Approach LOS	D		C			C
Queue Length 50th (ft)	112	~130	152		196	174
Queue Length 95th (ft)	#271	#475	202		340	247
Internal Link Dist (ft)	1210		835			1100
Turn Bay Length (ft)		300				
Base Capacity (vph)	374	853	1232		867	1414
Starvation Cap Reductn	0	0	0		0	0
Spillback Cap Reductn	0	0	0		0	0
Storage Cap Reductn	0	0	0		0	0

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Reduced v/c Ratio	0.62	1.00	0.57		0.65	0.47

Intersection Summary		
Cycle Length: 105		
Actuated Cycle Length: 85.1		
Natural Cycle: 75		
Control Type: Actuated-Uncoordinated		
Maximum v/c Ratio: 1.00		
Intersection Signal Delay: 32.0	Intersection LOS: C	
Intersection Capacity Utilization 80.3%	ICU Level of Service D	
Analysis Period (min) 15		

~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1:

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Volume (vph)	249	803	562	247	754	739
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	11	11	11	11
Grade (%)	0%		2%			-2%
Storage Length (ft)	0	300		0	0	
Storage Lanes	1	1		0	1	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	0.95	0.95	1.00	1.00
Frt		0.850	0.953			
Flt Protected	0.950				0.950	
Satd. Flow (prot)	1547	1439	2849	0	1570	1637
Flt Permitted	0.950				0.122	
Satd. Flow (perm)	1547	1439	2849	0	202	1637
Right Turn on Red		Yes		Yes		
Satd. Flow (RTOR)		618	73			
Link Speed (mph)	30		30			30
Link Distance (ft)	1290		915			1180
Travel Time (s)	29.3		20.8			26.8
Peak Hour Factor	0.85	0.93	0.87	0.85	0.91	0.86
Heavy Vehicles (%)	5%	1%	4%	4%	1%	2%
Adj. Flow (vph)	293	863	646	291	829	859
Shared Lane Traffic (%)						
Lane Group Flow (vph)	293	863	937	0	829	859
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		23			23
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.14	1.14	1.21	1.21	1.18	1.18
Turning Speed (mph)	15	9		9	15	
Turn Type	NA	Perm	NA		pm+pt	NA
Protected Phases	8		2		1	6
Permitted Phases		8			6	
Detector Phase	8	8	2		1	6
Switch Phase						
Minimum Initial (s)	3.0	3.0	8.0		2.0	8.0
Minimum Split (s)	21.0	21.0	21.0		6.0	21.0
Total Split (s)	24.0	24.0	38.0		43.0	81.0
Total Split (%)	22.9%	22.9%	36.2%		41.0%	77.1%
Maximum Green (s)	20.0	20.0	34.0		39.0	77.0
Yellow Time (s)	3.0	3.0	3.0		3.0	3.0
All-Red Time (s)	1.0	1.0	1.0		1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0		0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0		4.0	4.0
Lead/Lag			Lead		Lag	
Lead-Lag Optimize?			Yes		Yes	
Vehicle Extension (s)	2.0	2.0	3.0		3.0	3.0

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Recall Mode	None	None	Min		None	Min
Walk Time (s)	7.0	7.0	7.0			7.0
Flash Dont Walk (s)	10.0	10.0	10.0			10.0
Pedestrian Calls (#/hr)	0	0	0			0
Act Effct Green (s)	20.0	20.0	34.0		77.0	77.0
Actuated g/C Ratio	0.19	0.19	0.32		0.73	0.73
v/c Ratio	1.00	1.11	0.96		1.26	0.72
Control Delay	95.5	81.6	54.5		158.6	12.1
Queue Delay	0.0	0.0	0.0		0.0	0.0
Total Delay	95.5	81.6	54.5		158.6	12.1
LOS	F	F	D		F	B
Approach Delay	85.1		54.5			84.0
Approach LOS	F		D			F
Queue Length 50th (ft)	198	~305	303		~654	277
Queue Length 95th (ft)	#339	#546	#415		#892	374
Internal Link Dist (ft)	1210		835			1100
Turn Bay Length (ft)		300				
Base Capacity (vph)	294	774	971		656	1200
Starvation Cap Reductn	0	0	0		0	0
Spillback Cap Reductn	0	0	0		0	0
Storage Cap Reductn	0	0	0		0	0
Reduced v/c Ratio	1.00	1.11	0.96		1.26	0.72

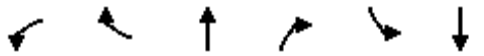
Intersection Summary

Area Type: CBD
Cycle Length: 105
Actuated Cycle Length: 105
Natural Cycle: 120
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 1.26
Intersection Signal Delay: 77.1 Intersection LOS: E
Intersection Capacity Utilization 97.8% ICU Level of Service F
Analysis Period (min) 15
~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1:

APPENDIX D

AM/PM Peak-Hour Intersection Capacity Analysis
Traffic Signal Improvement Alternatives



Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Volume (vph)	208	792	351	236	492	586
Peak Hour Factor	0.90	0.93	0.78	0.95	0.87	0.88
Heavy Vehicles (%)	6%	1%	4%	5%	2%	4%
Shared Lane Traffic (%)						
Lane Group Flow (vph)	231	852	698	0	566	666
Turn Type	NA	Perm	NA		pm+pt	NA
Protected Phases	8		2		1	6
Permitted Phases		8			6	
Detector Phase	8	8	2		1	6
Switch Phase						
Minimum Initial (s)	3.0	3.0	8.0		2.0	8.0
Minimum Split (s)	21.0	21.0	21.0		6.0	21.0
Total Split (s)	24.0	24.0	38.0		43.0	81.0
Total Split (%)	22.9%	22.9%	36.2%		41.0%	77.1%
Yellow Time (s)	3.0	3.0	3.0		3.0	3.0
All-Red Time (s)	1.0	1.0	1.0		1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0		0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0		4.0	4.0
Lead/Lag			Lag		Lead	
Lead-Lag Optimize?			Yes		Yes	
Recall Mode	None	None	Min		None	Min
Act Effct Green (s)	20.7	20.7	25.2		58.8	58.8
Actuated g/C Ratio	0.24	0.24	0.29		0.67	0.67
v/c Ratio	0.64	1.01	0.79		0.92	0.62
Control Delay	44.2	42.9	31.9		39.6	10.4
Queue Delay	0.0	0.0	0.0		0.0	0.0
Total Delay	44.2	42.9	31.9		39.6	10.4
LOS	D	D	C		D	B
Approach Delay	43.2		31.9			23.8
Approach LOS	D		C			C
Queue Length 50th (ft)	119	~154	161		227	174
Queue Length 95th (ft)	#271	#475	202		#396	247
Internal Link Dist (ft)	1210		835			1100
Turn Bay Length (ft)		300				
Base Capacity (vph)	361	847	1194		777	1393
Starvation Cap Reductn	0	0	0		0	0
Spillback Cap Reductn	0	0	0		0	0
Storage Cap Reductn	0	0	0		0	0
Reduced v/c Ratio	0.64	1.01	0.58		0.73	0.48

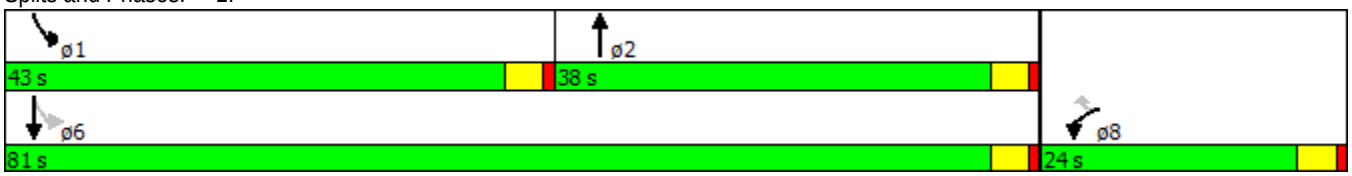
Intersection Summary	
Cycle Length: 105	
Actuated Cycle Length: 87.8	
Natural Cycle: 75	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.01	
Intersection Signal Delay: 32.7	Intersection LOS: C
Intersection Capacity Utilization 80.3%	ICU Level of Service D

Analysis Period (min) 15

~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1:



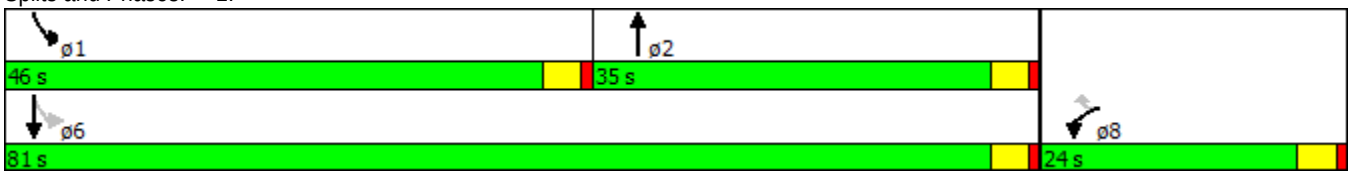
Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Volume (vph)	208	792	351	236	492	586
Confl. Peds. (#/hr)						
Confl. Bikes (#/hr)						
Peak Hour Factor	0.90	0.93	0.78	0.95	0.87	0.88
Growth Factor	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	6%	1%	4%	5%	2%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0
Parking (#/hr)						
Mid-Block Traffic (%)	0%		0%			0%
Shared Lane Traffic (%)						
Lane Group Flow (vph)	231	852	698	0	566	666
Turn Type	NA	Perm	NA		pm+pt	NA
Protected Phases	8		2		1	6
Permitted Phases		8			6	
Detector Phase	8	8	2		1	6
Switch Phase						
Minimum Initial (s)	3.0	3.0	8.0		2.0	8.0
Minimum Split (s)	21.0	21.0	21.0		6.0	21.0
Total Split (s)	24.0	24.0	35.0		46.0	81.0
Total Split (%)	22.9%	22.9%	33.3%		43.8%	77.1%
Yellow Time (s)	3.0	3.0	3.0		3.0	3.0
All-Red Time (s)	1.0	1.0	1.0		1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0		0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0		4.0	4.0
Lead/Lag			Lag		Lead	
Lead-Lag Optimize?			Yes		Yes	
Recall Mode	None	None	Min		None	Min
Act Effct Green (s)	20.7	20.7	24.6		59.3	59.3
Actuated g/C Ratio	0.23	0.23	0.28		0.67	0.67
v/c Ratio	0.64	0.98	0.81		0.90	0.62
Control Delay	44.5	36.7	34.5		37.2	10.3
Queue Delay	0.0	0.0	0.0		0.0	0.0
Total Delay	44.5	36.7	34.5		37.2	10.3
LOS	D	D	C		D	B
Approach Delay	38.4		34.5			22.7
Approach LOS	D		C			C
Queue Length 50th (ft)	122	108	165		232	174
Queue Length 95th (ft)	#271	#445	213		373	247
Internal Link Dist (ft)	1210		835			1100
Turn Bay Length (ft)		300				
Base Capacity (vph)	359	865	1088		818	1388
Starvation Cap Reductn	0	0	0		0	0
Spillback Cap Reductn	0	0	0		0	0
Storage Cap Reductn	0	0	0		0	0
Reduced v/c Ratio	0.64	0.98	0.64		0.69	0.48

Intersection Summary
Cycle Length: 105

Actuated Cycle Length: 88.2	
Natural Cycle: 75	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.98	
Intersection Signal Delay: 31.1	Intersection LOS: C
Intersection Capacity Utilization 80.3%	ICU Level of Service D
Analysis Period (min) 15	

\# 95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1:



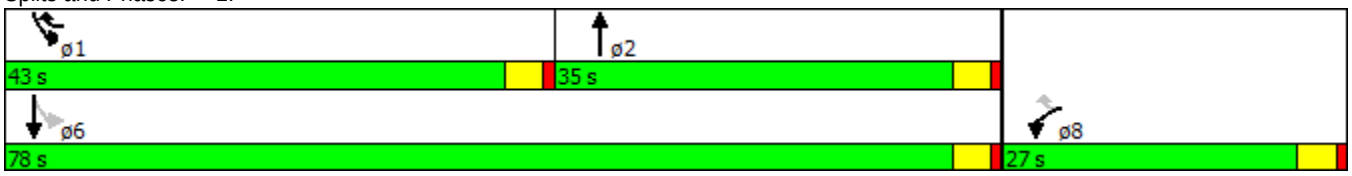
Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Volume (vph)	208	792	351	236	492	586
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	11	11	11	11
Grade (%)	0%		2%			-2%
Storage Length (ft)	0	300		0	0	
Storage Lanes	1	1		0	1	
Taper Length (ft)	25				25	
Satd. Flow (prot)	1533	1439	2822	0	1555	1605
Flt Permitted	0.950				0.170	
Satd. Flow (perm)	1533	1439	2822	0	278	1605
Right Turn on Red		Yes		Yes		
Satd. Flow (RTOR)		147	101			
Link Speed (mph)	30		30			30
Link Distance (ft)	1290		915			1180
Travel Time (s)	29.3		20.8			26.8
Peak Hour Factor	0.90	0.93	0.78	0.95	0.87	0.88
Heavy Vehicles (%)	6%	1%	4%	5%	2%	4%
Shared Lane Traffic (%)						
Lane Group Flow (vph)	231	852	698	0	566	666
Turn Type	NA	pm+ov	NA		pm+pt	NA
Protected Phases	8	1	2		1	6
Permitted Phases		8			6	
Detector Phase	8	1	2		1	6
Switch Phase						
Minimum Initial (s)	3.0	2.0	8.0		2.0	8.0
Minimum Split (s)	21.0	6.0	21.0		6.0	21.0
Total Split (s)	27.0	43.0	35.0		43.0	78.0
Total Split (%)	25.7%	41.0%	33.3%		41.0%	74.3%
Yellow Time (s)	3.0	3.0	3.0		3.0	3.0
All-Red Time (s)	1.0	1.0	1.0		1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0		0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0		4.0	4.0
Lead/Lag		Lead	Lag		Lead	
Lead-Lag Optimize?		Yes	Yes		Yes	
Recall Mode	None	None	Min		None	Min
Act Effct Green (s)	17.4	55.6	24.9		63.1	63.1
Actuated g/C Ratio	0.20	0.62	0.28		0.71	0.71
v/c Ratio	0.77	0.89	0.81		0.83	0.59
Control Delay	54.3	26.1	34.8		29.4	9.4
Queue Delay	0.0	0.0	0.0		0.0	0.0
Total Delay	54.3	26.1	34.8		29.4	9.4
LOS	D	C	C		C	A
Approach Delay	32.1		34.8			18.6
Approach LOS	C		C			B
Queue Length 50th (ft)	138	346	183		232	169
Queue Length 95th (ft)	#233	#720	213		#434	280
Internal Link Dist (ft)	1210		835			1100
Turn Bay Length (ft)		300				

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Base Capacity (vph)	418	1059	1103		788	1312
Starvation Cap Reductn	0	0	0		0	0
Spillback Cap Reductn	0	0	0		0	0
Storage Cap Reductn	0	0	0		0	0
Reduced v/c Ratio	0.55	0.80	0.63		0.72	0.51

Intersection Summary			
Area Type:	CBD		
Cycle Length: 105			
Actuated Cycle Length: 89			
Natural Cycle: 80			
Control Type: Actuated-Uncoordinated			
Maximum v/c Ratio: 0.89			
Intersection Signal Delay: 27.2		Intersection LOS: C	
Intersection Capacity Utilization 80.3%		ICU Level of Service D	
Analysis Period (min) 15			

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1:



Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Volume (vph)	249	803	562	247	754	739
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	11	11	11	11
Grade (%)	0%		2%			-2%
Storage Length (ft)	0	300		0	0	
Storage Lanes	1	1		0	1	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	0.95	0.95	1.00	1.00
Frt		0.850	0.953			
Flt Protected	0.950				0.950	
Satd. Flow (prot)	1547	1439	2849	0	1570	1637
Flt Permitted	0.950				0.105	
Satd. Flow (perm)	1547	1439	2849	0	174	1637
Right Turn on Red		Yes		Yes		
Satd. Flow (RTOR)		618	73			
Link Speed (mph)	30		30			30
Link Distance (ft)	1290		915			1180
Travel Time (s)	29.3		20.8			26.8
Peak Hour Factor	0.85	0.93	0.87	0.85	0.91	0.86
Heavy Vehicles (%)	5%	1%	4%	4%	1%	2%
Adj. Flow (vph)	293	863	646	291	829	859
Shared Lane Traffic (%)						
Lane Group Flow (vph)	293	863	937	0	829	859
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		23			23
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.14	1.14	1.21	1.21	1.18	1.18
Turning Speed (mph)	15	9		9	15	
Turn Type	NA	Perm	NA		pm+pt	NA
Protected Phases	8		2		1	6
Permitted Phases		8			6	
Detector Phase	8	8	2		1	6
Switch Phase						
Minimum Initial (s)	3.0	3.0	8.0		2.0	8.0
Minimum Split (s)	21.0	21.0	21.0		6.0	21.0
Total Split (s)	24.0	24.0	38.0		43.0	81.0
Total Split (%)	22.9%	22.9%	36.2%		41.0%	77.1%
Maximum Green (s)	20.0	20.0	34.0		39.0	77.0
Yellow Time (s)	3.0	3.0	3.0		3.0	3.0
All-Red Time (s)	1.0	1.0	1.0		1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0		0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0		4.0	4.0
Lead/Lag			Lag		Lead	
Lead-Lag Optimize?			Yes		Yes	
Vehicle Extension (s)	2.0	2.0	3.0		3.0	3.0

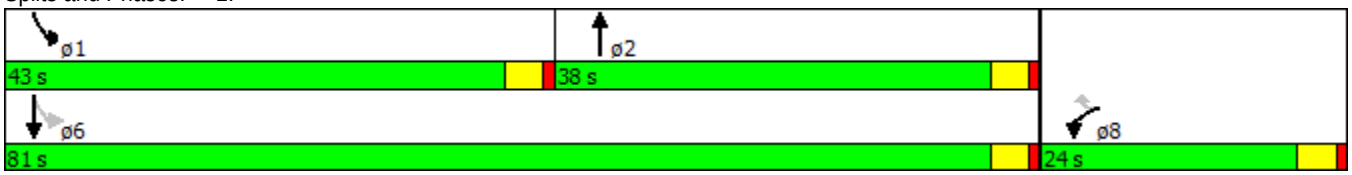
Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Recall Mode	None	None	Min		None	Min
Walk Time (s)	7.0	7.0	7.0			7.0
Flash Dont Walk (s)	10.0	10.0	10.0			10.0
Pedestrian Calls (#/hr)	0	0	0			0
Act Effct Green (s)	20.0	20.0	34.0		77.0	77.0
Actuated g/C Ratio	0.19	0.19	0.32		0.73	0.73
v/c Ratio	1.00	1.11	0.96		1.28	0.72
Control Delay	95.5	81.6	54.5		165.5	12.1
Queue Delay	0.0	0.0	0.0		0.0	0.0
Total Delay	95.5	81.6	54.5		165.5	12.1
LOS	F	F	D		F	B
Approach Delay	85.1		54.5			87.5
Approach LOS	F		D			F
Queue Length 50th (ft)	198	~305	303		~669	277
Queue Length 95th (ft)	#339	#546	#415		#907	374
Internal Link Dist (ft)	1210		835			1100
Turn Bay Length (ft)		300				
Base Capacity (vph)	294	774	971		646	1200
Starvation Cap Reductn	0	0	0		0	0
Spillback Cap Reductn	0	0	0		0	0
Storage Cap Reductn	0	0	0		0	0
Reduced v/c Ratio	1.00	1.11	0.96		1.28	0.72

Intersection Summary			
Area Type:	CBD		
Cycle Length: 105			
Actuated Cycle Length: 105			
Natural Cycle: 120			
Control Type: Actuated-Uncoordinated			
Maximum v/c Ratio: 1.28			
Intersection Signal Delay: 78.6		Intersection LOS: E	
Intersection Capacity Utilization 97.8%		ICU Level of Service F	
Analysis Period (min) 15			

~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1:



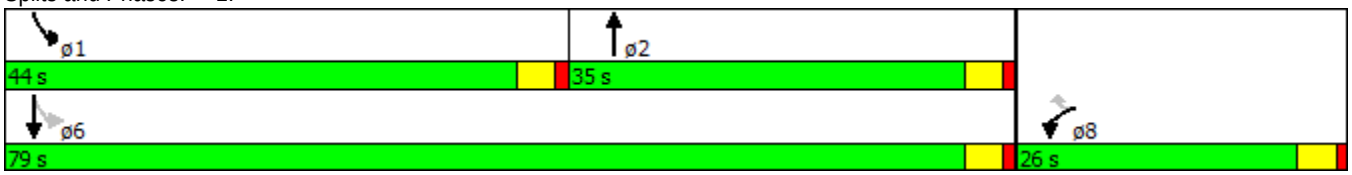
Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Volume (vph)	249	803	562	247	754	739
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	11	11	11	11
Grade (%)	0%		2%			-2%
Storage Length (ft)	0	300		0	0	
Storage Lanes	1	1		0	1	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	0.95	0.95	1.00	1.00
Frt		0.850	0.953			
Flt Protected	0.950				0.950	
Satd. Flow (prot)	1547	1439	2849	0	1570	1637
Flt Permitted	0.950				0.114	
Satd. Flow (perm)	1547	1439	2849	0	188	1637
Right Turn on Red		Yes		Yes		
Satd. Flow (RTOR)		640	70			
Link Speed (mph)	30		30			30
Link Distance (ft)	1290		915			1180
Travel Time (s)	29.3		20.8			26.8
Peak Hour Factor	0.85	0.93	0.87	0.85	0.91	0.86
Heavy Vehicles (%)	5%	1%	4%	4%	1%	2%
Adj. Flow (vph)	293	863	646	291	829	859
Shared Lane Traffic (%)						
Lane Group Flow (vph)	293	863	937	0	829	859
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		23			23
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.14	1.14	1.21	1.21	1.18	1.18
Turning Speed (mph)	15	9		9	15	
Turn Type	NA	Perm	NA		pm+pt	NA
Protected Phases	8		2		1	6
Permitted Phases		8			6	
Detector Phase	8	8	2		1	6
Switch Phase						
Minimum Initial (s)	3.0	3.0	8.0		2.0	8.0
Minimum Split (s)	21.0	21.0	21.0		6.0	21.0
Total Split (s)	26.0	26.0	35.0		44.0	79.0
Total Split (%)	24.8%	24.8%	33.3%		41.9%	75.2%
Maximum Green (s)	22.0	22.0	31.0		40.0	75.0
Yellow Time (s)	3.0	3.0	3.0		3.0	3.0
All-Red Time (s)	1.0	1.0	1.0		1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0		0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0		4.0	4.0
Lead/Lag			Lag		Lead	
Lead-Lag Optimize?			Yes		Yes	
Vehicle Extension (s)	2.0	2.0	3.0		3.0	3.0

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Recall Mode	None	None	Min		None	Min
Walk Time (s)	7.0	7.0	7.0			7.0
Flash Dont Walk (s)	10.0	10.0	10.0			10.0
Pedestrian Calls (#/hr)	0	0	0			0
Act Effct Green (s)	22.0	22.0	31.0		75.0	75.0
Actuated g/C Ratio	0.21	0.21	0.30		0.71	0.71
v/c Ratio	0.90	1.07	1.05		1.26	0.73
Control Delay	72.5	63.8	79.2		153.7	13.8
Queue Delay	0.0	0.0	0.0		0.0	0.0
Total Delay	72.5	63.8	79.2		153.7	13.8
LOS	E	E	E		F	B
Approach Delay	66.0		79.2			82.5
Approach LOS	E		E			F
Queue Length 50th (ft)	193	~277	~344		~659	302
Queue Length 95th (ft)	#319	#518	#446		#896	408
Internal Link Dist (ft)	1210		835			1100
Turn Bay Length (ft)		300				
Base Capacity (vph)	324	807	890		660	1169
Starvation Cap Reductn	0	0	0		0	0
Spillback Cap Reductn	0	0	0		0	0
Storage Cap Reductn	0	0	0		0	0
Reduced v/c Ratio	0.90	1.07	1.05		1.26	0.73

Intersection Summary

Area Type: CBD
Cycle Length: 105
Actuated Cycle Length: 105
Natural Cycle: 120
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 1.26
Intersection Signal Delay: 76.6 Intersection LOS: E
Intersection Capacity Utilization 97.8% ICU Level of Service F
Analysis Period (min) 15
~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1:



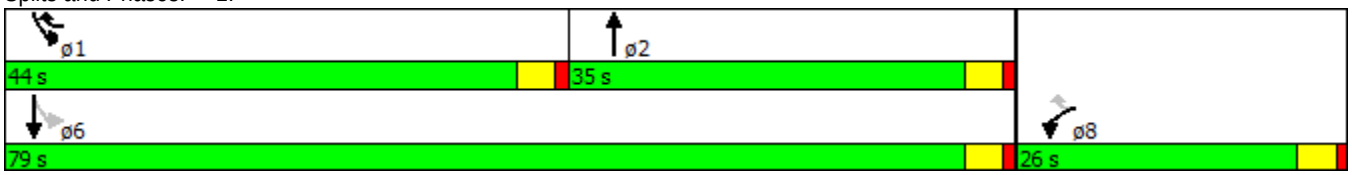
Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Volume (vph)	249	803	562	247	754	739
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	11	11	11	11
Grade (%)	0%		2%			-2%
Storage Length (ft)	0	300		0	0	
Storage Lanes	1	1		0	1	
Taper Length (ft)	25				25	
Lane Util. Factor	1.00	1.00	0.95	0.95	1.00	1.00
Frt		0.850	0.953			
Flt Protected	0.950				0.950	
Satd. Flow (prot)	1547	1439	2849	0	1570	1637
Flt Permitted	0.950				0.114	
Satd. Flow (perm)	1547	1439	2849	0	188	1637
Right Turn on Red		Yes		Yes		
Satd. Flow (RTOR)		58	70			
Link Speed (mph)	30		30			30
Link Distance (ft)	1290		915			1180
Travel Time (s)	29.3		20.8			26.8
Peak Hour Factor	0.85	0.93	0.87	0.85	0.91	0.86
Heavy Vehicles (%)	5%	1%	4%	4%	1%	2%
Adj. Flow (vph)	293	863	646	291	829	859
Shared Lane Traffic (%)						
Lane Group Flow (vph)	293	863	937	0	829	859
Enter Blocked Intersection	No	No	No	No	No	No
Lane Alignment	Left	Right	Left	Right	Left	Left
Median Width(ft)	12		23			23
Link Offset(ft)	0		0			0
Crosswalk Width(ft)	16		16			16
Two way Left Turn Lane						
Headway Factor	1.14	1.14	1.21	1.21	1.18	1.18
Turning Speed (mph)	15	9		9	15	
Turn Type	NA	pm+ov	NA		pm+pt	NA
Protected Phases	8	1	2		1	6
Permitted Phases		8			6	
Detector Phase	8	1	2		1	6
Switch Phase						
Minimum Initial (s)	3.0	2.0	8.0		2.0	8.0
Minimum Split (s)	21.0	6.0	21.0		6.0	21.0
Total Split (s)	26.0	44.0	35.0		44.0	79.0
Total Split (%)	24.8%	41.9%	33.3%		41.9%	75.2%
Maximum Green (s)	22.0	40.0	31.0		40.0	75.0
Yellow Time (s)	3.0	3.0	3.0		3.0	3.0
All-Red Time (s)	1.0	1.0	1.0		1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0		0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0		4.0	4.0
Lead/Lag		Lead	Lag		Lead	
Lead-Lag Optimize?		Yes	Yes		Yes	
Vehicle Extension (s)	2.0	3.0	3.0		3.0	3.0

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Recall Mode	None	None	Min		None	Min
Walk Time (s)	7.0		7.0			7.0
Flash Dont Walk (s)	10.0		10.0			10.0
Pedestrian Calls (#/hr)	0		0			0
Act Effct Green (s)	21.2	65.2	31.0		75.0	75.0
Actuated g/C Ratio	0.20	0.63	0.30		0.72	0.72
v/c Ratio	0.93	0.94	1.05		1.25	0.73
Control Delay	78.1	35.6	76.6		149.4	13.5
Queue Delay	0.0	0.0	0.0		0.0	0.0
Total Delay	78.1	35.6	76.6		149.4	13.5
LOS	E	D	E		F	B
Approach Delay	46.4		76.6			80.2
Approach LOS	D		E			F
Queue Length 50th (ft)	193	456	~344		~659	302
Queue Length 95th (ft)	#319	#784	#446		#896	408
Internal Link Dist (ft)	1210		835			1100
Turn Bay Length (ft)		300				
Base Capacity (vph)	326	922	896		665	1178
Starvation Cap Reductn	0	0	0		0	0
Spillback Cap Reductn	0	0	0		0	0
Storage Cap Reductn	0	0	0		0	0
Reduced v/c Ratio	0.90	0.94	1.05		1.25	0.73

Intersection Summary

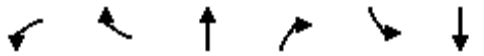
Area Type: CBD
Cycle Length: 105
Actuated Cycle Length: 104.2
Natural Cycle: 110
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 1.25
Intersection Signal Delay: 69.0 Intersection LOS: E
Intersection Capacity Utilization 97.8% ICU Level of Service F
Analysis Period (min) 15
~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.
95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 1:



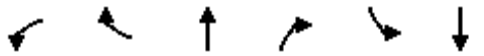
APPENDIX E

AM/PM Peak-Hour Intersection Capacity Analysis
Single-Lane Modern Roundabout Alternative



Movement	WBL	WBR	NBT	NBR	SBL	SBT
Right Turn Channelized		Yes		Yes		
Volume (veh/h)	208	792	351	236	492	586
Peak Hour Factor	0.90	0.93	0.78	0.95	0.87	0.88
Hourly flow rate (vph)	231	852	450	248	566	666
Approach Volume (veh/h)	231		450			1231
Crossing Volume (veh/h)	450		566			231
High Capacity (veh/h)	971		886			1155
High v/c (veh/h)	0.24		0.51			1.07
Low Capacity (veh/h)	788		712			953
Low v/c (veh/h)	0.29		0.63			1.29

Intersection Summary			
Maximum v/c High	1.07		
Maximum v/c Low	1.29		
Intersection Capacity Utilization	80.3%	ICU Level of Service	D

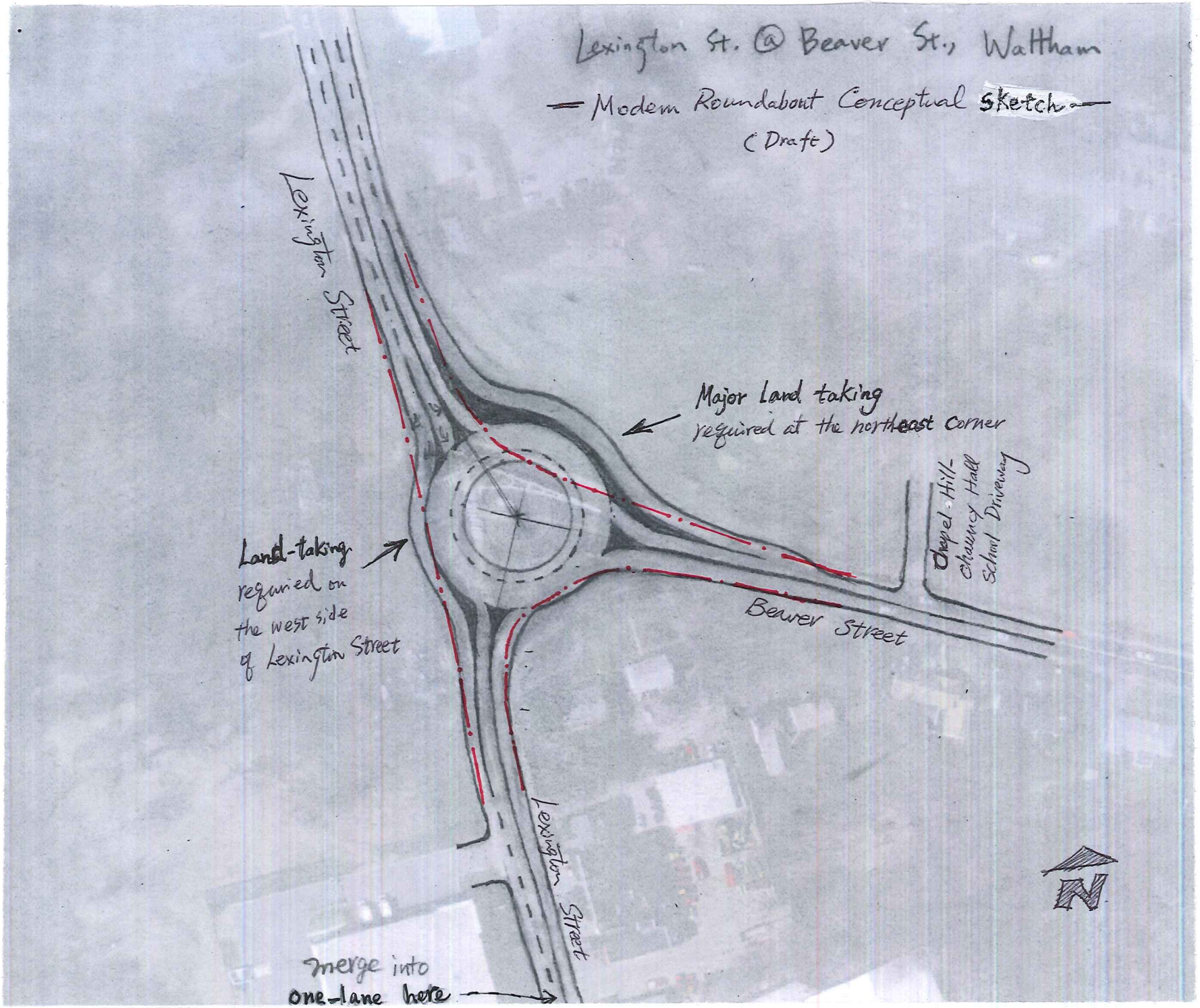


Movement	WBL	WBR	NBT	NBR	SBL	SBT
Right Turn Channelized		Yes		Yes		
Volume (veh/h)	249	803	562	247	754	739
Peak Hour Factor	0.85	0.93	0.87	0.85	0.91	0.86
Hourly flow rate (vph)	293	863	646	291	829	859
Approach Volume (veh/h)	293		646			1688
Crossing Volume (veh/h)	646		829			293
High Capacity (veh/h)	830		716			1100
High v/c (veh/h)	0.35		0.90			1.53
Low Capacity (veh/h)	663		564			904
Low v/c (veh/h)	0.44		1.15			1.87

Intersection Summary				
Maximum v/c High		1.53		
Maximum v/c Low		1.87		
Intersection Capacity Utilization		97.8%	ICU Level of Service	F

APPENDIX F

Modern Roundabout Draft Concept Plan


Lexington St. @ Beaver St., Waltham
Modern Roundabout Conceptual Sketch
(Draft)
Lexington Street
Major Land taking
required at the northeast corner
Land-taking
required on
the west side
of Lexington Street
Chapel Hill-
Chauncy Hall
School Driveway
Beaver Street
Lexington Street
Merge into
one-lane here
N