BOSTON REGION METROPOLITAN PLANNING ORGANIZATION

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Jeffrey B. Mullan
MassDOT Secretary and CEO
and MPO Chairman

Karl H. Quackenbush
Acting Director, MPO Staff

MEMORANDUM

DATE	**March 10, 2011**
TO	**Transportation Planning and Programming Committee of the Boston Region Metropolitan Planning Organization**
FROM	**Karl H. Quackenbush, CTPS Acting Director**
RE	**Draft CTPS memoranda presenting results from the study, Safety and Operations Analyses at Selected Intersections**

ACTION REQUIRED

Review and approval

PROPOSED MOTION

That the Transportation Planning and Programming Committee of the Boston Region Metropolitan Planning Organization vote to approve the seven technical memoranda on Safety and Operations Analyses at Selected Boston Region MPO Intersections for Bolton, Chelsea, Holbrook, Milford, Natick, Stoughton, and Wilmington, in the form of the drafts dated February 17, 2011.

PROJECT IDENTIFICATION

Unified Planning Work Program Classification
Planning Studies

CTPS Project Number
13246

Client(s)
Boston Region Metropolitan Planning Organization

CTPS Project Supervisors
Principal: Efi Pagitsas
Manager: Chen-Yuan Wang

Funding
MassDOT 3C PL Contract #66104

BACKGROUND

This study was a recommendation of the MPO's Congestion Management Process (CMP). The study's purpose was to select intersections from throughout the region and develop recommendations for improving their operations and the safety of the drivers, bicyclists, and pedestrians who use them.

DESCRIPTION OF THE ATTACHED MEMORANDA

The seven attached memoranda present analyses and recommendations for eight intersections. The intersections were selected through a comprehensive procedure with extensive data screening and numerous interactions with cities and towns. This procedure included review of MassDOT crash data, review of the status of Transportation Improvement Program projects, solicitation of recommendations through the Metropolitan Area Planning Council's outreach efforts, and communications with cities and towns regarding their interest in project implementation. The eight intersections are:

Community	**Street 1**	**Street 2**	**2006-2008 Crashes**	**EPDO***	**Current Traffic Control**
Bolton	Main Street (Route 117)	Still River Road (Route 110)	35	100	Traffic Signal
Chelsea	Broadway	Congress Avenue	58	142	Two-Way Stop
	Broadway	Everett Avenue	17	41	Two-Way Stop
Holbrook	Weymouth Street	Pine Street/ Sycamore Street	33	77	Two-Way Stop
Milford	Prospect Street (Route 140)	Water Street	29	70	Two-Way Stop
Natick	West Central Street (Route 135)	Speen Street	93	149	Traffic Signal
Stoughton	Central Street	Pearl Street	48	104	Traffic Signal
Wilmington	Lowell Street (Route 129)	Woburn Street	59	143	Traffic Signal

* EPDO (Equivalent Property Damage Only)
= 10 * Fatality Crashes + 5 * Personal Injury Crashes + 1 * Other Crashes

Each intersection is analyzed and discussed in a separate memorandum, except the two intersections in Chelsea. As those two are related, they are discussed together in one memorandum. Typical subjects of the memoranda are:

- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Preliminary Analysis of Traffic Signal Warrants *(if applicable)*
- Analyses of Improvement Alternatives
- Improvement Recommendations and Discussion

Each memorandum also includes a collection of technical appendices presenting methods and data applied in the study and detailed reports on intersection capacity analyses.

KHQ/CYW/cyw

MEMORANDUM

To: **Harold Brown, Bolton Director of Public Works** **February 17, 2011**
Eric Nasimento, MassDOT Highway Division District 3

From: **Chen-Yuan Wang and Efi Pagitsas**

Re: **Safety and Operations Analyses at Selected Boston Region MPO Intersections: Main Street (Route 117) at Still River Road (Route 110) in Bolton**

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersection of Main Street (Route 117) at Still River Road (Route 110) in Bolton. It contains the following sections:

- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Analyses of Improvement Alternatives
- Improvement Recommendations and Discussion

The memorandum also includes a collection of technical appendices that contain methods and data applied in the study and detailed reports of the intersection capacity analysis.

INTERSECTION LAYOUT AND TRAFFIC CONTROL

This signalized intersection is located about two miles west of Bolton Town Center. Main Street, a two-lane roadway running in the east-west direction, is the major street of the intersection. It is a part of State Route 117 that reaches Route 128/Interstate 95 in Waltham in the east and Interstate 190 in Leominster in the west and it intersects Route 495 in Bolton in the middle. Still River Road is a two-lane roadway running in the north-south direction. It is a part of State Route 110 that reaches Littleton in the north and West Boylston near Worcester in the south, and goes through Bolton, Lancaster, and Clinton in between. Both streets near the intersection are classified as urban principal/rural minor arterials and are under the jurisdiction of the Town.

Figure 1 shows the intersection layout and the area nearby. Approaching the intersection, Main Street (Route 117) widens to add an exclusive right-turn lane of nearly 400 feet in length (including the taper section) in both directions and the main lane therefore is shared by through and left-turn movements. Still River Road (Route 110) remains a single lane shared by all movements on both approaches. Near the intersection it is flared, and the stop lines are set back from the Route 117 traffic. There are no crosswalks or pedestrian signals on the approaches and no sidewalks on either side of the two streets. There is a shoulder about two feet wide on the north side of Main Street and on the east side of Still River Road.

CTPS

FIGURE 1
Main Street (Route 117) at Still River Road (Route 110), Bolton

Safety and Operations Improvements at Selected Intersections

The traffic signal is pretimed and operates in two traffic phases: (1) eastbound/westbound (EB/WB) all movements (left turns permitted), and (2) northbound/southbound (NB/SB) all movements. No pedestrian phases are provided in the signal cycles. Right turns on red are allowed on all approaches. Signal heads are hung by a diagonal cable. There are no detectors or conduits on the intersection approaches.

At the intersection, the southeast corner is occupied by a farm market complex (Bolton Orchard) and its parking lots, while the other corners are vacant land. Away from the intersection, in the west is mainly low-lying flat vacant land, and in the east are hilly areas with scattered single-family houses. Still River runs parallel to Route 110 about 500 feet west of this intersection, with its banks and surrounding wetlands designated as Bolton Flats State Wildlife Management Area. Nashoba Regional High School is located on Main Street about a mile east of this intersection. Further east, near Interstate 495, is Bolton Town Center, including the town hall/police station, a church, and a few local shops, located on Main Street.

ISSUES AND CONCERNS

Traffic is somewhat busy on Main Street in the eastbound direction in the morning and in the westbound direction in the evening, but the intersection is not extremely congested during daily peak traffic periods. The main concerns at this intersection are the high crash numbers and the severity of the crashes. A review of the crash data from 2006 to 2008 indicates that nearly 45% of the total crashes resulted in personal injuries, and one resulted in a fatality (see the next section for further analyses).

Most sections of Main Street (Route 117) in Bolton have a speed limit of 45 miles per hour (MPH), except the 30-MPH limit in the town center section. At this intersection, it is reduced to 30 MPH in both directions, about 800 feet ahead of the town center. A “Dangerous Intersection Ahead” warning sign is located in the westbound lane, about 1,000 feet ahead of the intersection, followed by a lane-designation sign, the 30-MPH speed limit sign, and a “traffic signal ahead” warning sign. Most sections of Still River Road have a speed limit of 40 MPH. It is reduced to 30 MPH in both directions about 800 feet ahead of the intersection.

Approaching the intersection from the east, Main Street winds through woody area and goes downhill toward the intersection. Although the warning signs and the speed limit signs are appropriately in place ahead of the intersection, drivers tend to travel above the speed limit in this straight section and where there are open surroundings. Approaching from the west, drivers also tend to travel above the speed limit, as that section of Main Street is straight, with open fields and wetlands on both sides.

Above all, the critical issue for this intersection may well be the existing lane designation of both approaches of Main Street. Under the configuration (a left-turn/through shared lane and a right-turn exclusive lane), EB or WB through movements are frequently blocked by left turns during green lights when their opposite through traffic is heavy. During peak hours, sometimes just one stopped left-turn vehicle could deter most vehicles on the same approach from passing the intersection. The traffic blockage may be hazardous for some drivers when they approach the intersection during a green light and do not slow down.

In addition to the usual angle collisions between a left-turning vehicle and an opposite through vehicle at an intersection that permits left turns, the current Main Street layout potentially contribute to an increase in other types of collisions, such as a rear-end collision between a left-turning vehicle and a vehicle immediately following it, or a sideswipe collision between a vehicle attempting to go around a stopped left-turning vehicle and a vehicle immediately following it in the adjacent right-turn lane. Some of these collisions can be serious if one or more of the involved vehicles is traveling at a high speed.

Meanwhile, the configuration is not compatible with the existing traffic conditions, as both approaches of Main Street actually carry a low right-turn volume that may not require an exclusive lane. The recent turning movement counts (June 9, 2010) indicate that it carries a majority of through movements with a relatively low volume of right turns on both approaches (see the section Improvement Alternatives for further analysis).

The issues and concerns for this intersection can be summarized as follows:

- High number of crashes
- Severity of the crashes (nearly half resulting in personal injuries from 2006 to 2008)
- Difficult EB/WB lane configuration causing blockage of the main travel lane shared by left turns and through movements during green lights
- No pedestrian signal heads or push buttons

CRASH DATA ANALYSIS

Based on the 2006–2008 MassDOT Registry of Motor Vehicles Division crash data, Table 1 shows that on average of about 12 crashes occurred at the intersection each year. Nearly 45% of the total crashes resulted in personal injuries, and one resulted in a fatality. The crash types consist of 25% angle collisions, nearly 45% rear-end collisions, and about 30% sideswipe and single-vehicle collisions. No crashes involved pedestrians or bicycles. About half of the total crashes occurred during peak periods.

A review of the vehicle travel directions indicates that the rear-end collisions mostly involved vehicles traveling in the same direction on Main Street. They were likely the rear-end collisions related to the Main Street layout mentioned above. Both these rear-end collisions and the high proportion of crashes occurring in peak periods indicate that the Main Street layout might have been a factor in causing these rear-end and other types of crashes at the intersection.

Crash rate[1] is another effective tool for examining the relative safety of a particular location. Based on the above data and the recently collected traffic volume data, the crash rate for this intersection is calculated as 1.76 (see Appendix A for the calculation sheet). The rate is much higher than the average rate for the signalized locations in MassDOT Highway Division's District 3, which is estimated to be 0.93.[2]

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[1] Crash rates normalize crash frequency (crashes per year) by vehicle exposure (traffic volumes or miles traveled). Crash rates are expressed as "crashes per million entering vehicles" for intersection locations and as "crashes per million miles traveled" for roadway segments.

[2] The average crash rates estimated by the MassDOT Highway Division are based upon a database that contains intersection crash rates submitted to the Highway Division as part of the review process for an environmental

TABLE 1
Summary of Crash Data (2006–2008)

Statistics Period		2006	2005	2006	2006–08	Average
Total number of crashes		11	13	11	35	12
Severity	Property damage only	6	7	6	19	6
	Personal injury	3	6	5	14	5
	Fatality	1	0	0	1	0
	Not reported	1	0	0	1	0
Collision Type	Angle	1	4	4	9	3
	Rear-end	8	6	2	16	5
	Sideswipe	0	1	2	3	1
	Head-on	0	0	0	0	0
	Single vehicle	2	2	3	7	2
	Not reported	0	0	0	0	0
Crashes involving pedestrian(s)		0	0	0	0	0
Crashes involving cyclist(s)		0	0	0	0	0
Occurred during weekday peak periods*		6	5	6	17	6
Wet or icy pavement conditions		2	2	3	7	2
Dark/lighted conditions		0	2	4	6	2

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

INTERSECTION CAPACITY ANALYSIS

Boston Region MPO staff collected turning-movement counts at the intersection on June 9, 2010. The data were recorded in 15-minute intervals for the peak traffic periods in the morning, from 7:00 to 9:00, and in the evening, from 4:00 to 6:00. The intersection carried about 1,500 vehicles in the morning peak hour, from 7:00 to 8:00, and about 1,650 vehicles in the evening peak hour, from 4:45 to 5:45 (see Table 2). No pedestrians were observed during each of the two peak hours.[3] However, in another trip visiting the site in August staff observed two joggers crossing the intersection. Two bicycles were observed in the AM peak hour and two in the PM peak hour.

TABLE 2
AM and PM Peak-Hour Traffic Volumes and Pedestrian Crossings

Street name		Main Street (Route 117)						Still River Road (Route 110)						Total
Direction		Eastbound			Westbound			Northbound			Southbound			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	Turning volume	23	839	10	31	333	15	10	91	44	28	58	31	1513
	Approach volume	872			379			145			117			
	Pedestrian crossings	0			0			0			0			0
PM peak hour	Turning volume	29	365	12	22	897	25	42	65	20	11	112	38	1638
	Approach volume	406			944			127			161			
	Pedestrian crossings	0			0			0			0			0

impact report or functional design report. The most recent average crash rates, which are updated on a nearly yearly basis, are based on all entries in the database, not just those entries made within the past year.

[3] In another trip visiting the site in August, staff observed two joggers crossing the intersection at around 8:00 AM.

Based on the turning-movement counts and the signal timings measured at the site, the intersection capacity was analyzed using an intersection capacity analysis program, Synchro.[4] The intersection was modeled as a pretimed two-phase traffic signal with no pedestrian phases. It was evaluated to operate at level of service (LOS) C with an average delay of about 20 seconds per vehicle in both the AM and PM peak hours (see Table 3). The level of service criteria are based on the *Highway Capacity Manual 2000*.[5] Detailed analysis settings and results for both the AM and PM peak hour are included in Appendix B.

TABLE 3
Intersection Capacity Analysis, Existing Conditions

Street name		**Main Street (Route 117)**						**Still River Road (Route 110)**						**Overall**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	LOS	**C**		**A**	**B**		**A**	**C**			**C**			**C**
	Delay (sec/veh)	24		4	13		4	24			23			21
PM peak hour	LOS	**B**		**A**	**C**		**A**	**C**			**C**			**C**
	Delay (sec/veh)	15		4	27		3	26			26			23

Although the analysis shows that the intersection operates at a desirable level of service with acceptable delays, it does not reflect the occasional blockages of the Main Street main lane by the stopped left-turning traffic during the green lights. Review of traffic simulations did show the blockages at times in the westbound direction in the AM peak hour and in the eastbound direction in the PM peak hour. The blockages in turn could increase crashes at the intersection, which was not reflected in the capacity analysis.

ANALYSES OF IMPROVEMENT ALTERNATIVES

The existing traffic signal is pretimed and operates in two phases: (1) EB/WB (Main Street) all movements with permissive left turns, and (2) NB/SB (Still River Road) all movements, with no exclusive or concurrent pedestrian phases. Field measurements obtained using a stopwatch estimate that each signal cycle consists of an EB/WB (Main Street) phase of 50 seconds of green time plus 6 seconds of clearance (yellow plus all red) time and a NB/SB (Still River Road) phase of 21 seconds of green time plus 7 seconds of clearance time. The system is outdated and needs to be upgraded into a fully actuated system with pedestrian signal heads and push buttons.

Meanwhile, the existing lane configuration on Main Street is not compatible with the existing traffic conditions and may need to be reconfigured in order to improve traffic operations and the intersection safety. The recent turning movement counts (June 9, 2010) indicate that Main Street carries a majority of through movements and a relatively low number and low percentage of right turns on both approaches in the AM and PM peak periods. On the other hand, the counts show a somewhat higher number and percentage of left turns from both approaches in both time

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[4] Synchro is developed and distributed by Trafficware, Ltd. It can perform capacity analysis and traffic simulation (when combined with SimTraffic) for an individual intersection or a series of intersections.

[5] Transportation Research Board, *Highway Capacity Manual 2000*, National Research Council, Washington D.C., 2000.

periods, except an almost equal number and percentage of right and left turns on the westbound approach in the PM peak period (see Table 4). These findings indicated that one potential improvement option is to convert the two existing approach lanes into a left-turn exclusive lane and a through/right-turn shared lane on both approaches of Main Street.

TABLE 4
Main Street Right-Turn and Left-Turn Proportions
Based on June 6, 2010, Turning-Movement Counts

Turning-Movement Counts		Right-Turn	Left-Turn	All Movements	Right-Turn Percentage	Left-Turn Percentage
AM Peak Period 7:00 - 9:00	Eastbound	29	58	1,560	2%	4%
	Westbound	34	47	711	5%	7%
PM Peak Period 4:00 - 6:00	Eastbound	28	45	724	4%	6%
	Westbound	43	40	1,802	2%	2%

Based on the above analyses, two alternatives were examined for this intersection:

1) Upgrade the Traffic Signal to a Fully Actuated System with Pedestrian Signals and Operate Main Street Traffic under Existing Lane Configuration (a Left-Turn/Through Shared Lane and a Right-Turn Exclusive Lane)
2) Upgrade the Traffic Signal to a Fully Actuated System with Pedestrian Signals and Change Main Street Lane Configuration into a Left-Turn Exclusive Lane and a Through/Right-Turn Shared Lane

Both alternatives were examined as a fully actuated uncoordinated traffic signal. The signal cycle consists of an EB/WB (Main Street) phase of 48 seconds maximum green time plus 6 seconds clearance time, an NB/SB (Still River Road) phase of 11 seconds maximum green time plus 7 seconds clearance time, and an on-call exclusive pedestrian phase of 28 seconds. Table 5 summarizes the results from the intersection capacity analyses for both alternatives and the existing conditions. Details of the signal settings and analysis results for both peak hours are included in Appendix C for Alternative 1 and in Appendix D for Alternative 2.

As Table 5 shows, both alternatives would improve the intersection operation from LOS C to LOS B with the new actuated signal system. Alternative 2 is estimated to have similar or slightly less overall and approach delays than Alternative 1. Traffic simulations of Alternative 1 still show the left-turn blockages at times during Main Street green lights, while simulations of Alternative 2 show a continuous traffic flow on the main lane (shared by through movements and right turns) in both directions and left turns mostly clear of the intersection during the green lights. Though not shown in the capacity analyses, the new lane configuration of Alternative 2 would potentially reduce some crashes that are caused by the existing Main Street layout.

The above alternatives analyses indicate that Alternative 2 is more advantageous than Alternative 1. A future-year scenario of 15% growth[6] over a 20-year planning horizon was also tested for Alternative 2. The tests show that with the projected traffic growth Alternative 2 would maintain at LOS B with an average delay of about 18 seconds in the AM peak hour and would operate at an acceptable LOS C with an average delay of about 22 seconds in the PM peak hour.

TABLE 5
Intersection Capacity Analysis of Alternative Improvements
Existing Traffic Volumes

Street name		**Main Street (Route 117)**		**Still River Road (Route 110)**		**Overall**
Approach		**Eastbound**	**Westbound**	**Northbound**	**Southbound**	
AM peak hour	Existing	C/23	B/12	C/24	C/23	C/21
	Alternative 1	B/13	A/6	C/34	C/32	B/15
	Alternative 2	B/12	A/6	C/34	C/32	B/14
PM peak hour	Existing	B/14	C/26	C/26	C/26	C/23
	Alternative 1	A/7	B/14	C/35	C/35	B/16
	Alternative 2	A/6	B/14	C/35	C/35	B/16

Note: Performance measures: Level of Service (A to F)/Average Delay (seconds per vehicle)
Alternative 1: Upgrade Signal System and Maintain Main Street Existing Lane Configuration
Alternative 2: Upgrade Signal System and Change Main Street Lane Configuration

IMPROVEMENT RECOMMENDATIONS AND DISCUSSION

The above safety and operations analyses indicate that the existing traffic signal system and the layout of Main Street (Route 117) approaches are not adequate for the traffic conditions at this intersection. To improve the safety and operations, this study examined two improvement alternatives: (1) upgrade the traffic signal to a fully actuated system with pedestrian signals and operate Main Street traffic under the existing lane configuration, and (2) upgrade the traffic signal to a fully actuated system with pedestrian signals and change Main Street lane configuration into a left-turn exclusive lane and a through/right-turn shared lane. Alternative 2 was found to be more advantageous in traffic operations and would potentially reduce some crashes related to the existing intersection layout.

We therefore recommend upgrading the traffic signal system and reconfiguring the existing layout of the Main Street approaches. The upgrade of signal system and the intersection should include the following features:

- A fully actuated traffic signal system with pedestrian signal heads and push buttons
- Sidewalks on all corners, where pedestrians can wait for the opportunity to cross
- Crosswalks (and curb cuts) for crossing the WB and NB approaches

[6] The growth assumption is based on a review of the traffic projections in the intersection vicinity from the Boston Region MPO's transportation-planning model.

Figure 2 shows the conceptual diagram for the intersection reconfiguration. Each of the reconfigured Main Street approaches should include the following features:

- A shared through/right-turn lane
- An exclusive left-turn lane (with a storage length of about 100 feet)
- A traffic median next to the left-turn lane to separate traffic from the opposite direction
- Necessary signage changes (lane designation signs, etc.)

In addition, each of the Still River Road approaches should be channelized for right turns (see Figure 2). The channelization would not only protect the right turners but would also provide a refuge island for pedestrians and shorten the crossing distances for pedestrians on both streets.

Currently there are five driveways for the business at the southeast corner. In order to preserve the intersection's functional area and to reduce crashes at the intersection, we propose closing the two driveways that are closest to the intersection from both streets (see Figure 2).

A brief review of the intersection's aerial photograph (Figure 1) indicates that the conversion may not require additional land takings. The future left-turn exclusive lane (the inside lane) can be shifted slightly inward and aligned straight to the traffic median on the opposite approach. This would allow left turns on Main Street to be protected when they are waiting for traffic gaps at the intersection. The extensive length of the existing right-turn exclusive lane (nearly 400 feet, including the taper) would potentially allow the conversion to provide sufficient left-turn storage space of about 100 feet in length.[7]

More precise horizontal and vertical alignments for the reconfiguration should be carefully examined in the functional design stage for the intersection. In the meantime, potential improvements to enhance the safety and operations for pedestrians and bicyclists should be explored:

- Investigate pedestrian activities in the area and examine the potential for adding sidewalks on both streets or either street.
- Maintain or expand the existing shoulder (preferably 4 feet wide) for bicycle travel on Route 117.

The reconfiguration of the Main Street approaches is essential for improving the operations and safety at this intersection. Currently Main Street and Still River Road are both under the jurisdiction of the Town of Bolton. The implementation of the proposed improvements would require the Town to advance this study and to work closely with MassDOT through the project implantation process (see Appendix E). At this preliminary stage, the cost of the signal system upgrade and the reconstruction of the intersection and the Main Street approaches can only be roughly estimated as $500,000 to $750,000.

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[7] Synchro tests of the future year AM and PM scenarios estimated the 95thpercentile left-turn queue length as no more than 50 feet in both directions. To accommodate the relatively high percentage of heavy vehicles (up to 15% in the AM peak hour for the westbound left turns) and possible unexpected high traffic growth, the left-turn storage length should be about 100 feet.

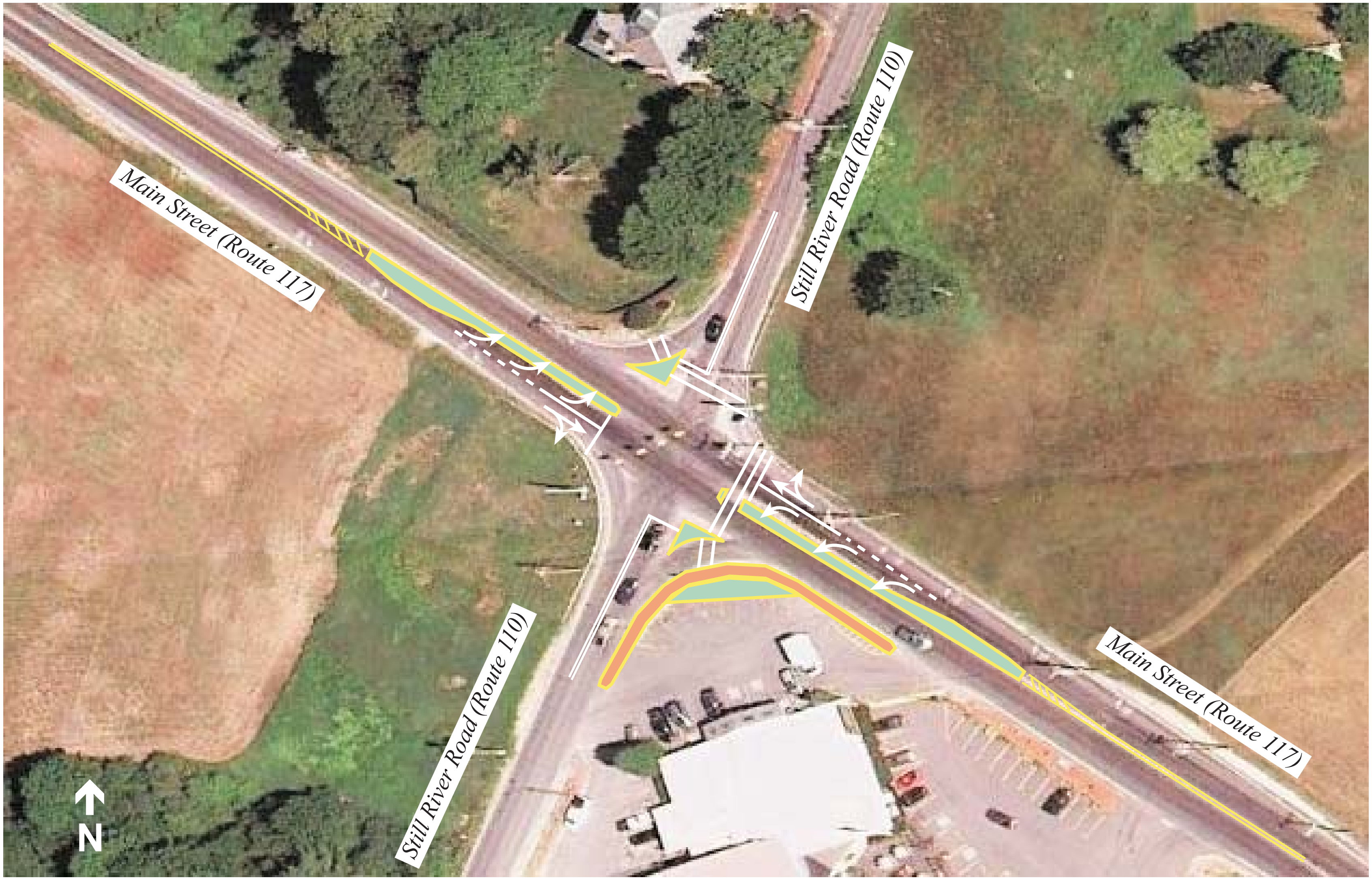


FIGURE 2
Intersection Reconfiguration Conceptual Diagram
Main Street (Route 117) at Still River Road (Route 110), Bolton

CTPS

Safety and Operations Improvements at Selected Intersections

Appendix A

Intersection Crash Rate Calculation
Main Street (Route 117) at Still River Road (Route 110), Bolton

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Bolton COUNT DATE : 6/9/10

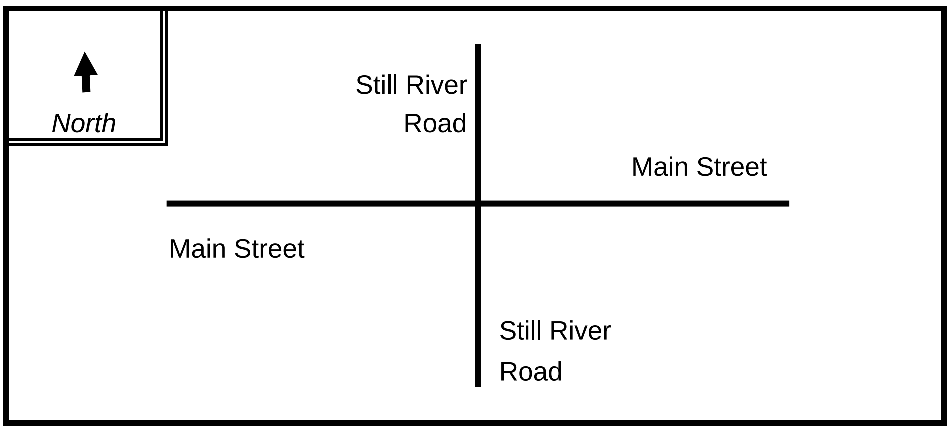
DISTRICT : 3 UNSIGNALIZED : SIGNALIZED : X

~ INTERSECTION DATA ~

MAJOR STREET : Main Street (Route 117)

MINOR STREET(S) : Still River Raod (Route 110)

INTERSECTION DIAGRAM (Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	EB	WB	NB	SB		
PEAK HOURLY VOLUMES (AM/PM) :	406	944	127	161		**1,638**

" K " FACTOR : **0.090** INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **18,200**

TOTAL # OF CRASHES : 35 # OF YEARS : 3 AVERAGE # OF CRASHES PER YEAR (**A**) : **11.67**

CRASH RATE CALCULATION : **1.76** RATE = $\frac{(A * 1,000,000)}{(V * 365)}$

Comments : MassDOT District 3 Average Rate = 0.93

Project Title & Date: Safety and Operations Analyses at Selceted Intersections

Appendix B

AM/PM Peak Hour Intersection Capacity Analysis
Existing Traffic Conditions
Main Street (Route 117) at Still River Road (Route 110), Bolton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	23	839	10	31	333	15	10	91	44	28	58	31
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)									1			1
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	5%	5%	5%	15%	8%	10%	2%	2%	15%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm		Perm	Perm		Perm	Perm			Perm		
Protected Phases		4			8			2			6	
Permitted Phases	4		4	8		8	2			6		
Detector Phase	4	4	4	8	8	8	2	2		6	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	53.0	53.0	53.0	53.0	53.0	53.0	19.0	19.0		19.0	19.0	
Total Split (s)	56.0	56.0	56.0	56.0	56.0	56.0	28.0	28.0	0.0	28.0	28.0	0.0
Total Split (%)	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	33.3%	33.3%	0.0%	33.3%	33.3%	0.0%
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	
All-Red Time (s)	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0		3.0	3.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	6.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	4.0	7.0	7.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max	Max	Max	Max	Max	Max	Max		Max	Max	
Act Effct Green (s)		50.0	50.0		50.0	50.0		21.0			21.0	
Actuated g/C Ratio		0.60	0.60		0.60	0.60		0.25			0.25	
v/c Ratio		0.85	0.01		0.49	0.02		0.33			0.27	
Control Delay		23.6	3.9		12.5	3.5		23.6			22.8	
Queue Delay		0.0	0.0		0.0	0.0		0.0			0.0	
Total Delay		23.6	3.9		12.5	3.5		23.6			22.8	
LOS		C	A		B	A		C			C	
Approach Delay		23.3			12.1			23.6			22.8	
Approach LOS		C			B			C			C	

Intersection Summary	
Cycle Length: 84	
Actuated Cycle Length: 84	
Offset: 28 (33%), Referenced to phase 4:EBTL and 8:WBTL, Start of Green	
Natural Cycle: 75	
Control Type: Pretimed	
Maximum v/c Ratio: 0.85	
Intersection Signal Delay: 20.5	Intersection LOS: C
Intersection Capacity Utilization 87.9%	ICU Level of Service E
Analysis Period (min) 15	

Splits and Phases: 3: Route 117 (Main Street) & Route 110 (Still River Road)

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	29	365	12	22	897	25	42	65	20	11	112	38
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)									1			1
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	2%	2%	2%	2%	2%	2%	1%	1%	1%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm		Perm	Perm		Perm	Perm			Perm		
Protected Phases		4			8			2			6	
Permitted Phases	4		4	8		8	2			6		
Detector Phase	4	4	4	8	8	8	2	2		6	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	53.0	53.0	53.0	53.0	53.0	53.0	19.0	19.0		19.0	19.0	
Total Split (s)	56.0	56.0	56.0	56.0	56.0	56.0	28.0	28.0	0.0	28.0	28.0	0.0
Total Split (%)	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	33.3%	33.3%	0.0%	33.3%	33.3%	0.0%
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	
All-Red Time (s)	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0		3.0	3.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	6.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	4.0	7.0	7.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max	Max	Max	Max	Max	Max	Max		Max	Max	
Act Effct Green (s)		50.0	50.0		50.0	50.0		21.0			21.0	
Actuated g/C Ratio		0.60	0.60		0.60	0.60		0.25			0.25	
v/c Ratio		0.59	0.01		0.88	0.03		0.31			0.35	
Control Delay		14.8	3.6		26.5	3.0		25.9			25.5	
Queue Delay		0.0	0.0		0.0	0.0		0.0			0.0	
Total Delay		14.8	3.6		26.5	3.0		25.9			25.5	
LOS		B	A		C	A		C			C	
Approach Delay		14.4			25.9			25.9			25.5	
Approach LOS		B			C			C			C	

Intersection Summary	
Cycle Length: 84	
Actuated Cycle Length: 84	
Offset: 28 (33%), Referenced to phase 4:EBTL and 8:WBTL, Start of Green	
Natural Cycle: 75	
Control Type: Pretimed	
Maximum v/c Ratio: 0.88	
Intersection Signal Delay: 23.0	Intersection LOS: C
Intersection Capacity Utilization 95.3%	ICU Level of Service F
Analysis Period (min) 15	

Splits and Phases: 3: Route 117 (Main Street) & Route 110 (Still River Road)

Appendix C

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 1
Upgrade Signal System and Maintain Main Street Existing Lane Configuration
Main Street (Route 117) at Still River Road (Route 110), Bolton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	23	839	10	31	333	15	10	91	44	28	58	31
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)									1			1
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	5%	5%	5%	15%	8%	10%	2%	2%	15%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm		Perm	Perm		Perm	Perm			Perm		
Protected Phases		4			8			2			6	
Permitted Phases	4		4	8		8	2			6		
Detector Phase	4	4	4	8	8	8	2	2		6	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0	21.0	21.0	21.0	21.0	15.0	15.0		15.0	15.0	
Total Split (s)	54.0	54.0	54.0	54.0	54.0	54.0	18.0	18.0	0.0	18.0	18.0	0.0
Total Split (%)	54.0%	54.0%	54.0%	54.0%	54.0%	54.0%	18.0%	18.0%	0.0%	18.0%	18.0%	0.0%
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	
All-Red Time (s)	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0		3.0	3.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	6.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	4.0	7.0	7.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max	Max	Max	Max	Max	None	None		None	None	
Act Effct Green (s)		48.0	48.0		48.0	48.0		10.0			10.0	
Actuated g/C Ratio		0.68	0.68		0.68	0.68		0.14			0.14	
v/c Ratio		0.75	0.01		0.36	0.02		0.57			0.48	
Control Delay		12.7	2.9		6.2	2.1		34.2			31.5	
Queue Delay		0.0	0.0		0.0	0.0		0.0			0.0	
Total Delay		12.7	2.9		6.2	2.1		34.2			31.5	
LOS		B	A		A	A		C			C	
Approach Delay		12.6			6.1			34.2			31.5	
Approach LOS		B			A			C			C	

Intersection Summary	
Cycle Length: 100	
Actuated Cycle Length: 71	
Natural Cycle: 90	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.75	
Intersection Signal Delay: 14.5	Intersection LOS: B
Intersection Capacity Utilization 87.9%	ICU Level of Service E
Analysis Period (min) 15	

Splits and Phases: 3: Route 117 (Main Street) & Route 110 (Still River Road)

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	28.0
Total Split (s)	28.0
Total Split (%)	28%
Yellow Time (s)	3.5
All-Red Time (s)	0.5
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	29	365	12	22	897	25	42	65	20	11	112	38
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)									1			1
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	2%	2%	2%	2%	2%	2%	1%	1%	1%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm		Perm	Perm		Perm	Perm			Perm		
Protected Phases		4			8			2			6	
Permitted Phases	4		4	8		8	2			6		
Detector Phase	4	4	4	8	8	8	2	2		6	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0	21.0	21.0	21.0	21.0	15.0	15.0		15.0	15.0	
Total Split (s)	54.0	54.0	54.0	54.0	54.0	54.0	18.0	18.0	0.0	18.0	18.0	0.0
Total Split (%)	54.0%	54.0%	54.0%	54.0%	54.0%	54.0%	18.0%	18.0%	0.0%	18.0%	18.0%	0.0%
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	
All-Red Time (s)	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0		3.0	3.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	6.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	4.0	7.0	7.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max	Max	Max	Max	Max	None	None		None	None	
Act Effct Green (s)		48.0	48.0		48.0	48.0		10.9			10.9	
Actuated g/C Ratio		0.67	0.67		0.67	0.67		0.15			0.15	
v/c Ratio		0.39	0.01		0.79	0.03		0.54			0.58	
Control Delay		6.8	2.2		14.6	2.6		35.3			34.9	
Queue Delay		0.0	0.0		0.0	0.0		0.0			0.0	
Total Delay		6.8	2.2		14.6	2.6		35.3			34.9	
LOS		A	A		B	A		D			C	
Approach Delay		6.6			14.3			35.3			34.9	
Approach LOS		A			B			D			C	

Intersection Summary	
Cycle Length: 100	
Actuated Cycle Length: 71.9	
Natural Cycle: 110	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.79	
Intersection Signal Delay: 16.0	Intersection LOS: B
Intersection Capacity Utilization 95.3%	ICU Level of Service F
Analysis Period (min) 15	

Splits and Phases: 3: Route 117 (Main Street) & Route 110 (Still River Road)

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	28.0
Total Split (s)	28.0
Total Split (%)	28%
Yellow Time (s)	3.5
All-Red Time (s)	0.5
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix D

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 2
Upgrade Signal System and Change Main Street Lane Configuration
Main Street (Route 117) at Still River Road (Route 110), Bolton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	23	839	10	31	333	15	10	91	44	28	58	31
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)									1			1
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	5%	5%	5%	15%	8%	10%	2%	2%	15%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		4			8			2			6	
Permitted Phases	4			8			2			6		
Detector Phase	4	4		8	8		2	2		6	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	54.0	54.0	0.0	54.0	54.0	0.0	18.0	18.0	0.0	18.0	18.0	0.0
Total Split (%)	54.0%	54.0%	0.0%	54.0%	54.0%	0.0%	18.0%	18.0%	0.0%	18.0%	18.0%	0.0%
Yellow Time (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		3.0	3.0		3.0	3.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	6.0	6.0	4.0	6.0	6.0	4.0	7.0	7.0	4.0	7.0	7.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)	48.0	48.0		48.0	48.0			9.9			9.9	
Actuated g/C Ratio	0.68	0.68		0.68	0.68			0.14			0.14	
v/c Ratio	0.04	0.72		0.13	0.31			0.57			0.49	
Control Delay	4.3	11.9		5.8	5.7			34.3			31.6	
Queue Delay	0.0	0.0		0.0	0.0			0.0			0.0	
Total Delay	4.3	11.9		5.8	5.7			34.3			31.6	
LOS	A	B		A	A			C			C	
Approach Delay		11.7			5.7			34.3			31.6	
Approach LOS		B			A			C			C	

Intersection Summary

Cycle Length: 100
Actuated Cycle Length: 71
Natural Cycle: 90
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.72
Intersection Signal Delay: 13.9 Intersection LOS: B
Intersection Capacity Utilization 70.0% ICU Level of Service C
Analysis Period (min) 15

Splits and Phases: 3: Route 117 (Main Street) & Route 110 (Still River Road)

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	28.0
Total Split (s)	28.0
Total Split (%)	28%
Yellow Time (s)	3.5
All-Red Time (s)	0.5
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	29	365	12	22	897	25	42	65	20	11	112	38
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)									1			1
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	2%	2%	2%	2%	2%	2%	1%	1%	1%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		4			8			2			6	
Permitted Phases	4			8			2			6		
Detector Phase	4	4		8	8		2	2		6	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	54.0	54.0	0.0	54.0	54.0	0.0	18.0	18.0	0.0	18.0	18.0	0.0
Total Split (%)	54.0%	54.0%	0.0%	54.0%	54.0%	0.0%	18.0%	18.0%	0.0%	18.0%	18.0%	0.0%
Yellow Time (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		3.0	3.0		3.0	3.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	6.0	6.0	4.0	6.0	6.0	4.0	7.0	7.0	4.0	7.0	7.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)	48.0	48.0		48.0	48.0			10.9			10.9	
Actuated g/C Ratio	0.67	0.67		0.67	0.67			0.15			0.15	
v/c Ratio	0.15	0.33		0.04	0.78			0.54			0.58	
Control Delay	6.6	6.0		4.3	14.2			35.3			34.9	
Queue Delay	0.0	0.0		0.0	0.0			0.0			0.0	
Total Delay	6.6	6.0		4.3	14.2			35.3			34.9	
LOS	A	A		A	B			D			C	
Approach Delay		6.0			14.0			35.3			34.9	
Approach LOS		A			B			D			C	

Intersection Summary	
Cycle Length: 100	
Actuated Cycle Length: 71.9	
Natural Cycle: 100	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.78	
Intersection Signal Delay: 15.7	Intersection LOS: B
Intersection Capacity Utilization 79.2%	ICU Level of Service D
Analysis Period (min) 15	

Splits and Phases: 3: Route 117 (Main Street) & Route 110 (Still River Road)

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	28.0
Total Split (s)	28.0
Total Split (%)	28%
Yellow Time (s)	3.5
All-Red Time (s)	0.5
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix E

MassDOT Project Implementation Process

The following description of the implementation process is based on Chapter 2 of the *MassDOT Highway Division's Project Development and Design Guide (2005)*. The text below borrows heavily from that document.

1 NEEDS IDENTIFICATION

For each of the locations at which an improvement is to be implemented, MassDOT Highway Division leads an effort to define the problem, establishes project goals and objectives, and defines the scope of the planning needed for implementation. To that end, it has to complete a Project Need Form (PNF), which states in general terms the deficiencies or needs related to the transportation facility or location. The PNF documents the problems and explains why corrective action is needed. For this study, the information defining the need for the project will be drawn primarily, perhaps exclusively, from the present report. Also, at this point in the process, MassDOT Highway Division meets with potential participants, such as the Boston Region Metropolitan Planning Organization (MPO) and community members, to allow for an informal review of the project.

The PNF is reviewed by the MassDOT Highway Division district office whose jurisdiction includes the location of the proposed project. MassDOT Highway Division also sends the PNF to the MPO, for informational purposes. The outcome of this step determines whether the project requires further planning, whether it is already well supported by prior planning studies, and, therefore, whether it is ready to move forward into the design phase, or whether it should be dismissed from further consideration.

2 PLANNING

This phase will likely not be required for the implementation of the improvements proposed in this planning study, as this planning report should constitute the outcome of this step. However, in general, the purpose of this implementation step is for the project proponent to identify issues, impacts, and approvals that may need to be obtained, so that the subsequent design and permitting processes are understood.

The level of planning needed will vary widely, based on the complexity of the project. Typical tasks include: define the existing context, confirm project need, establish goals and objectives, initiate public outreach, define the project, collect data, develop and analyze alternatives, make recommendations, and provide documentation. Likely outcomes include consensus on the project definition to enable it to move forward into environmental documentation (if needed) and design, or a recommendation to delay the project or dismiss it from further consideration.

3 PROJECT INITIATION

At this point in the process, the proponent, MassDOT Highway Division, fills out, for each improvement, a Project Initiation Form (PIF), which is reviewed by its Project Review Committee (PRC) and the MPO. The PRC is composed of the Chief

Engineer, each District Highway Director, and representatives of the Project Management, Environmental, Planning, Right-of-Way, Traffic, and Bridge departments, and the Capital Expenditure Program Office (CEPO). The PIF documents the project type and description, summarizes the project planning process, identifies likely funding and project management responsibility, and defines a plan for interagency and public participation. First the PRC reviews and evaluates the proposed project based on the Executive Office of Transportation and Public Works's statewide priorities and criteria. If the result is positive, MassDOT Highway Division moves the project forward to the design phase, and to programming review by the MPO. The PRC may provide a Project Management Plan to define roles and responsibilities for subsequent steps. The MPO review includes project evaluation based on the MPO's regional priorities and criteria. The MPO may assign project evaluation criteria score, a Transportation Improvement Program (TIP) year, a tentative project category, and a tentative funding category.

4 ENVIRONMENTAL, DESIGN, AND RIGHT-OF-WAY PROCESS

This step has four distinct but closely integrated elements: public outreach, environmental documentation and permitting (if required), design, and right-of-way acquisition (if required). The outcome of this step is a fully designed and permitted project ready for construction. However, a project does not have to be fully designed in order for the MPO to program it in the TIP.

5 PROGRAMMING

Programming, which typically begins during the design phase, can actually occur at any time during the process, from planning to design. In this step, which is distinct from project initiation, where the MPO receives preliminary information on the proposed project, the proponent requests that the MPO place the project in the region's TIP. The MPO considers the project in terms of regional needs, evaluation criteria, and compliance with the regional Transportation Plan and decides whether to place it in the draft TIP for public review and then in the final TIP.

6 PROCUREMENT

Following project design and programming, MassDOT Highway Division publishes a request for proposals. It then reviews the bids and awards the contract to the qualified bidder with the lowest bid.

7 CONSTRUCTION

After a construction contract is awarded, MassDOT Highway Division and the contractor develop a public participation plan and a management plan for the construction process.

8 PROJECT ASSESSMENT

The purpose of this step is to receive constituents’ comments on the project development process and the project’s design elements. MassDOT Highway Division can apply what is learned in this process to future projects.

MEMORANDUM

To: **John DePriest** **February 17, 2011**
Director of Planning and Development, City of Chelsea

From: **Chen-Yuan Wang and Efi Pagitsas**

Re: **Safety and Operations Analyses at Selected Boston Region MPO Intersections: Broadway at Congress Avenue/Third Street and Broadway at Everett Avenue/Cross Street in Chelsea**

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersections of Broadway at Congress Avenue/Third Street and at Everett Avenue/Cross Street in Chelsea. The two intersections are located in close proximity and should therefore be examined together. The memorandum contains the following sections:

- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Preliminary Traffic Signal Warrants Analysis
- Analyses of Improvement Alternatives
- Improvement Recommendations and Discussion

The memorandum also includes a collection of technical appendices that contain methods and data applied in the study and detailed reports of the intersection capacity analysis.

INTERSECTION LAYOUT AND TRAFFIC CONTROL

The two intersections are located in the central area of Chelsea, just a few blocks west of the historic Bellingham Square. Broadway can be regarded as an extension of Route 107 from the Chelsea/Revere border to the Chelsea/East Boston border. It functions as an urban principal arterial and carries a high proportion of regional traffic. South of Bellingham Square, it operates in two lanes westbound only (inbound to Boston). Both sides of Broadway from Bellingham Square to its intersection with Everett Avenue/Cross Street are mostly commercial developments with on-street parking.

Figure 1 shows the intersection layout and the area nearby. The two intersections are about 200 feet from each other. The eastern intersection, Broadway at Congress Avenue/Third Street, is currently under a stop control on Congress Avenue. Congress Avenue and Third Street both operate one-way northbound only, with on-street parking on the west side. The western intersection, Broadway at Everett Avenue/Cross Street, is under a stop control on Everett

CTPS

FIGURE 1
Broadway at Congress Avenue/Third Street and at Everett Avenue/Cross Street, Chelsea

Safety and Operations Improvements at Selected Intersections

Avenue. Everett Avenue and Cross Street operate one-way southbound only, with on-street parking on both sides of Everett Avenue and on the east side of Cross Street.

Although there are no lane division markings on any of the streets at the two intersections, traffic generally progresses in two lanes (especially during peak periods). Traffic at the eastern intersection is controlled by two stop signs, one on each side of the Congress Avenue approach. Traffic at the western intersection is controlled by flashing beacons that indicate red to the Everett Street approach and yellow to the Broadway approach.

Crosswalks exist across all approaches at both intersections. Sidewalks exist on both sides of all the streets of the two intersections. There are no pedestrian crossing signals at the two intersections.

The intersection vicinity is thickly developed, with multi-family apartments and commercial developments. Pedestrian activity is heavy at the two intersections. Based on recent pedestrian counts, in June, each intersection carries about 200 to 250 in the AM peak traffic hour and over 400 pedestrians, in the PM peak traffic hour.. There are also bike activities in the area. Bicyclists from the North Shore area use Broadway to commute to Boston and its vicinity, and some local youths use bikes to get around the area in the afternoon hours. Recent counts indicate that each intersection carries about 5 bikes in the AM peak traffic hour and 15 bikes in the PM peak traffic hour.

The area has several Massachusetts Bay Transportation Authority (MBTA) bus routes in service, including Routes 111, 111C, 112, 114, 116, and 117. There are two bus stops, one on Broadway (with a shaded waiting area) and another on Everett Avenue, near the intersection of Broadway at Everett Avenue/Cross Street. Both locations appear to be appropriately located, at the near side of the intersection with on-street parking being prohibited.

ISSUES AND CONCERNS

A review of the recent crash data from 2006 to 2008 indicates that that the two intersections have a high number of crashes and a crash rate much higher than other unsignalized intersections in the area. Alarmingly, they both have a high pedestrian/bicyclist crash rate (see the next section for further analysis).

During peak periods, traffic is heavy on all approaches of the two intersections. Traffic is busy but not extremely congested on Broadway. Traffic on Broadway is free of controls but has to stop from time to time to yield to pedestrians. Traffic on Congress Avenue is heavy and congested due to the stop control. Congress Street is not only a major collector in the city but also a major access route to Route 1 (via the Tobin Bridge) to Boston. It becomes Third Street and merges into Everett Avenue just two blocks north of this intersection, where an entrance ramp to Route 1 Southbound is located.

Everett Avenue is a principal urban arterial in the city running from the Chelsea/Everett border to the intersection at Broadway. During peak hours, traffic on Everett Avenue is heavy. It is congested, and motorists sometimes experience extensive delay due to the stop control at the intersection.

As mentioned, the two intersections carry not only busy traffic but also heavy pedestrian movements, some bike traffic, and several MBTA bus routes. It is usually difficult to handle various transportation modes at a busy intersection, as their travel speed and behavior characteristics are quite different. These difficult situations may well be some of the causes of the high pedestrian and bike crash rates at the two intersections.

The issues and concerns for these two intersections can be summarized as:

- High number of crashes involving pedestrians or bicyclists
- High number of crashes and high crash rate of motor vehicles
- Traffic congestion during peak hours, with extensive delays for motorists on the Congress Avenue and Everett Avenue approaches

CRASH DATA ANALYSIS

Based on the 2006–2008 Massachusetts Department of Transportation (MassDOT) Registry of Motor Vehicles Division crash data, Table 1 shows that on average of about 20 crashes occurred annually at the intersection of Broadway at Congress Avenue/Third Street. About 35% of the crashes resulted in personal injuries. The crash types consist of about 60% angle collisions and 40% other collisions. The relatively high proportion of angle-type collisions is common for locations with two-way stop control. There were three head-on collisions in the 3-year period, which is unusual for one-way street operations.[1] During the 3-year period, one crash involved a pedestrian and three involved bicyclists.

The crash rate[2] is another effective tool for examining the relative safety of a particular location. Based on the crash data and the available recent traffic counts, the crash rate for this intersection is calculated as 3.88 (see Appendix A for the calculation). The rate is much higher than the average rate for the unsignalized locations in MassDOT Highway District 4, which is estimated as 0.59.[3]

Table 2 shows that an average of six crashes occurred at the intersection of Broadway at Everett Avenue/Cross Street each year. About 35% of the crashes resulted in personal injuries. The crash types consist of about 40% angle collisions, about 30% single-vehicle collisions, and about 30% other collisions. About half of the crashes occurred during weekday peak periods. This rate is

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[1] The crashes might have been caused by insufficient signage in the area of the two intersections. Currently a “No Right Turn” plaque is mounted under the stop sign on the Congress Street approach. However, there is not any indication of “No Left Turn” on the Everett Avenue approach at its intersection with Broadway. Motorists could mistakenly turn left at the intersection and collide with others going in the proper direction on Broadway. The crash could happen near the upstream intersection at Congress Avenue, as there is no way to turn around in that section of Broadway.

[2] Crash rates are estimated based on crash frequency (crashes per year) and vehicle exposure (traffic volume or miles traveled). Crash rates are expressed as “crashes per million entering vehicles” for intersection locations and as “crashes per million miles traveled” for roadway segments.

[3] The average crash rates estimated by the MassDOT Highway Division are based on a database that contains intersection crash rates submitted to the Highway Division as part of the review process for an environmental impact report or functional design report. The most recent average crash rates, which are updated on a nearly yearly basis, are based on all entries in the database, not just those entries made within the past year.

TABLE 1
Summary of Crash Data (2006–2008)
Broadway at Congress Avenue/Third Street, Chelsea

Statistics Period		**2006**	**2007**	**2008**	**3-Year**	**Average**
Total number of crashes		28	17	12	57	19
Severity	Property damage only	11	10	7	28	9
	Personal injury	12	6	3	21	7
	Fatality	0	0	0	0	0
	Not reported	5	1	2	8	3
Collision Type	Angle	17	12	5	34	11
	Rear-end	4	2	0	6	2
	Sideswipe	2	0	5	7	2
	Head-on	2	1	0	3	1
	Single vehicle	2	2	2	6	2
	Not reported	1	0	0	1	0
Crashes involved pedestrian(s)		0	0	1	1	0
Crashes involved bicyclist(s)		2	1	0	3	1
Occurred during weekday peak periods*		3	1	1	5	2
Wet or icy pavement conditions		10	4	2	16	5
Dark/lighted conditions		7	9	3	19	6

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

TABLE 2
Summary of Crash Data (2006–2008)
Broadway at Everett Avenue/Cross Street, Chelsea

Statistics Period		**2006**	**2007**	**2008**	**3-Year**	**Average**
Total number of crashes		7	5	5	17	6
Severity	Property damage only	5	1	4	10	3
	Personal injury	2	3	1	6	2
	Fatality	0	0	0	0	0
	Not reported	0	1	0	1	0
Collision Type	Angle	4	1	2	7	2
	Rear-end	0	1	0	1	0
	Sideswipe	0	1	1	2	1
	Head-on	0	0	0	0	0
	Single vehicle	3	2	0	5	2
	Not reported	0	0	2	2	1
Crashes involved pedestrian(s)		2	2	1	5	2
Crashes involved bicyclist(s)		1	0	0	1	0
Occurred during weekday peak periods*		3	3	3	9	3
Wet or icy pavement conditions		2	0	0	2	1
Dark/lighted conditions		1	0	1	2	1

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

considered relatively high,[4] and it is an indication of congested conditions during peak periods. Most alarmingly, there were five crashes that involved pedestrians and one that involved a bicyclist during the 3-year period.

The crash rate for this intersection is calculated as 1.27 (see the Appendix A for the calculation). The rate is lower than the average rate for the unsignalized locations in MassDOT Highway District 4, which is estimated as 0.59.

The above analyses show that the two intersections have a high number of crashes and a crash rate much higher than other unsignalized intersections in the area. More alarmingly, they both have a high pedestrian/bicyclist crash rate.

INTERSECTION CAPACITY ANALYSIS

Staff collected turning movement counts at the two intersections on June 4, 2009. The data were recorded in 15-minute intervals for peak traffic periods in the morning, from 7:00 to 9:00, and in the evening, from 4:00 to 6:00. Meanwhile, 24-hour automatic traffic counts for 3 midweek days were collected by the MassDOT Highway Division in the week beginning May 11, 2009. Based on the 24-hour traffic counts, the turning movement counts at the two intersections were adjusted and balanced.

Table 3 shows that the intersection of Broadway at Congress Avenue/Third Street carried about 1,100 vehicles in the morning peak hour, from 7:30 to 8:30, and about 1,200 vehicles in the evening peak hour, from 4:00 to 5:00. About 250 and 450 pedestrians crossed the intersection during the AM and PM peak hour, respectively. About 5 cyclists in the AM peak hour (mainly traveling on Broadway and appearing to be commuters) and 15 cyclists in the PM peak hour (including commuters and some young residents using bikes recreationally) crossed the intersection (not shown in the table).

TABLE 3
AM and PM Peak-Hour Traffic Volumes and Pedestrian Crossings
Broadway at Congress Avenue/Third Street, Chelsea

Street name		**Broadway**						**Congress Ave.**			**Third St.**			**Total**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	Turning volume	NA			NA	474	139	87	402	NA	NA			1102
	Approach volume	0			613			489			0			
	Ped. crossings	50			50			70			75			245
PM peak hour	Turning volume	NA			NA	352	132	148	574	NA	NA			1204
	Approach volume	0			482			722			0			
	Ped. crossings	60			75			120			190			445

4 We used one-third of total crashes as the threshold for the peak period crashes.

Table 4 shows that the intersection of Broadway at Everett Avenue/Third Street carried about 1,000 vehicles in the morning peak hour, from 7:30 to 8:30, and about 1,100 vehicles in the evening peak hour, from 4:00 to 5:00. About 200 and 460 pedestrians crossed the intersection during the AM and PM peak hour, respectively. About 5 and 15 cyclists crossed the intersection during the AM and PM peak hour, respectively (not shown in the table).

TABLE 4
AM and PM Peak Hour Traffic Volumes and Pedestrian Crossings
Broadway at Everett Avenue/Cross Street, Chelsea

Street name		**Broadway**						**Cross St.**			**Everett Ave.**			**Total**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	Turning volume	NA			296	257	NA	NA			NA	361	70	984
	Approach volume	0			553			0			431			
	Ped. crossings	60			45			20			70			195
PM peak hour	Turning volume	NA			235	266	NA	NA			NA	475	121	1097
	Approach volume	0			501			0			596			
	Ped. crossings	145			80			75			175			465

Based on the adjusted turning movement counts, staff performed capacity analyses for the two intersections using the computer program Synchro.[5] The analyses were performed according to the unsignalized intersection capacity analysis method of the Highway Capacity Manual.[6]

The analysis of the intersection of Broadway at Congress Avenue/Third Street indicates that traffic on the stop-control approach (Congress Avenue) operates at level of service (LOS) F and endures extensive delays in the PM peak hour (see Table 5). Details of the analysis for both the AM and PM peak hours are included in Appendix B.

The analysis of Broadway at Everett Avenue/Cross Street indicates that traffic on the stop-control approach (Everett Avenue) operates at LOS F and endures extensive delays in both the AM and PM peak hours (see Table 6). Details of the analysis for both the AM and PM peak hours are included in Appendix C.

It should be noted that delays on Broadway at the two intersections could actually be higher than the estimations shown in the tables. Due to heavy pedestrian crossings in the peak hours, vehicles on Broadway from time to time have to yield to crossing pedestrians.

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[5] Synchro is intersection capacity analysis and traffic signal coordination software developed and distributed by Trafficware Ltd. It can be combined with SimTraffic to perform traffic simulation for an individual intersection or a series of intersections.

[6] Transportation Research Board, *Highway Capacity Manual 2000*, National Research Council, Washington D.C., 2000.

TABLE 5
Existing Intersection Capacity Analysis
Broadway at Congress Avenue/Third Street, Chelsea

Street name		**Broadway**						**Congress Ave.**			**Third St.**		
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
AM peak hour	LOS	NA			**A**			**F**			NA		
	Delay (sec/veh)	NA			0			79			NA		
PM peak hour	LOS	NA			**A**			**F**			NA		
	Delay (sec/veh)	NA			0			> 180			NA		

TABLE 6
Existing Intersection Capacity Analysis
Broadway at Everett Avenue/Cross Street, Chelsea

Street name		**Broadway**						**Cross St.**			**Everett Ave.**		
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
AM peak hour	LOS	NA			**A**			NA			**F**		
	Delay (sec/veh)	NA			5			NA			> 180		
PM peak hour	LOS	NA			**A**			NA			**F**		
	Delay (sec/veh)	NA			4			NA			> 180		

PRELIMINARY TRAFFIC SIGNAL WARRANTS ANALYSIS

One of the potential improvements for these intersections is to introduce traffic signal control. According to the Manual for Uniform Traffic Control Devices (MUTCD),[7] an engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location must be performed to determine whether installation of a traffic signal is justified at a particular location. The investigation must include criteria related to the following traffic signal warrants and other factors related to existing operations and safety at the study location:

1. Eight-Hour Vehicular Volume Warrant
2. Four-Hour Vehicular Volume Warrant
3. Peak-Hour Warrant
4. Pedestrian Volume Warrant
5. School Crossing Warrant
6. Coordinated Signal System Warrant
7. Crash Experience Warrant
8. Roadway Network Warrant
9. Intersection Near a Grade Crossing

[7] Federal Highway Administration, U.S. Department of Transportation, *Chapter 4C. Traffic Control Signal Needs*, 2009 Edition, December 2009.

A traffic control signal should not be installed unless two or more of the factors contained in these warrants are met. Moreover, the satisfaction of a warrant or warrants in itself does not justify the installation of a signal unless an engineering study indicates that the installation will improve the overall safety and/or operation of the intersection.

In this study, we performed a preliminary analysis of the applicable traffic signal warrants based on the hourly volumes averaged from the available 24-hour traffic counts. The applicable factors are contained in Warrants 1, 2, 4, and 7, assuming that each of the two intersections operates as an isolated location. Warrant 3 is intended for unusual cases, such as office complexes or manufacturing plants that attract or discharge large numbers of vehicles over a short time, the intersection is not close to any schools. Because of the lack of such buildings, factors related to Warrants 3, 5, 8, and 9 were not considered.

The examination of Warrants 1, 2, and 7 was based on hourly traffic volumes of an average day, which were derived from three mid-week days' traffic counts collected by the MassDOT Highway Division in the week of May 11, 2009. The counts were considered seasonal or slightly higher than the average (see Appendix D for the detailed summary of hourly volumes for all of the approaches at the intersection). Analyses of the traffic counts indicate that the intersection of Broadway at Congress Avenue/Third Street meets the traffic conditions required by Warrant 1, 2, and 7. The intersection of Broadway at Everett Avenue/Cross Street meets only the traffic conditions required by Warrant 2 (Four-Hour Vehicular Volume Warrant).

Warrant 4, the pedestrian volume warrant, is intended for application where traffic volume on a major street is so heavy that pedestrians experience excessive delay in crossing the major street. The examination, based on the hourly traffic volumes from the MassDOT counts and the pedestrian volumes from the staff's turning movement counts, indicates that neither of the intersections meets the required intensive traffic conditions (using both the four-hour and the one-hour criteria), even though the pedestrian volumes are high at the two intersections.

The analysis finds that the two intersections meet at least one or more signal warrants under separate examinations. Detailed analysis of the hourly traffic volumes and pedestrian volumes for Warrants 1, 2, 4, and 7 are summarized in Appendix E for both intersections.

ANALYSIS OF IMPROVEMENT ALTERNATIVES

The above analyses show that the stop controls at the two intersections are insufficient to handle the existing traffic conditions. Common improvement alternatives to stop controls include modern roundabouts and traffic signals. Modern roundabouts were not considered in this study, as they are difficult to fit into the intersections' tight space and are not compatible with the existing street system.

Analysis of traffic signal warrants indicates that both of the two intersections justify the installation of a traffic signal. The traffic signal would interrupt traffic on Broadway to permit traffic from Congress Avenue (and from Everett Avenue) to proceed and reduce the its congested conditions of the minor streets. Properly designed, it would be expected to reduce the frequency and severity of certain types of crashes, especially right-angle collisions.

More significantly, it would potentially reduce conflicts between pedestrians or bicycles and vehicles. Currently the two intersections are somewhat chaotic during peak hours, when both the vehicular and pedestrian traffic are heavy and frequently crossing each other. Properly designed and combined with pedestrian signals, the signal system can provide exclusive or concurrent pedestrian phases for pedestrians to cross the intersections more comfortably and safely.

On the other hand, the traffic signal would potentially increase delays for motorists traveling on parts of Broadway that currently are free of signal controls. As they are located in close proximity along a principal arterial, the traffic signals at the two intersections should be coordinated. The signal coordination would potentially expedite traffic flow and reduce delays for motorists on Broadway.

To evaluate the improvement alternatives, staff used Synchro to perform a two-stage traffic signal optimization analysis. In the first stage, the two intersections were analyzed and optimized separately as individual locations. Once the most suitable operation was identified for each of the two intersections, staff conducted the second-stage analysis, in which the two intersections were coordinated and analyzed as one network system.

An essential factor in timing the signals for the two intersections is the time required for pedestrians to safely cross each of them. We examined the crossing distances of all the approaches at the two intersections and found that a 24-second pedestrian signal phase should be sufficient for pedestrians to cross either of them safely without any unexpected conditions. The estimation applied a 3-foot-per-second pedestrian walking speed in considering the elderly and children living in the area (see Appendix F for detailed estimations at all the approaches).

In the first stage, two alternatives were examined for the two intersections under the existing layouts: (1) a simple two-phase traffic signal operation allowing concurrent pedestrian crossings, and (2) a two-phase traffic operation combined with an on-call exclusive pedestrian signal phase for all pedestrian crossings. Synchro tests show that traffic at both intersections would operate at desirable level of service (LOS) B in the first alternative and would operate at desirable LOS C or acceptable LOS D in the second alternative. However, the second alternative is considered safer for pedestrians than the first alternative, as in the current operation pedestrians still encounter potential conflicts with turning vehicles.[8] We therefore selected the second alternative (signal operations with exclusive pedestrian phases) at this stage. Detailed Synchro analyses and results for both intersections are included in Appendices G and H, respectively.

In the second stage, we tested different combinations of network cycle lengths and offsets for the two intersections through applications of the Synchro network optimization functions. The tests show that the coordinated signals would operate at a better level of service than the uncoordinated signals for almost all the approaches. Although the optimized coordination would increase the average signal cycle length by about a quarter minute, both signals would still operate in a relatively short cycle of under 90 seconds (including the exclusive pedestrian phases). In the PM peak hour, the pedestrian phase would occur in almost every cycle. The signal at Congress Avenue is selected as the master intersection as it has a higher traffic volume

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[8] The conflicts can be reduced by providing an exclusive signal phase and travel lane for turning vehicles so that only through traffic would be concurrent with pedestrians on the same street. However, expansion of either of the intersections does not appear feasible, as the area is fully developed, with limited space available.

than the other signal. Detailed Synchro analyses and results for both intersections are included in Appendices I and J, respectively.

Tables 7 and 8 summarize the capacity analyses and approach delays at the two stages for the two intersections. Under the coordinated signal system, the intersection of Broadway at Congress Avenue/Third Street would operate at desirable LOS C in the AM peak hour and at acceptable LOS D in the PM peak hour in the coordinated scenario (see Table 7); the intersection of Broadway at Everett Avenue/Cross Street would operate at desirable LOS B and LOS C in the AM and PM peak hours, respectively, with minimal delays (see Table 8). Synchro traffic simulations show that traffic on Broadway flows smoothly with the coordinated signal system, with minimal delays in the peak hours at the Everett Avenue/Cross Street intersection.

TABLE 7
Intersection Capacity Analysis of Selected Alternatives
Broadway at Congress Avenue/Third Street, Chelsea

Street Name		**Broadway**	**Congress Avenue**	**Overall**
Approach		**Westbound**	**Northbound**	
AM peak hour	**Existing**	A/0	F/79	NA
	Stage 1	C/34	D/39	D/37
	Stage 2	C/27	D/42	C/33
PM peak hour	**Existing**	A/0	F/>180	NA
	Stage 1	E/56	D/42	D/48
	Stage 2	C/33	D/39	D/37

Note: Performance Measures: Level of Service (A to F)/Average Delay (seconds per vehicle)
Selected alternative in Stage 1: Uncoordinated Two-Phase (NB/WB) Traffic Signal with Exclusive Pedestrian Phase under the Existing Intersection Layout
Selected alternative in Stage 2: Coordinated Two-Phase (NB/WB) Traffic Signal with Exclusive Pedestrian Phase under the Existing Intersection Layout

TABLE 8
Intersection Capacity Analysis of Selected Alternatives
Broadway at Everett Avenue/Cross Street, Chelsea

Street Name		**Broadway**	**Everett Avenue**	**Overall**
Approach		**Westbound**	**Southbound**	
AM peak hour	**Existing**	A/5	F/>180	NA
	Stage 1	C/32	C/32	C/32
	Stage 2	A/4	D/38	B/19
PM peak hour	**Existing**	A/4	F/>180	NA
	Stage 1	D/49	D/37	D/42
	Stage 2	A/9	D/37	C/24

Note: Performance Measures: Level of Service (A to F)/Average Delay (seconds per vehicle)
Selected alternative in Stage 1: Uncoordinated Two-Phase (NB/WB) Traffic Signal with Exclusive Pedestrian Phase under the Existing Intersection Layout
Selected alternative in Stage 2: Coordinated Two-Phase (NB/WB) Traffic Signal with Exclusive Pedestrian Phase under the Existing Intersection Layout

In addition, a future-year scenario of 10% growth over a 20-year planning horizon was tested for the coordinated signal system.[9] Synchro tests show that the intersection of Broadway at Congress Avenue/Third Street would operate at acceptable LOS D in both the AM and PM peak hours; the intersection of Broadway at Everett Avenue/Cross Street would still operate at desirable LOS B and LOS C in the AM and PM peak hours.

IMPROVEMENT RECOMMENDATIONS AND DISCUSSION

The two intersections have a high number of crashes and a crash rate much higher than other unsignalized intersections in the area. More alarmingly, they both have a high pedestrian/bicyclist crash rate. To improve the existing conditions, we conducted a series of safety and operations analyses for the two intersections.

The crash data analysis indicates that traffic congestion during peak periods, a high number of pedestrian crossings, and conflicts between motorists and non-motorists might have been some of the causes of crashes at the two intersections. The capacity analysis ascertains that traffic on Congress Avenue and Everett Avenue endures extensive delays during peak hours. The preliminary signal warrant analysis finds that the two intersections both warrant the installation of traffic signals.

To evaluate potential long-term improvement alternatives, we used Synchro to perform a two-stage traffic signal optimization analysis. In the first stage, the two intersections were analyzed and optimized individually. In the second stage, the two intersections were coordinated and analyzed as one network system. The analysis finds that a coordinated traffic signal system with exclusive pedestrian signal phases would be most beneficial for the two intersections. The coordinated signal system would potentially expedite traffic flow on Broadway. Meanwhile, by including actuated exclusive pedestrian signal phases, the system would improve pedestrian safety at the two intersections.

We therefore recommend that in the long term the two intersections be signalized and coordinated. The two intersections carry heavy pedestrian volumes. The proposed traffic signals are essential more for the pedestrians than for the vehicular traffic, especially at the Everett Avenue/Cross Street intersection.[10] The signals would provide exclusive phases to stop all the traffic for pedestrians to cross the intersections safely and comfortably.

The signal system for the two intersections should include the following features:

- Install a fully actuated and coordinated traffic signal system with pedestrian signals.
- Install pedestrian signal heads with push buttons and accessible (audible) signals at all corners of the intersections.
- Include on-call exclusive pedestrian phases in the signal cycles.
- Install overhead signal indications supported by mast arms, which can be clearly viewed from all approaches.

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[9] The growth assumption is based on a quick review of the traffic projections in the area from the recent Boston Region MPO transportation-planning model.

[10] The proposed Congress Avenue/Third Street intersection signal alone would create traffic gaps for users of this intersection. However, without the proposed traffic signal to stop traffic at intervals, pedestrians at the Everett Avenue/Cross Street intersection would still encounter delays and conflicts with vehicular traffic.

In addition, the following geometric elements should be considered in the functional design stage of the signalization:

- Maintain the existing crosswalks and sidewalks.
- Consider installing pedestrian bulb-outs at the corners of the two intersections where there is on-street parking.

The bulb-out has several advantages: (a) it shortens the distances for pedestrians to cross Broadway and Everett Avenue/Congress Avenue, (b) it narrows the width of Broadway and Everett Avenue/Congress Avenue and slows down the traffic, and (c) it allows pedestrians to have a better view of the street conditions. At this preliminary planning stage, we identified the northeastern corner at the intersection of Broadway at Everett Avenue/Cross Street as an appropriate location to install the bulb-out. At the functional design stage, other potential locations should be further examined.

As the future traffic signals can operate under the existing intersection layouts, the main cost for this recommended improvement would be the new traffic/pedestrian signal system and the installation of any proposed bulb-outs. The total cost of the traffic and pedestrian signals and the coordination system is roughly estimated as $500,000 to $750,000. Each pedestrian bulb-out would cost about $25,000 to $50,000, depending on its size and materials. More precise costs can be estimated at the functional design stage. Currently all the streets and the two intersections are under the jurisdiction of the City of Chelsea. The implementation would require the City to work closely with MassDOT through the project implantation process (see Appendix K).

In the short term, we propose the following improvements for the two intersections:

Broadway at Congress Avenue/Third Street

- Regularly maintain pavement markings to make them prominent to motorists.[11]
- Install a series (at least three) of “SLOW” pavement markings on the WB Broadway approach.
- Install the “Share the Road with Bicyclists” assembly (W11-1/W16-1 in the Manual on Uniform Traffic Control Devices) at appropriate locations along Broadway in the area.
- Install “sharrow” (see Figure 2) pavement makings on Broadway to provide an additional reminder that bicycles use this roadway.

Broadway at Everett Avenue/Cross Street

- Regularly maintain pavement markings to make them prominent to motorists.
- Add a stop sign on each side of the Everett Avenue approach to supplement the flashing beacons.
- Install “No left Turn” regulatory signs on both sides of Everett Avenue ahead of the intersection or mount a “No Left Turn” plaque below the future stop sign on the east side of Everett Avenue.

[11] If necessary, the crosswalks can be painted with a red or green background with white striped lines to provide a contrast and prominent appearance. The color of maroon seems to match the surrounding brick buildings.

- Remove the first parking space on the east side of Everett Avenue.[12]
- Extend the sidewalk on the northeast corner as a pedestrian bulb-out.[13]

Figure 2

Example of "Sharrow" Pavement Marking

The Everett Avenue/Cross Street intersection had five crashes involving pedestrians from 2006 to 2008. Although these short-term improvements would not be as effective as the proposed traffic/pedestrian signal system, they would potentially improve the safety of the two intersections by reducing the conflicts between motorists and non-motorists. Not including the proposed pedestrian bulb-out, they should cost about several thousand dollars and could be implemented in a relatively short time. They are also compatible with the future signal system.

[12] Because the parking space is very close to the intersection, a parked car there usually blocks the view between the motorists on Everett Avenue and on Broadway.

[13] The bulb-out can take the place of a parking space on Everett Avenue that could be removed, and could extend to the existing bus bay on Broadway.

Appendix A

Intersection Crash Rate Calculation
Broadway at Congress Avenue/Third Street, Chelsea
Broadway at Everett Avenue/Cross Street, Chelsea

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Chelsea

COUNT DATE : 6/4/09

DISTRICT : 4

UNSIGNALIZED : X

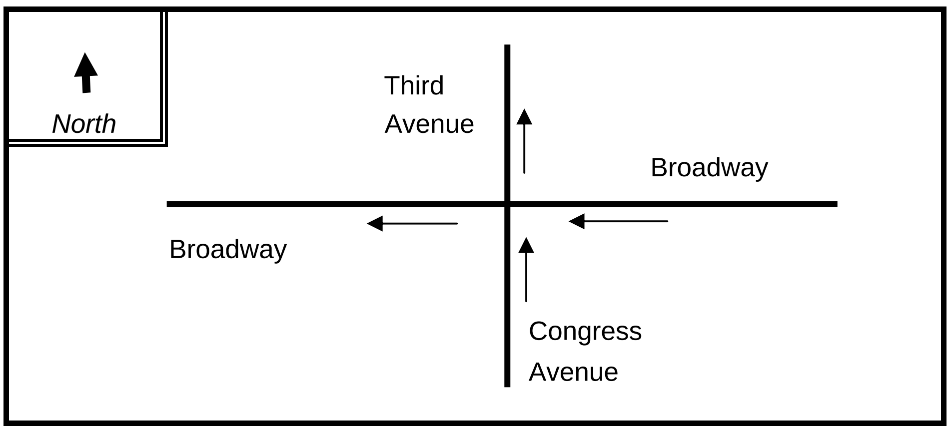
SIGNALIZED :

~ INTERSECTION DATA ~

MAJOR STREET : Broadway

MINOR STREET(S) : Congress Avenue/Third Avenue

INTERSECTION DIAGRAM
(Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	WB	NB				
PEAK HOURLY VOLUMES (AM/PM) :	484	722				1,206

" K " FACTOR : **0.090**

INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **13,400**

TOTAL # OF CRASHES : 57

OF YEARS : 3

AVERAGE # OF CRASHES PER YEAR (**A**) : **19.00**

CRASH RATE CALCULATION : **3.88**

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

Comments : MassDOT District 4 Average Rate = 0.59

Project Title & Date: Safety and Operations Analyses at Selceted Intersections

Moving Massachusetts Forward. massDOT Highway

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Chelsea

COUNT DATE : 6/4/09

DISTRICT : 4

UNSIGNALIZED : X

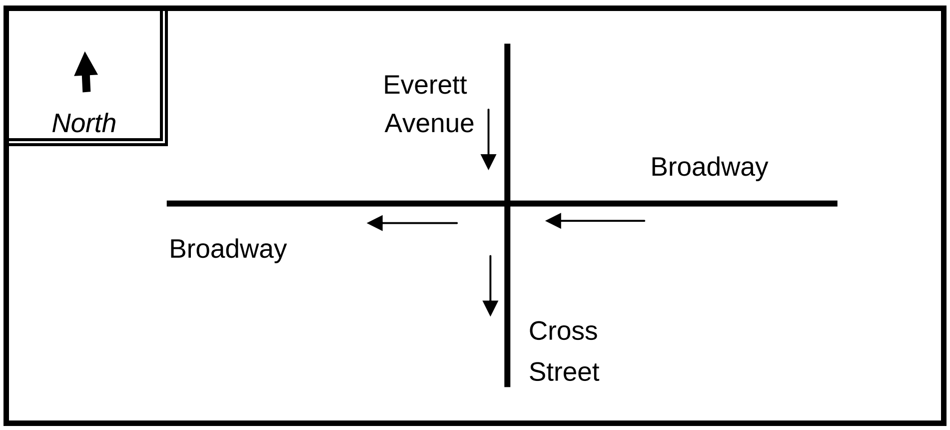
SIGNALIZED :

~ INTERSECTION DATA ~

MAJOR STREET : Broadway

MINOR STREET(S) : Everett Avenue/Cross Street

INTERSECTION DIAGRAM
(Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	WB	SB				
PEAK HOURLY VOLUMES (AM/PM) :	501	596				**1,097**

" K " FACTOR : **0.090**

INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **12,189**

TOTAL # OF CRASHES : 17

OF YEARS : 3

AVERAGE # OF CRASHES PER YEAR (**A**) : **5.67**

CRASH RATE CALCULATION : **1.27**

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

Comments : MassDOT District 4 Average Rate = 0.59

Project Title & Date: Safety and Operations Analyses at Selceted Intersections

Appendix B

AM/PM Peak Hour Intersection Capacity Analysis
Existing Traffic Conditions
Broadway at Congress Avenue/Third Street, Chelsea

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	0	0	0	0	474	139	87	402	0	0	0	0
Sign Control		Free			Free			Stop			Stop	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Hourly flow rate (vph)	0	0	0	0	533	156	98	452	0	0	0	0
Pedestrians		50			50			70			75	
Lane Width (ft)		0.0			11.0			10.0			0.0	
Walking Speed (ft/s)		3.0			3.0			3.0			3.0	
Percent Blockage		0			5			6			0	
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	764			70			386	834	120	962	756	469
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	764			70			386	834	120	962	756	469
tC, single (s)	4.1			4.1			7.5	6.5	6.9	7.5	6.5	6.9
tC, 2 stage (s)												
tF (s)	2.2			2.2			3.5	4.0	3.3	3.5	4.0	3.3
p0 queue free %	100			100			80	0	100	0	100	100
cM capacity (veh/h)	858			1443			486	283	812	0	318	546

Direction, Lane #	WB 1	WB 2	NB 1	NB 2
Volume Total	355	334	248	301
Volume Left	0	0	98	0
Volume Right	0	156	0	0
cSH	1700	1700	339	283
Volume to Capacity	0.21	0.20	0.73	1.06
Queue Length 95th (ft)	0	0	138	296
Control Delay (s)	0.0	0.0	39.9	111.5
Lane LOS			E	F
Approach Delay (s)	0.0		79.2	
Approach LOS			F	

Intersection Summary			
Average Delay	35.1		
Intersection Capacity Utilization	45.8%	ICU Level of Service	A
Analysis Period (min)	15		

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	0	0	0	0	352	132	148	574	0	0	0	0
Sign Control		Free			Free			Stop			Stop	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hourly flow rate (vph)	0	0	0	0	371	139	156	604	0	0	0	0
Pedestrians		60			75			120			190	
Lane Width (ft)		0.0			11.0			10.0			0.0	
Walking Speed (ft/s)		3.0			3.0			3.0			3.0	
Percent Blockage		0			8			11			0	
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	699			120			365	819	195	1007	750	505
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	699			120			365	819	195	1007	750	505
tC, single (s)	4.1			4.1			7.5	6.5	6.9	7.5	6.5	6.9
tC, 2 stage (s)												
tF (s)	2.2			2.2			3.5	4.0	3.3	3.5	4.0	3.3
p0 queue free %	100			100			66	0	100	0	100	100
cM capacity (veh/h)	907			1316			462	276	673	0	304	518

Direction, Lane #	WB 1	WB 2	NB 1	NB 2
Volume Total	247	262	357	403
Volume Left	0	0	156	0
Volume Right	0	139	0	0
cSH	1700	1700	335	276
Volume to Capacity	0.15	0.15	1.07	1.46
Queue Length 95th (ft)	0	0	327	564
Control Delay (s)	0.0	0.0	104.3	260.5
Lane LOS			F	F
Approach Delay (s)	0.0		187.1	
Approach LOS			F	

Intersection Summary			
Average Delay	112.0		
Intersection Capacity Utilization	50.0%	ICU Level of Service	A
Analysis Period (min)	15		

Appendix C

AM/PM Peak Hour Intersection Capacity Analysis
Existing Traffic Conditions
Broadway at Everett Avenue/Cross Street, Chelsea

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	0	0	0	296	257	0	0	0	0	0	361	70
Sign Control		Free			Free			Stop			Stop	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Hourly flow rate (vph)	0	0	0	333	289	0	0	0	0	0	406	79
Pedestrians		60			45			70			70	
Lane Width (ft)		0.0			11.0			0.0			10.0	
Walking Speed (ft/s)		3.0			3.0			3.0			3.0	
Percent Blockage		0			5			0			6	
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	359			70			1221	1094	115	1069	1094	274
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	359			70			1221	1094	115	1069	1094	274
tC, single (s)	4.1			4.3			7.5	6.5	6.9	7.5	6.6	7.0
tC, 2 stage (s)												
tF (s)	2.2			2.3			3.5	4.0	3.3	3.5	4.0	3.3
p0 queue free %	100			78			0	100	100	100	0	88
cM capacity (veh/h)	1133			1479			0	156	880	125	152	673

Direction, Lane #	WB 1	WB 2	SB 1	SB 2
Volume Total	429	193	270	214
Volume Left	333	0	0	0
Volume Right	0	0	0	79
cSH	1479	1700	152	212
Volume to Capacity	0.22	0.11	1.78	1.01
Queue Length 95th (ft)	22	0	498	226
Control Delay (s)	6.7	0.0	427.6	111.2
Lane LOS	A		F	F
Approach Delay (s)	4.7		287.9	
Approach LOS			F	

Intersection Summary			
Average Delay	128.7		
Intersection Capacity Utilization	43.0%	ICU Level of Service	A
Analysis Period (min)	15		

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	0	0	0	235	266	0	0	0	0	0	475	121
Sign Control		Free			Free			Stop			Stop	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hourly flow rate (vph)	0	0	0	247	280	0	0	0	0	0	500	127
Pedestrians		145			80			75			175	
Lane Width (ft)		0.0			11.0			0.0			10.0	
Walking Speed (ft/s)		3.0			3.0			3.0			3.0	
Percent Blockage		0			8			0			16	
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	455			75			1232	1025	155	1030	1025	460
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	455			75			1232	1025	155	1030	1025	460
tC, single (s)	4.1			4.2			7.5	6.5	6.9	7.5	6.5	6.9
tC, 2 stage (s)												
tF (s)	2.2			2.2			3.5	4.0	3.3	3.5	4.0	3.3
p0 queue free %	100			84			0	100	100	100	0	72
cM capacity (veh/h)	935			1515			0	166	799	111	164	459

Direction, Lane #	WB 1	WB 2	SB 1	SB 2
Volume Total	341	187	333	294
Volume Left	247	0	0	0
Volume Right	0	0	0	127
cSH	1515	1700	164	227
Volume to Capacity	0.16	0.11	2.03	1.29
Queue Length 95th (ft)	15	0	650	387
Control Delay (s)	6.1	0.0	532.3	203.8
Lane LOS	A		F	F
Approach Delay (s)	3.9		378.3	
Approach LOS			F	

Intersection Summary			
Average Delay	207.3		
Intersection Capacity Utilization	44.8%	ICU Level of Service	A
Analysis Period (min)	15		

Appendix D

Summary of hourly traffic volumes
May/June, 2009
Broadway at Congress Avenue/Third Street, Chelsea
Broadway at Everett Avenue/Cross Street, Chelsea

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 1 WB
1-WAY

Site Reference: 000000000526
Site ID: 090150000104
Location: BROADWAY, EAST OF CONGRESS AVE/3RD ST.
Direction: WEST

File: 104.prn
City: CHELSEA
County: VOL ONE-WAY

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		99	140	106		115			115	345
02:00		62	91	77		76			76	230
03:00		55	55	76		62			62	186
04:00		54	65	97		72			72	216
05:00		93	113	124		110			110	330
06:00		270	292	303		288			288	865
07:00		485	483	512		493			493	1480
08:00		535	562	570		555			555	1667
09:00		623	686	685		664			664	1994
10:00		624	593	612		609			609	1829
11:00		585	635			610			610	1220
12:00		681	682			681			681	1363
13:00		594	672			633			633	1266
14:00		662	630			646			646	1292
15:00		654	601			627			627	1255
16:00	694	778	595			689			689	2067
17:00	669	685	658			670			670	2012
18:00	669	603	626			632			632	1898
19:00	559	580	565			568			568	1704
20:00	503	523	521			515			515	1547
21:00	426	439	483			449			449	1348
22:00	347	354	385			362			362	1086
23:00	252	260	256			256			256	768
24:00	156	166	173			165			165	495
'OTALS	4275	10464	10562	3162	0	10547	0	0	10547	28463
: AVG WKDY	40.5	99.2	100.1	29.9						
: AVG WEEK	40.5	99.2	100.1	29.9						
ιM Times		12:00	09:00	09:00		12:00			12:00	
ιM Peaks		681	686	685		681			681	
'M Times	16:00	16:00	13:00			16:00			16:00	
'M Peaks	694	778	672			689			689	

u3

AWD 10547
FAC .90 (.96)
ADT 9,100

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 2 NB
1-WAY

Site Reference: 000000000885
Site ID: 090150000201
Location: CONGRESS AVE., SOUTH OF BROADWAY
Direction: NORTH

File: 201.prn
City: CHELSEA
County: VOL ONE-WAY

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		87	118	103		102			102	308
02:00		71	100	89		86			86	260
03:00		84	61	83		76			76	228
04:00		67	67	64		66			66	198
05:00		108	132	133		124			124	373
06:00		275	316	340		310			310	931
07:00		508	457	485		483			483	1450
08:00		529	538	548		538			538	1615
09:00		507	535	504		515			515	1546
10:00		480	534	500		504			504	1514
11:00		426	449			437			437	875
12:00		507	545			526			526	1052
13:00		559	610			584			584	1169
14:00		611	585			598			598	1196
15:00		651	656			653			653	1307
16:00	764	702	641			702			702	2107
17:00	651	655	626			644			644	1932
18:00	630	648	586			621			621	1864
19:00	530	578	551			553			553	1659
20:00	466	417	462			448			448	1345
21:00	417	378	398			397			397	1193
22:00	284	324	351			319			319	959
23:00	216	230	211			219			219	657
24:00	142	170	178			163			163	490
'OTALS	4100	9572	9707	2849	0	9668	0	0	9668	26228
. AVG WKDY	42.4	99	100.4	29.4						
. AVG WEEK	42.4	99	100.4	29.4						
.M Times		08:00	12:00	08:00		08:00			08:00	
.M Peaks		529	545	548		538			538	
'M Times	16:00	16:00	15:00			16:00			16:00	
'M Peaks	764	702	656			702			702	

u6

AWD 9668
FAC .90 (.98)
ADT 8,500

Broadway @ Everett Ave.

Mass Highway Department
WEEKLY SUMMARY FOR LANE
Starting: 6/16/2009

STA. 1

Site Reference: 000000000714
Site ID: 090200000104
Location: BROADWAY WB, BTWN EVERETT AVE & 3rd ST.
Direction: ROAD TOTAL

1-WAY

File: 104-R.prn
City: CHELSEA
County: VOL

TIME	MON 22	TUE 16	WED 17	THU 18	FRI 19	WKDAY AVG	SAT 20	SUN 21	WEEK AVG	TOTAL
01:00	117		71	78	78	86	178	176	116	698
02:00	92		45	51	64	63	146	190	98	588
03:00	76		54	50	62	60	123	130	82	495
04:00	81		50	49	65	61	95	102	73	442
05:00	120		74	81	86	90	66	65	82	492
06:00	234		183	162	152	182	108	56	149	895
07:00	237		260	267	272	259	168	91	215	1295
08:00	343		288	384	383	349	200	136	289	1734
09:00	419		296	463	446	406	252	173	341	2049
10:00	395		291	413	374	368	345	241	343	2059
11:00	417		318	353	400	372	463	304	375	2255
12:00	493		328	403	432	414	475	372	417	2503
13:00	468		414	443	492	454	541	393	458	2751
14:00	457	466	415	424	508	454	478	479	461	3227
15:00	511	465	365	477	541	471	439	408	458	3206
16:00	457	486	457	488	497	477	478	403	466	3266
17:00	472	515	483	516	534	504	517	347	483	3384
18:00	472	506	466	468	507	483	465	371	465	3255
19:00	356	391	450	459	456	422	517	345	424	2974
20:00	334	459	402	391	463	409	507	345	414	2901
21:00	272	368	315	296	394	329	434	350	347	2429
22:00	282	314	298	271	404	313	395	334	328	2298
23:00	187	217	183	194	318	219	385	268	250	1752
24:00	158	140	149	132	246	165	248	195	181	1268
TOTALS	7450	4327	6655	7313	8174	7410	8023	6274	7315	48216
% AVG WKDY	100.5	58.3	89.8	98.6	110.3		108.2	84.6		
% AVG WEEK	101.8	59.1	90.9	99.9	111.7		109.6	85.7		
AM Times	12:00		12:00	09:00	09:00	12:00	12:00	12:00	12:00	
AM Peaks	493		328	463	446	414	475	372	417	
PM Times	15:00	17:00	17:00	17:00	15:00	17:00	13:00	14:00	17:00	
PM Peaks	511	515	483	516	541	504	541	479	483	

U3

AWD 7410

FAC .90(.96)

ADT 6,400

Mass Highway Department
WEEKLY SUMMARY FOR LANE
Starting: 6/1/2009

STA. 2

Site Reference: 000000000684
Site ID: 090200000201
Location: EVERETT AVE NB, BTWN CHERRY ST & BROADWY
Direction: ROAD TOTAL SB

1-WAY

File: 201.prn
City: CHELSEA
County: VOL

TIME	MON 1	TUE 2	WED 3	THU 4	FRI 5	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		112	109	122	147	122			122	490
02:00		75	82	98	112	91			91	367
03:00		68	69	79	97	78			78	313
04:00		86	113	80	91	92			92	370
05:00		98	93	78	91	90			90	360
06:00		142	152	146	147	146			146	587
07:00		246	231	218	248	235			235	943
08:00		383	357	382	330	363			363	1452
09:00		437	417	425	430	427			427	1709
10:00		448	396	421	411	419			419	1676
11:00		472	434	438		448			448	1344
12:00		430	458	482		456			456	1370
13:00		511	495	525		510			510	1531
14:00	525	520	516	481		510			510	2042
15:00	525	500	525	547		524			524	2097
16:00	571	565	580	575		572			572	2291
17:00	609	545	561	601		579			579	2316
18:00	529	588	504	542		540			540	2163
19:00	542	483	533	535		523			523	2093
20:00	433	454	453	471		452			452	1811
21:00	434	438	392	422		421			421	1686
22:00	373	361	361	401		374			374	1496
23:00	256	245	238	289		257			257	1028
24:00	165	184	177	202		182			182	728
TOTALS	4962	8391	8246	8560	2104	8411	0	0	8411	32263
% AVG WKDY	58.9	99.7	98	101.7	25					
% AVG WEEK	58.9	99.7	98	101.7	25					
AM Times		11:00	12:00	12:00	09:00	12:00			12:00	
AM Peaks		472	458	482	430	456			456	
PM Times	17:00	18:00	16:00	17:00		17:00			17:00	
PM Peaks	609	588	580	601		579			579	

u3

AWD 8411
FAC .90 (.96)
ADT 7,300

Appendix E

Analysis of Traffic Signal Warrants 1, 2, 4, and 7
Based on 2009 Traffic Counts
Broadway at Congress Avenue/Third Street, Chelsea
Broadway at Everett Avenue/Cross Street, Chelsea

Traffic Signal Warrents Analysis:
Broadway @ Congress/Third Ave, Chelsea

Court	Hourly Traffic Vol.		Intersection Ped. Vol.		**Examination of Signal Warrants:**			
Period	Main St.	Minor St.	Total	50%	**Warrant 1**	**Warrant 2**	**Warrant 4**	**Warrant 7**
7:00	493	483	184	92				X
8:00	555	538	264	132		X		X
9:00	664	515			X	X		X
10:00	609	504			X	X		X
11:00	610	437			X	X		X
12:00	681	526			X	X		X
13:00	633	584			X	X		X
14:00	646	598			X	X		X
15:00	627	653			X	X		X
16:00	689	702	445	223	X	X	X	X
17:00	670	644	470	235	X	X	X	X
18:00	632	621			X	X		X
19:00	568	553				X		X
20:00	515	448						X
Criteria:								
Warrant 1	> 600	> 200						
Warrant 2	Figure 4C-1							
Warrant 7	> 480	> 160						
Warrant 4	Figures 4C-5 and 4C-7							
Results:					**Satisfied**	**Satisfied**	**No**	**Satisfied**

Note: For Warrant 4, the main street (Broadway) traffic volumes and 50% pedestrian crossings were used.
The check marks in the warrant examination are for the 4-hour criterion.
As shown, only two hours in the afternoon meet the criterion.

Traffic Signal Warrents Analysis:
Broadway @ Everett Ave, Chelsea

Court Period	Hourly Traffic Vol. Main St.	Hourly Traffic Vol. Minor St.	Intersection Ped. Vol. Total	Intersection Ped. Vol. 50%	Examination of Signal Warrants: Warrant 1	Warrant 2	Warrant 4	Warrant 7
7:00	259	235	123	62				
8:00	370	363	170	85				
9:00	443	427						
10:00	394	419						
11:00	390	448						
12:00	443	456						
13:00	468	510				X		
14:00	463	510				X		
15:00	510	524				X		X
16:00	481	572	472	236		X		X
17:00	507	579	470	235		X		X
18:00	482	540				X		X
19:00	424	523						
20:00	376	452						
Criteria:								
Warrant 1	> 600	> 200						
Warrant 2	Figure 4C-1							
Warrant 7	> 480	> 160						
Warrant 4	Figures 4C-5 and 4C-7							
Results:					**No**	**Satisfied**	**No**	**No**

Note: For Warrant 4, the main street (Broadway) traffic volumes and 50% pedestrian crossings were used.

Appendix F

Pedestrian Signal Time Estimations
Broadway at Congress Avenue/Third Street, Chelsea
Broadway at Everett Avenue/Cross Street, Chelsea

Broadway @ Congress Avenue/Third Street, Chelsea

Crossing location	Broadway WB	Broadway EB	Congress Ave.	Third St.
Crossing distance (feet)	45	45	30	30
Walk indication interval	7.0	7.0	7.0	7.0
Pedestrian clearance time (ped. walk speed = 3.5 ft/sec.)	12.9	12.9	8.6	8.6
Pedestrian clearance time (ped. walk speed = 3 ft/sec.)	15.0	15.0	10.0	10.0
Total pedestrain phase time (ped. walk speed = 3.5 ft/sec.)	19.9	19.9	15.6	15.6
Total pedestrain phase time (ped. walk speed = 3 ft/sec.)	22.0	22.0	17.0	17.0

Broadway @ Everett Avenue/Cross Street, Chelsea

Crossing location	Broadway WB	Broadway EB	Everett Ave.	Cross St.
Crossing distance (feet)	50	40	45	30
Walk indication interval	7.0	7.0	7.0	7.0
Pedestrian clearance time (ped. walk speed = 3.5 ft/sec.)	14.3	11.4	12.9	8.6
Pedestrian clearance time (ped. walk speed = 3 ft/sec.)	16.7	13.3	15.0	10.0
Total pedestrain phase time (ped. walk speed = 3.5 ft/sec.)	21.3	18.4	19.9	15.6
Total pedestrain phase time (ped. walk speed = 3 ft/sec.)	23.7	20.3	22.0	17.0

Note:

1. Crossing Distnaces were estimated from aerial photography in the vicinity.
2. Pedestrian walk speed 3 ft/sec. is used for this study, while estimations of MUTCD's satndard speed (3.5 ft/sec.) also are listed for reference.

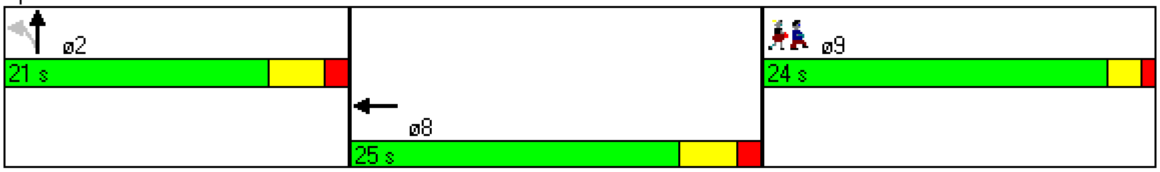
Appendix G

AM/PM Peak Hour Intersection Capacity Analysis
Stage 1: Uncoordinated Traffic Signal Alternative
Broadway at Congress Avenue/Third Street, Chelsea

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	0	0	0	0	474	139	87	402	0	0	0	0
Confl. Peds. (#/hr)	75		70	70		75	50		50	50		50
Confl. Bikes (#/hr)						1			3			
Peak Hour Factor	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	0%	0%	0%	0%	8%	20%	2%	2%	0%	0%	0%	0%
Bus Blockages (#/hr)	0	0	0	0	0	10	0	0	0	0	0	0
Parking (#/hr)	0	0	0	0	0	10	5	0	0	0	0	0
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type							Perm					
Protected Phases					8			2				
Permitted Phases							2					
Detector Phase					8		2	2				
Switch Phase												
Minimum Initial (s)					4.0		4.0	4.0				
Minimum Split (s)					11.0		11.0	11.0				
Total Split (s)	0.0	0.0	0.0	0.0	25.0	0.0	21.0	21.0	0.0	0.0	0.0	0.0
Total Split (%)	0.0%	0.0%	0.0%	0.0%	35.7%	0.0%	30.0%	30.0%	0.0%	0.0%	0.0%	0.0%
Yellow Time (s)					3.5		3.5	3.5				
All-Red Time (s)					1.5		1.5	1.5				
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	4.0	4.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode					Max		None	None				
Act Effct Green (s)					20.9			15.3				
Actuated g/C Ratio					0.33			0.24				
v/c Ratio					0.83			0.84				
Control Delay					34.6			38.7				
Queue Delay					0.0			0.0				
Total Delay					34.6			38.7				
LOS					C			D				
Approach Delay					34.6			38.7				
Approach LOS					C			D				

Intersection Summary	
Cycle Length: 70	
Actuated Cycle Length: 64.3	
Natural Cycle: 70	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.84	
Intersection Signal Delay: 36.5	Intersection LOS: D
Intersection Capacity Utilization 47.4%	ICU Level of Service A
Analysis Period (min) 15	

Splits and Phases: 1: Int



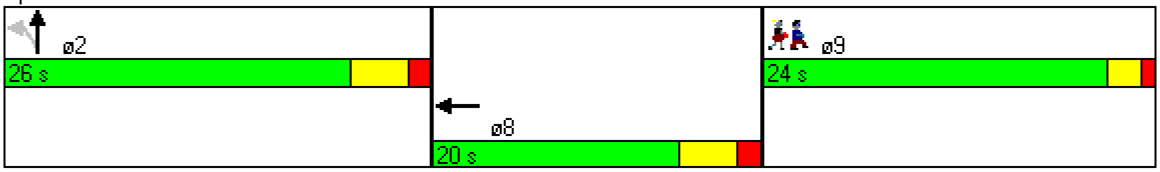
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	34%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	0	0	0	0	352	132	148	574	0	0	0	0
Confl. Peds. (#/hr)	190		120	120		190	60		75	75		60
Confl. Bikes (#/hr)						1			3			
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	0%	0%	0%	0%	3%	11%	1%	1%	0%	0%	0%	0%
Bus Blockages (#/hr)	0	0	0	0	0	10	0	0	0	0	0	0
Parking (#/hr)	0	0	0	0	0	20	0	0	10	0	0	0
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type							Perm					
Protected Phases					8			2				
Permitted Phases							2					
Detector Phase					8		2	2				
Switch Phase												
Minimum Initial (s)					4.0		4.0	4.0				
Minimum Split (s)					11.0		11.0	11.0				
Total Split (s)	0.0	0.0	0.0	0.0	20.0	0.0	26.0	26.0	0.0	0.0	0.0	0.0
Total Split (%)	0.0%	0.0%	0.0%	0.0%	28.6%	0.0%	37.1%	37.1%	0.0%	0.0%	0.0%	0.0%
Yellow Time (s)					3.5		3.5	3.5				
All-Red Time (s)					1.5		1.5	1.5				
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	4.0	4.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode					Max		None	None				
Act Effct Green (s)					15.0			20.8				
Actuated g/C Ratio					0.21			0.30				
v/c Ratio					0.94			0.91				
Control Delay					56.4			41.7				
Queue Delay					0.0			0.0				
Total Delay					56.4			41.7				
LOS					E			D				
Approach Delay					56.4			41.7				
Approach LOS					E			D				

Intersection Summary	
Cycle Length: 70	
Actuated Cycle Length: 69.8	
Natural Cycle: 70	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.94	
Intersection Signal Delay: 47.6	Intersection LOS: D
Intersection Capacity Utilization 51.6%	ICU Level of Service A
Analysis Period (min) 15	

Splits and Phases: 1: Int



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	34%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

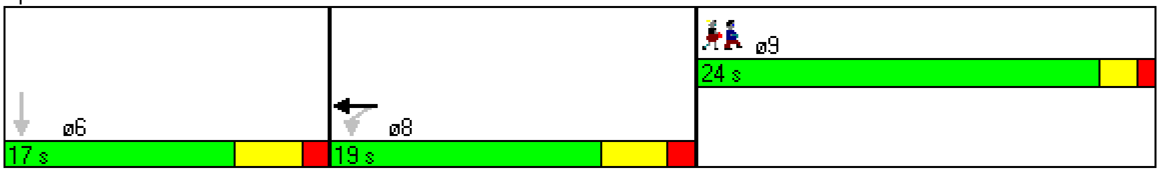
Appendix H

AM/PM Peak Hour Intersection Capacity Analysis
Stage 1: Uncoordinated Traffic Signal Alternative
Broadway at Everett Avenue/Cross Street, Chelsea

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	0	0	0	296	257	0	0	0	0	0	361	70
Confl. Peds. (#/hr)	70		20	20		70	60		45	45		60
Confl. Bikes (#/hr)						3						
Peak Hour Factor	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	0%	0%	0%	9%	5%	0%	0%	0%	0%	0%	4%	3%
Bus Blockages (#/hr)	0	0	0	0	0	10	0	0	0	0	0	5
Parking (#/hr)				0	0	0				0	0	0
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type				Perm								
Protected Phases					8							
Permitted Phases				8							6	
Detector Phase				8	8						6	
Switch Phase												
Minimum Initial (s)				4.0	4.0						4.0	
Minimum Split (s)				11.0	11.0						11.0	
Total Split (s)	0.0	0.0	0.0	19.0	19.0	0.0	0.0	0.0	0.0	0.0	17.0	0.0
Total Split (%)	0.0%	0.0%	0.0%	31.7%	31.7%	0.0%	0.0%	0.0%	0.0%	0.0%	28.3%	0.0%
Yellow Time (s)				3.5	3.5						3.5	
All-Red Time (s)				1.5	1.5						1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode				Max	Max						None	
Act Effct Green (s)					14.9						11.7	
Actuated g/C Ratio					0.27						0.21	
v/c Ratio					0.86dl						0.77	
Control Delay					30.3						32.4	
Queue Delay					1.6						0.0	
Total Delay					31.8						32.4	
LOS					C						C	
Approach Delay					31.8						32.4	
Approach LOS					C						C	

Intersection Summary	
Cycle Length: 60	
Actuated Cycle Length: 54.6	
Natural Cycle: 60	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.77	
Intersection Signal Delay: 32.1	Intersection LOS: C
Intersection Capacity Utilization 44.7%	ICU Level of Service A
Analysis Period (min) 15	
dl Defacto Left Lane. Recode with 1 though lane as a left lane.	

Splits and Phases: 3: Int



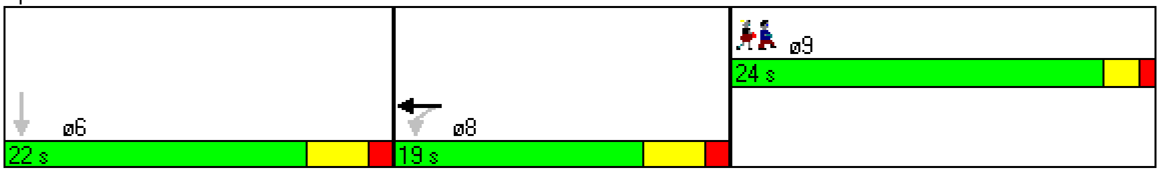
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	40%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	0	0	0	235	266	0	0	0	0	0	475	121
Confl. Peds. (#/hr)	175		75	75		175	145		80	80		145
Confl. Bikes (#/hr)						3						
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	0%	0%	0%	3%	3%	3%	0%	0%	0%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	20	0	0	0	0	0	0	10
Parking (#/hr)				0	20	0				0	10	10
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type				Perm								
Protected Phases					8							
Permitted Phases				8							6	
Detector Phase				8	8						6	
Switch Phase												
Minimum Initial (s)				4.0	4.0						4.0	
Minimum Split (s)				11.0	11.0						11.0	
Total Split (s)	0.0	0.0	0.0	19.0	19.0	0.0	0.0	0.0	0.0	0.0	22.0	0.0
Total Split (%)	0.0%	0.0%	0.0%	29.2%	29.2%	0.0%	0.0%	0.0%	0.0%	0.0%	33.8%	0.0%
Yellow Time (s)				3.5	3.5						3.5	
All-Red Time (s)				1.5	1.5						1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode				Max	Max						None	
Act Effct Green (s)					14.0						16.4	
Actuated g/C Ratio					0.22						0.25	
v/c Ratio					0.96dl						0.86	
Control Delay					45.3						37.0	
Queue Delay					3.3						0.0	
Total Delay					48.6						37.0	
LOS					D						D	
Approach Delay					48.6						37.0	
Approach LOS					D						D	

Intersection Summary	
Cycle Length: 65	
Actuated Cycle Length: 64.4	
Natural Cycle: 65	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.89	
Intersection Signal Delay: 42.3	Intersection LOS: D
Intersection Capacity Utilization 46.4%	ICU Level of Service A
Analysis Period (min) 15	
dl Defacto Left Lane. Recode with 1 though lane as a left lane.	

Splits and Phases: 3: Int



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	37%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

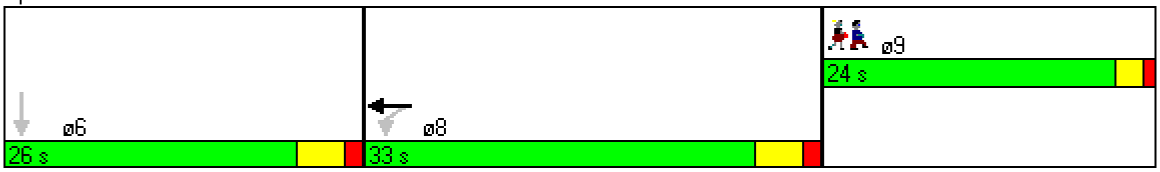
Appendix I

AM/PM Peak Hour Intersection Capacity Analysis
Stage 2: Coordinated Traffic Signal Alternative
Broadway at Congress Avenue/Third Street, Chelsea

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	0	0	0	296	257	0	0	0	0	0	361	70
Confl. Peds. (#/hr)	70		20	20		70	60		45	45		60
Confl. Bikes (#/hr)						3						
Peak Hour Factor	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	0%	0%	0%	9%	5%	0%	0%	0%	0%	0%	4%	3%
Bus Blockages (#/hr)	0	0	0	0	0	10	0	0	0	0	0	5
Parking (#/hr)				0	0	0				0	0	0
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type				Perm								
Protected Phases					8							
Permitted Phases				8							6	
Detector Phase				8	8						6	
Switch Phase												
Minimum Initial (s)				4.0	4.0						4.0	
Minimum Split (s)				11.0	11.0						11.0	
Total Split (s)	0.0	0.0	0.0	33.0	33.0	0.0	0.0	0.0	0.0	0.0	26.0	0.0
Total Split (%)	0.0%	0.0%	0.0%	39.8%	39.8%	0.0%	0.0%	0.0%	0.0%	0.0%	31.3%	0.0%
Yellow Time (s)				3.5	3.5						3.5	
All-Red Time (s)				1.5	1.5						1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode				C-Max	C-Max						None	
Act Effct Green (s)					35.7						18.1	
Actuated g/C Ratio					0.43						0.22	
v/c Ratio					0.48						0.75	
Control Delay					3.8						37.9	
Queue Delay					0.3						0.0	
Total Delay					4.1						37.9	
LOS					A						D	
Approach Delay					4.1						37.9	
Approach LOS					A						D	

Intersection Summary	
Cycle Length: 83	
Actuated Cycle Length: 83	
Offset: 5 (6%), Referenced to phase 8:WBTL, Start of Green	
Natural Cycle: 60	
Control Type: Actuated-Coordinated	
Maximum v/c Ratio: 0.75	
Intersection Signal Delay: 18.9	Intersection LOS: B
Intersection Capacity Utilization 44.7%	ICU Level of Service A
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	29%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

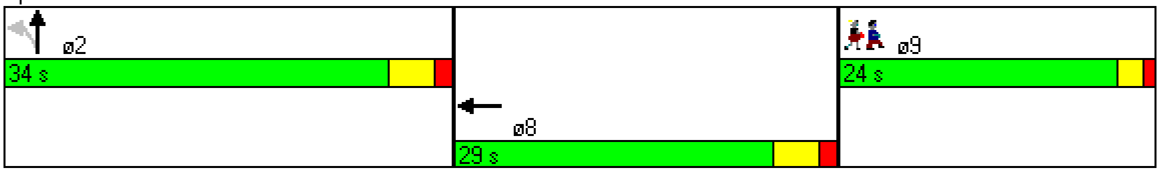
Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	0	0	0	0	352	132	148	574	0	0	0	0
Confl. Peds. (#/hr)	190		120	120		190	60		75	75		60
Confl. Bikes (#/hr)						1			3			
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	0%	0%	0%	0%	3%	11%	1%	1%	0%	0%	0%	0%
Bus Blockages (#/hr)	0	0	0	0	0	10	0	0	0	0	0	0
Parking (#/hr)	0	0	0	0	0	20	0	0	10	0	0	0
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type							Perm					
Protected Phases					8			2				
Permitted Phases							2					
Detector Phase					8		2	2				
Switch Phase												
Minimum Initial (s)					4.0		4.0	4.0				
Minimum Split (s)					11.0		11.0	11.0				
Total Split (s)	0.0	0.0	0.0	0.0	29.0	0.0	34.0	34.0	0.0	0.0	0.0	0.0
Total Split (%)	0.0%	0.0%	0.0%	0.0%	33.3%	0.0%	39.1%	39.1%	0.0%	0.0%	0.0%	0.0%
Yellow Time (s)					3.5		3.5	3.5				
All-Red Time (s)					1.5		1.5	1.5				
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	4.0	4.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode					C-Max		None	None				
Act Effct Green (s)					25.5			27.5				
Actuated g/C Ratio					0.29			0.32				
v/c Ratio					0.68			0.86				
Control Delay					33.2			39.0				
Queue Delay					0.1			0.0				
Total Delay					33.3			39.0				
LOS					C			D				
Approach Delay					33.3			39.0				
Approach LOS					C			D				

Intersection Summary

Cycle Length: 87
Actuated Cycle Length: 87
Offset: 0 (0%), Referenced to phase 8:WBT, Start of Green, Master Intersection
Natural Cycle: 70
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 0.86
Intersection Signal Delay: 36.7 Intersection LOS: D
Intersection Capacity Utilization 51.6% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 1: Int



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	28%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix J

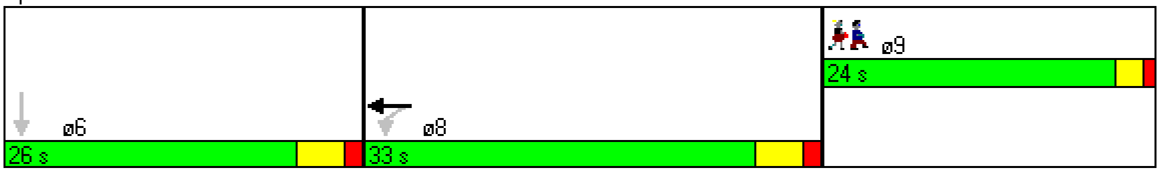
AM/PM Peak Hour Intersection Capacity Analysis
Stage 2: Coordinated Traffic Signal Alternative
Broadway at Everett Avenue/Cross Street, Chelsea

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	0	0	0	296	257	0	0	0	0	0	361	70
Confl. Peds. (#/hr)	70		20	20		70	60		45	45		60
Confl. Bikes (#/hr)						3						
Peak Hour Factor	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	0%	0%	0%	9%	5%	0%	0%	0%	0%	0%	4%	3%
Bus Blockages (#/hr)	0	0	0	0	0	10	0	0	0	0	0	5
Parking (#/hr)				0	0	0				0	0	0
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type				Perm								
Protected Phases					8							
Permitted Phases				8							6	
Detector Phase				8	8						6	
Switch Phase												
Minimum Initial (s)				4.0	4.0						4.0	
Minimum Split (s)				11.0	11.0						11.0	
Total Split (s)	0.0	0.0	0.0	33.0	33.0	0.0	0.0	0.0	0.0	0.0	26.0	0.0
Total Split (%)	0.0%	0.0%	0.0%	39.8%	39.8%	0.0%	0.0%	0.0%	0.0%	0.0%	31.3%	0.0%
Yellow Time (s)				3.5	3.5						3.5	
All-Red Time (s)				1.5	1.5						1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode				C-Max	C-Max						None	
Act Effct Green (s)					35.7						18.1	
Actuated g/C Ratio					0.43						0.22	
v/c Ratio					0.48						0.75	
Control Delay					3.8						37.9	
Queue Delay					0.3						0.0	
Total Delay					4.1						37.9	
LOS					A						D	
Approach Delay					4.1						37.9	
Approach LOS					A						D	

Intersection Summary

Cycle Length: 83
Actuated Cycle Length: 83
Offset: 5 (6%), Referenced to phase 8:WBTL, Start of Green
Natural Cycle: 60
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 0.75
Intersection Signal Delay: 18.9 Intersection LOS: B
Intersection Capacity Utilization 44.7% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 3: Int



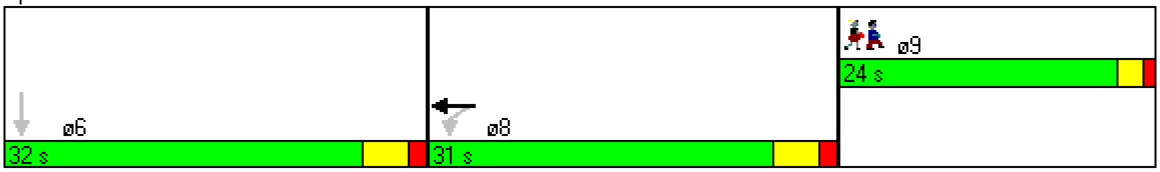
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	29%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	0	0	0	235	266	0	0	0	0	0	475	121
Confl. Peds. (#/hr)	175		75	75		175	145		80	80		145
Confl. Bikes (#/hr)						3						
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	0%	0%	0%	3%	3%	3%	0%	0%	0%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	20	0	0	0	0	0	0	10
Parking (#/hr)				0	20	0				0	10	10
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type				Perm								
Protected Phases					8							
Permitted Phases				8							6	
Detector Phase				8	8						6	
Switch Phase												
Minimum Initial (s)				4.0	4.0						4.0	
Minimum Split (s)				11.0	11.0						11.0	
Total Split (s)	0.0	0.0	0.0	31.0	31.0	0.0	0.0	0.0	0.0	0.0	32.0	0.0
Total Split (%)	0.0%	0.0%	0.0%	35.6%	35.6%	0.0%	0.0%	0.0%	0.0%	0.0%	36.8%	0.0%
Yellow Time (s)				3.5	3.5						3.5	
All-Red Time (s)				1.5	1.5						1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	4.0	4.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode				C-Max	C-Max						None	
Act Effct Green (s)					29.3						23.7	
Actuated g/C Ratio					0.34						0.27	
v/c Ratio					0.57						0.80	
Control Delay					8.0						37.7	
Queue Delay					0.7						0.0	
Total Delay					8.6						37.7	
LOS					A						D	
Approach Delay					8.6						37.7	
Approach LOS					A						D	

Intersection Summary	
Cycle Length: 87	
Actuated Cycle Length: 87	
Offset: 3 (3%), Referenced to phase 8:WBTL, Start of Green	
Natural Cycle: 60	
Control Type: Actuated-Coordinated	
Maximum v/c Ratio: 0.80	
Intersection Signal Delay: 24.4	Intersection LOS: C
Intersection Capacity Utilization 46.4%	ICU Level of Service A
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	28%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix K

MassDOT Project Implementation Process

The following description of the implementation process is based on Chapter 2 of the *MassDOT Highway Division's Project Development and Design Guide (2005)*. The text below borrows heavily from that document.

1 NEEDS IDENTIFICATION

For each of the locations at which an improvement is to be implemented, MassDOT Highway Division leads an effort to define the problem, establishes project goals and objectives, and defines the scope of the planning needed for implementation. To that end, it has to complete a Project Need Form (PNF), which states in general terms the deficiencies or needs related to the transportation facility or location. The PNF documents the problems and explains why corrective action is needed. For this study, the information defining the need for the project will be drawn primarily, perhaps exclusively, from the present report. Also, at this point in the process, MassDOT Highway Division meets with potential participants, such as the Boston Region Metropolitan Planning Organization (MPO) and community members, to allow for an informal review of the project.

The PNF is reviewed by the MassDOT Highway Division district office whose jurisdiction includes the location of the proposed project. MassDOT Highway Division also sends the PNF to the MPO, for informational purposes. The outcome of this step determines whether the project requires further planning, whether it is already well supported by prior planning studies, and, therefore, whether it is ready to move forward into the design phase, or whether it should be dismissed from further consideration.

2 PLANNING

This phase will likely not be required for the implementation of the improvements proposed in this planning study, as this planning report should constitute the outcome of this step. However, in general, the purpose of this implementation step is for the project proponent to identify issues, impacts, and approvals that may need to be obtained, so that the subsequent design and permitting processes are understood.

The level of planning needed will vary widely, based on the complexity of the project. Typical tasks include: define the existing context, confirm project need, establish goals and objectives, initiate public outreach, define the project, collect data, develop and analyze alternatives, make recommendations, and provide documentation. Likely outcomes include consensus on the project definition to enable it to move forward into environmental documentation (if needed) and design, or a recommendation to delay the project or dismiss it from further consideration.

3 PROJECT INITIATION

At this point in the process, the proponent, MassDOT Highway Division, fills out, for each improvement, a Project Initiation Form (PIF), which is reviewed by its Project Review Committee (PRC) and the MPO. The PRC is composed of the Chief

Engineer, each District Highway Director, and representatives of the Project Management, Environmental, Planning, Right-of-Way, Traffic, and Bridge departments, and the Capital Expenditure Program Office (CEPO). The PIF documents the project type and description, summarizes the project planning process, identifies likely funding and project management responsibility, and defines a plan for interagency and public participation. First the PRC reviews and evaluates the proposed project based on the Executive Office of Transportation and Public Works's statewide priorities and criteria. If the result is positive, MassDOT Highway Division moves the project forward to the design phase, and to programming review by the MPO. The PRC may provide a Project Management Plan to define roles and responsibilities for subsequent steps. The MPO review includes project evaluation based on the MPO's regional priorities and criteria. The MPO may assign project evaluation criteria score, a Transportation Improvement Program (TIP) year, a tentative project category, and a tentative funding category.

4 ENVIRONMENTAL, DESIGN, AND RIGHT-OF-WAY PROCESS

This step has four distinct but closely integrated elements: public outreach, environmental documentation and permitting (if required), design, and right-of-way acquisition (if required). The outcome of this step is a fully designed and permitted project ready for construction. However, a project does not have to be fully designed in order for the MPO to program it in the TIP.

5 PROGRAMMING

Programming, which typically begins during the design phase, can actually occur at any time during the process, from planning to design. In this step, which is distinct from project initiation, where the MPO receives preliminary information on the proposed project, the proponent requests that the MPO place the project in the region's TIP. The MPO considers the project in terms of regional needs, evaluation criteria, and compliance with the regional Transportation Plan and decides whether to place it in the draft TIP for public review and then in the final TIP.

6 PROCUREMENT

Following project design and programming, MassDOT Highway Division publishes a request for proposals. It then reviews the bids and awards the contract to the qualified bidder with the lowest bid.

7 CONSTRUCTION

After a construction contract is awarded, MassDOT Highway Division and the contractor develop a public participation plan and a management plan for the construction process.

8 PROJECT ASSESSMENT

The purpose of this step is to receive constituents' comments on the project development process and the project's design elements. MassDOT Highway Division can apply what is learned in this process to future projects.

MEMORANDUM

To: **Thomas Cummings** — **February 17, 2011**
Holbrook Public Works Superintendent

From: **Chen-Yuan Wang and Efi Pagitsas**

Re: **Safety and Operations Analyses at Selected Boston Region MPO Intersections: Weymouth Street at Pine Street/Sycamore Street in Holbrook**

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersection of Weymouth Street at Pine Street/Sycamore Street in Holbrook. It contains the following sections:

- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Preliminary Analysis of Traffic Signal Warrants
- Analysis of Traffic Signal Option
- Analysis of Modern Roundabout Option
- Improvement Recommendations and Discussion

The memorandum also includes a collection of technical appendices that contain methods and data applied in the study and detailed reports of the intersection capacity analysis.

INTERSECTION LAYOUT AND TRAFFIC CONTROL

This unsignalized intersection is located in the northeastern section of the town. Weymouth Street, a two-lane roadway running in the east-west direction, is the major street of the intersection. It serves as a cross-town minor urban arterial between Holbrook and Weymouth. Pine Street, located on the north side of the intersection, is a two-lane minor urban arterial serving mainly the town. Sycamore Street, located on the south side of the intersection, is a two-lane urban collector serving mainly the neighborhood south of Weymouth Street.

Figure 1 shows the intersection layout and the area nearby. No exclusive right- or left-turn lanes are provided on any of the approaches. Both approaches of Weymouth Street near the intersection are slightly flared to allow through vehicles to bypass one or two stopped vehicles waiting to turn left. Both approaches of the minor streets have a short median (less than 50 feet long) to separate the traffic approaching the intersection from the traffic moving away from the intersection.

CTPS

FIGURE 1
Weymouth Street at Pine Street/Sycamore Street, Holbrook

Safety and Operations Improvements at Selected Intersections

Crosswalks exist across all approaches, except the westbound Weymouth Street approach. Sidewalks are installed on all approaches within 50 feet of the intersection corners. Away from the intersection, they exist only on the north side of Weymouth Street and on the west side of Pine Street and Sycamore Street. None of the approaches has bike lanes. The land use in the intersection vicinity is mainly single-family residential.

Currently the intersection is under a two-way stop control on Pine Street and Sycamore Street. There are two stop signs placed on each approach: one on the median and one on the curb. In addition, two intersection traffic-control beacons are hung from two mast arms extending from the northwest and southeast corners of the intersection. Each beacon contains two single-section signal faces: one indicates a flashing yellow on Weymouth Street and the other indicates a flashing red on Pine Street (or Sycamore Street).

The intersection control beacons should be helpful to drivers' awareness of the intersection. However, the signals appear to be small and not visible from any of the approaches from a distance of about 200 feet or greater from the intersection. The signal position seems to be outside the sight distance for the northbound drivers, which may be due to the extent and the angle of the associated suspended mast arm.

The Weymouth Street approaches are on a slight incline from both directions, with a steeper incline from the east than from the west. There are no buildings at the corners of the intersection, and drivers at all approaches appear to be within sufficient sight distance from each other. However, drivers in the southbound and the westbound approaches may have some difficulty seeing each other due to foliage at the northeast corner.

The intersection and its connected roadways are located in a suburban area with a rural environment, and the prevailing vehicles tend to travel above the speed limits. Currently Weymouth Street has a speed limit of 35 MPH (miles per hour) approaching the intersection from both directions. Pine Street has a speed limit of 25 MPH (reduced from 35 MPH west of Park Drive) and Sycamore Street has a speed limit of 30 MPH (reduced from 35 MPH south of Stevens Drive) approaching the intersection.

To alert drivers, sequential "SLOW" pavement markings for approaching traffic exist on all approaches about 500 feet from the intersection. "STOP" pavement markings are placed before the stop lines on Pine Street and Sycamore Street. In addition, intersection warning signs "CAUTION INTERSECTION AHEAD" are placed on both approaches of Weymouth Street about 200 feet from the intersection. Advance stop-control warning signs ("STOP AHEAD") are also placed on Pine Street and Sycamore Street, about 250 feet from the intersection.[1] These traffic control devices are appropriately located, and, along with the traffic beacons, they make the drivers aware that they are approaching an intersection.

ISSUES AND CONCERNS

Consultations with the Holbrook Department of Public Works indicate two major issues at this intersection. First, the intersection had a high crash rate in the past few years. Review of the recent crash data shows that the intersection has a high number of crashes and a crash rate higher than other unsignalized intersections in the area (see the next section for further analyses).

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[1] The "SLOW" pavement markings and "STOP AHEAD" warning signs on Pine Street and Sycamore Street appear to be new, as they do not show in the intersection aerial photograph taken in early 2008.

Second, the Sycamore Street approach is congested in the morning peak traffic period, and the Pine Street approach is congested during the evening peak traffic period. It is conceivable that the congestion is partly due to commuting traffic using Sycamore Street and/or Pine Street as alternate routes to avoid the congested traffic conditions on Route 139 (Plymouth Street/Union Street) and Route 37 (North/South Franklin Street) and at the intersection of Route 139 and Route 37 near the town center. During other hours of the day, Pine Street and Sycamore Street are not congested, and the stop control operates sufficiently.

From field visit and speaking with town officials, the issues and concerns about this intersection can be summarized as follows:

- High number of crashes and crash rate
- Traffic speeding on Weymouth Street
- Traffic congestion on both minor street approaches during peak hours
- Flashing beacons are small in size and not conspicuous
- Sight distance concerns due to foliage

CRASH DATA ANALYSIS

Based on the 2004-2008 MassDOT Registry of Motor Vehicles Division crash data, Table 1 shows that on average 12 crashes occurred at the intersection each year. About two-thirds of the total crashes involved property damage only, and about one-third resulted in personal injuries. The crash types consist of about 80% angle collisions, 7% sideswipe collisions, 3% rear-end collisions, and 10% “not reported.” No crashes involved pedestrians or bicycles. About 35% of the total crashes occurred during peak periods. About 25% of the total crashes happened when the roadway pavement was wet or icy.

TABLE 1
Summary of RMV Crash Data (2004-2008)

Statistics Period		2004	2005	2006	2007	2008	5-Year	Annual
Total Number of Crashes		12	14	17	9	7	59	12
Severity	Property Damage Only	6	10	11	6	1	34	7
	Personal Injury	5	4	5	2	4	20	4
	Fatality	0	0	0	0	0	0	0
	Not Reported	1	0	1	1	2	5	1
Collision Type	Angle	11	12	14	5	5	47	9
	Rear-end	0	1	0	0	1	2	0
	Sideswipe	0	0	1	3	0	4	1
	Head-on	0	0	0	0	0	0	0
	Single Vehicle	0	0	0	0	0	0	0
	Not Reported	1	1	2	1	1	6	1
Involved Pedestrian(s)		0	0	0	0	0	0	0
Involved Cyclist(s)		0	0	0	0	0	0	0
Occurred during Weekday Peak Periods*		4	4	5	3	4	20	4
Wet or Icy Pavement Conditions		3	5	3	3	1	15	3
Dark/Lighted Conditions		2	2	0	2	3	9	2

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

Staff reviewed the directions of the vehicles involved in the angle collisions. The collisions were mainly between vehicles entering the intersection from Pine Street or Sycamore Street (which are both stop controlled) and those traveling on Weymouth Street (which lacks controls).

Several factors could contribute to these collisions, including:

- Pine and Sycamore Streets drivers' failure to wait for sufficient traffic gaps on Weymouth Street.
- In the morning, the northbound Sycamore Street approach has a higher traffic volume than the Weymouth approach, where vehicles must stop; the same happens in the evening peak hour, when Pine Street southbound has the highest traffic volume of all approaches.
- Traffic congestion and delays on Pine Street or Sycamore Street challenging drivers' patience and forcing them to behave aggressively.
- Drivers on Weymouth Street traveling at high speed and failing to slow down in time to avoid the collisions.
- Drivers' lack of attention to the traffic and roadway conditions.

The crash statistics in the five-year period show that the number of crashes had a trend of decreasing after 2006. This may be attributed to the addition of pavement makings to warn drivers and slow down the vehicles on all approaches.

Crash rate[2] is another effective tool to examine the relative safety of a particular location. Based on the 2004-2008 crash data and the recently collected traffic volume data, the crash rate for this intersection is calculated as 2.12 (see Appendix A for the calculation). This crash rate is much higher than the average rate for the unsignalized locations in MassDOT Highway Division District 5, which is estimated to be 0.62.[3]

INTERSECTION CAPACITY ANALYSIS

MPO staff collected turning-movement counts at the intersection on June 9, 2009. The data were recorded in 15-minute intervals for the peak traffic periods in the morning, from 7:00 to 9:00, and in the evening, from 4:00 to 6:00. The intersection carried about 1,350 vehicles in the morning peak hour, from 7:15 to 8:15, and about 1,350 vehicles in the evening peak hour, from 5:00 to 6:00 (see Table 2). Two pedestrians and one pedestrian were observed during the AM and PM peak hour, respectively. No bicycles were observed entering the intersection in the AM or PM peak hour.

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[2] Crash rates relate to crash frequency (crashes per year) and vehicle exposure (traffic volumes or miles traveled). Crash rates are expressed as "crashes per million entering vehicles" for intersection locations and as "crashes per million miles traveled" for roadway segments.

[3] The average crash rates estimated by the MassDOT Highway Division (as of January 29, 2010) are based upon 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. The most recent average crash rates, which are updated on a nearly yearly basis, are based on all entries in the database, not just those entries made within the past year.

Based on the turning-movement counts and the signal timing measured at the site, the intersection capacity was analyzed by using an intersection capacity analysis program, Synchro.[4] The intersection was modeled as an unsignalized intersection with stop controls at Sycamore Street and on Pine Street. As Table 3 shows, both stop-controlled streets operate at level of service (LOS) F with delays of more than 3 minutes in both the morning and the evening peak hours. The criteria for the level of service are based on Highway Capacity Manual 2000.[5] Detailed analysis settings and results for both the AM and PM peak hour are included in Appendix B.

TABLE 2
AM and PM Peak-Hour Traffic Volumes and Pedestrian Crossings

Street name		**Weymouth Street**						**Sycamore Street**			**Pine Street**			**Total**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	**Turning volume**	229	201	23	15	176	69	39	493	39	20	50	16	1370
	Approach volume	453			260			571			86			
	Ped. crossings	3			0			0			1			4
PM peak hour	**Turning volume**	33	216	60	40	206	34	56	177	38	49	380	65	1354
	Approach volume	309			280			271			494			
	Ped. crossings	0			1			1			0			2

TABLE 3
Intersection Capacity Analysis, Existing Conditions

Street name		**Weymouth Street**						**Sycamore Street**			**Pine Street**		
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
AM peak hour	**LOS**	**A**			**A**			**F**			**F**		
	Delay (sec/veh)	5			1			> 180			> 180		
PM peak hour	**LOS**	**A**			**A**			**F**			**F**		
	Delay (sec/veh)	1			1			> 180			> 180		

PRELIMINARY ANALYSIS OF TRAFFIC SIGNAL WARRANTS

For this intersection, three improvement alternatives were considered: (1) to maintain the existing two-way stop control with modifications or additions of traffic-control devices, (2) to install a traffic signal in place of the existing two-way stop control, and (3) to convert the intersection to a modern roundabout. A preliminary analysis of traffic signal warrants was performed as groundwork for further analyses of the first two alternatives.

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[4] Synchro is developed and distributed by Trafficware, Ltd. It can perform capacity analysis and traffic simulation (when combined with SimTraffic) for an individual intersection or a series of coordinated intersections.

[5] Transportation Research Board, *Highway Capacity Manual 2000*, National Research Council, Washington D. C., 2000.

According to Manual for Uniform Traffic Control Devices[6] (MUTCD), an engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location should be performed to determine whether installation of a traffic control signal is justified at a particular location. The investigation should include applicable factors contained in the following traffic signal warrants and other factors related to existing operation and safety at the study location:

1. Eight-Hour Vehicular Volume Warrant
2. Four-Hour Vehicular Volume Warrant
3. Peak-Hour Warrant
4. Pedestrian Volume Warrant
5. School Crossing Warrant
6. Coordinated Signal System Warrant
7. Crash Experience Warrant
8. Roadway Network Warrant
9. Intersection Near a Grade Crossing

A traffic control signal should not be installed unless one or more of the factors reflected in these warrants are met. Moreover, the satisfaction of a warrant or warrants in itself does not justify the signal installation unless an engineering study indicates that the installation will improve the overall safety and/or operation of the intersection.

In this study, we performed a preliminary analysis of the applicable traffic signal warrants based on available traffic data. The applicable factors for this intersection are contained in Warrants 1, 2, and 7. Warrant 3 is intended for unusual cases, such as office complexes, manufacturing plants, industrial complexes, or high-occupancy-vehicle facilities that attract or discharge large numbers of vehicles over a short time period. The intersection is regarded as a stand-alone location, not a part of a coordinated traffic system, where pedestrian volume is low and is not close to any schools. Therefore Warrants 3, 4, 5, 6, 8, and 9 were not tested.

Table 4 shows the examination of Warrants 1, 2, and 7 based on hourly volumes of an average day, which were derived from three mid-week days' 24-hour automatic traffic counts. The counts were collected by MassDOT's Highway Division in the week beginning May 11, 2009, which were considered seasonal or slightly higher than average (see Appendix C for the detailed summary of hourly volumes for all the approaches at the intersection).

The analysis finds that the intersection does not meet the traffic conditions required by Warrant 1 (Eight-Hour Vehicular Volume Warrant), but meets the conditions required by Warrant 2 (Four-Hour Vehicular Volume Warrant). Warrant 7 is not satisfied, as the traffic conditions do not meet the required criterion for the five-year period, although the number of 2008 crashes is higher than the required criterion of 5 or more reportable crashes within a 12-month period.

[6] Federal Highway Administration, U.S. Department of Transportation, *Chapter 4C. Traffic Control Signal Needs*, 2009 Edition, December 2009.

TABLE 4
Summary of Hourly Volumes and Warrant Fulfillment

Hourly Period Starting Time	Weymouth St. (main street)		Pine/Sycamore St. (minor street)		Sum of Main Street	Higher of Minor Street	Traffic Volumes above the Minimum Requirement		
	EB	WB	SB	NB			Warrant 1	Warrant 2	Warrant 7
6:00	201	145	51	480	346	480			
7:00	460	253	94	601	713	601	X	X	X
8:00	354	234	113	532	588	532	X	X	X
9:00	189	155	106	262	344	262			
10:00	165	130	128	219	295	219			
11:00	176	163	136	206	339	206			
12:00	182	173	180	224	355	224			
13:00	183	172	182	201	355	201			
14:00	242	182	232	220	424	232			X
15:00	265	253	330	224	518	330	X	X	X
16:00	271	271	438	216	542	438	X	X	X
17:00	284	266	471	255	550	471	X	X	X
18:00	240	197	354	230	437	354		X	X
19:00	178	137	224	166	315	224			

Note: **Warrant 1 is not fulfilled.** It requires that certain traffic conditions (observed vehicular volumes higher than its specified minimum volumes) exist for each of any 8 hours of an average day.
Warrant 2 is fulfilled. It requires that the traffic conditions (minimum volumes specified differently from Warrant 1) exist for each of any 4 hours of an average day.
Warrant 7 (Crash Experience) is not fulfilled. It requires certain traffic conditions (vehicular volumes higher than 80 % of the volumes specified in Warrant 1) as an additional requirement to the number of crashes.

ANALYSIS OF TRAFFIC SIGNAL ALTERNATIVE

The preliminary analysis of traffic signal warrants shows that the required traffic conditions of Warrant 2 are satisfied at this intersection. This section will examine if and how a traffic signal control would work at this intersection.

Currently all the approaches entering the intersection operate as a single lane. Synchro tests of the installation of a traffic signal control indicate that under the existing intersection layout the intersection would operate at an overall level of service (LOS) C in the AM peak hour and LOS B in the PM peak hour, with all individual approaches running at a desirable LOS B or C (see Table 5). The signal was modeled as a two-phase operation with a traffic cycle of 55 seconds and an on-call exclusive pedestrian signal phase of 25 seconds (see Appendix D for details of the analysis for both AM and PM peak hours).

In addition, a future year scenario of 10% growth over a 20-year planning horizon was tested for the traffic signal option. The growth assumption is based on a review of the traffic projections at the intersection from the recent Boston Region MPO transportation-planning model. As shown in Table 6, the signalized intersection, without any major geometric design modifications, would operate at acceptable LOS D in the AM peak hour and at desirable LOS C in the PM peak hour under the projected traffic conditions (see Appendix E for details of the analysis results).

TABLE 5
Intersection Capacity Analysis:
Traffic Signal Option under Existing Traffic Conditions

Street name		**Weymouth Street**						**Sycamore Street**			**Pine Street**			**Overall**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		**LT**	**TH**	**RT**	**LT**	**TH**	**RT**	**LT**	**TH**	**RT**	**LT**	**TH**	**RT**	
AM peak hour	LOS	**C**			**B**			**C**			**B**			**C**
	Delay (sec/veh)	35			14			33			15			29
PM peak hour	LOS	**C**			**B**			**B**			**B**			**B**
	Delay (sec/veh)	20			19			14			19			18

TABLE 6
Intersection Capacity Analysis:
Traffic Signal Option under 2030 Projected Traffic Conditions

Street name		**Weymouth Street**						**Sycamore Street**			**Pine Street**			**Overall**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	LOS	**D**			**B**			**D**			**B**			**D**
	Delay (sec/veh)	46			16			42			15			36
PM peak hour	LOS	**C**			**C**			**B**			**C**			**C**
	Delay (sec/veh)	22			21			15			21			20

Analysis shows that a traffic signal would operate acceptably at this intersection. However, on Weymouth Street vehicular delay would increase and rear-end collisions might increase. Even though Warrant 2 of the signal warrants has been satisfied, consideration should be given to providing alternative control type other than a traffic signal. These measures are further discussed in the section of recommendations and discussion.

REVIEW OF ROUNDABOUT OPTION

Another improvement option considered for this intersection is the installation of 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 operate satisfactorily in both AM and PM peak hours. All the approaches would operate at less than 85% of the estimated capacity, which is regarded as the threshold for roundabout operations.[7] Detailed analyses of individual approaches for both peak hours are shown in Appendix F.

[7] Federal Highway Administration, U.S. Department of Transportation, *Roundabouts: An Informational Guide, Chapter 4: Operation*, FHWA-RD-00-67, June 2000.

In addition, a future-year scenario of 10% growth over a 20-year planning horizon was tested for the single-lane roundabout option. The assumed roundabout intersection would still operate acceptably, with volume-to-capacity ratios under 85% for all approaches in both of the peak hours under the projected traffic conditions (see Appendix G for details of the analysis results).

The above analyses show that a modern roundabout at this location is operationally feasible under the existing and projected traffic conditions. However, further review of the geometric-design elements indicates that the roundabout option is not favorable for this intersection.

As this single-lane roundabout would be located in the middle of a suburban minor arterial with a prevailing traffic speed of 35 MPH or higher, the following basic design elements were considered:[8]

- 25 MPH maximum entry design
- 115 to 130 feet inscribed-circle diameter
- Raised and extended splitter island with crosswalk cut
- 20,000 vehicles daily service volumes

Based on these design elements, the roundabout conversion would likely require some land-takings at and near the intersection.[9] In addition, the vertical curves on both approaches of Weymouth Street could complicate the roundabout maneuver during snowy or icy conditions. Finally, it would require sufficient distance on Weymouth Street for vehicles to slow down from 35 MPH to 25 MPH. Therefore, the modern roundabout option is considered unfavorable at this location.

RECOMMENDATIONS AND DISCUSSION

To improve the safety and operations at this intersection, three improvement alternatives were considered: (1) to maintain the existing two-way stop control with modifications or additions of traffic control devices, (2) to install a traffic signal in place of the stop control, and (3) to convert the intersection to a modern roundabout.

Among them, the conversion to a roundabout would involve more design modifications than the other alternatives, with potential land takings, though it was analyzed as operationally acceptable under the existing and 2030 projected traffic conditions. The installation of a traffic signal was analyzed as justified and operationally acceptable. However, it should be considered carefully as only one of the traffic signal warrants (Warrant 2: Four-Hour Vehicular Volume Warrant) is satisfied and the traffic signal could increase vehicle delays on Weymouth Street. The first alternative requires no design modifications and could be implemented in a short time.

Considering that (1) the intersection is congested only during peak hours on minor streets with mostly commuting traffic, and (2) its safety could potentially be improved through correcting the existing control devices, we propose a three-step improvement for this intersection. The first step

[8] Federal Highway Administration, U.S. Department of Transportation, *Roundabouts: An Informational Guide, Chapter 6: Geometric Design,* FHWA-RD-00-67, June 2000.

[9] Review of the State Roadway Inventory file indicates that near the intersection, Weymouth Street has a 40-foot right-of-way (ROW), Pine Street has a 50-foot ROW, and Sycamore Street has a 40-foot ROW. The intersection space is insufficient for accommodating an inscribed circle of 115 to 130 feet in diameter.

is to modify and add traffic control devices to enhance the existing operation at the intersection. The second step is to monitor the intersection's safety and traffic conditions after the enhancement. The last step is to install a traffic signal if safety has not been improved and traffic conditions deteriorate. The three steps are further discussed below.

Step 1: Modify and Install Traffic Control Devices to Enhance the Existing Operation

Currently there are traffic control devices in place to supplement the existing two-way stop control operation. These include:

- Flashing beacons at the intersection to alert drivers on all approaches
- Advance signs on all approaches to warn drivers approaching the intersection
- Advance pavement markings to reduce the speed of vehicles approaching the intersection

The crash statistics from 2004 to 2008 show that the number of crashes had a trend of decreasing after 2006. This may be attributed to the addition of pavement makings to warn drivers and to reduce vehicle speeds on all approaches. To further enhance the drivers' awareness and to reduce speeds of vehicles approaching the intersection, the following improvements should be considered:

- Increase the signal size of flashing beacons at the intersection.
- Install speed-limit-sign beacons to supplement speed-limit signs on all approaches.
- Clear excessive vegetation on the northeast corner of the intersection.

As mentioned, the intersection-control flashing beacons are not conspicuous for all approaches, and the signal position seems to be somewhat off for the northbound drivers. It is important to increase the size of flashing signals for this intersection. The required size of the signals and the extent of master arms should be further examined and designed by a certified engineering consultant or agency.

Step 2: Monitor the Safety and Traffic Conditions after the Enhancement

After the Step 1 improvements have been implemented, the intersection should be monitored continuously. If the safety at the intersection has been improved and the traffic conditions remain about the same as existing conditions, the intersection should be continuously monitored. If the safety has not been improved or the traffic conditions deteriorate such that local residents have difficulty getting out of the intersection during peak hours, the traffic signal option should be considered.

Step 3: Install a Traffic Signal with Necessary Intersection Modifications

The traffic signal would interrupt traffic on Weymouth Street at intervals to permit traffic from Pine Street and Sycamore Street to proceed. Properly designed, it is expected to reduce the frequency and severity of certain types of crashes, especially right-angle collisions. Average vehicle delays in peak hours are expected to decrease on Pine Street and Sycamore Street but to increase on Weymouth Street.

Under the existing and projected 2030 traffic conditions, the intersection was analyzed as acceptable with the existing intersection layout (a single lane shared by all movements for all the approaches). The projected traffic conditions were based on the existing traffic patterns. They should be reexamined during the functional design stage.

The existing sidewalks and crosswalks are properly located. The future signalization and reconstruction of the intersection should preserve these pedestrian facilities. The signal system should include pedestrian signal heads with push buttons and accessible (audible) pedestrian signals for the operation of exclusive pedestrian signal phases.

Finally, this study also found that one improvement at a different location could potentially help mitigate the congestion at this intersection. It is the improvement of traffic operations at the intersection of Route 139 (Plymouth Street/Union Street) and Route 37 (North/South Franklin Street) near the town center. As mentioned, the congestion on the stop-controlled approaches at this intersection is partly due to commuting traffic using Sycamore Street and/or Pine Street as alternative routes to avoid the congested conditions in the town center area. Improving traffic operations at the intersection of Route 139 and Route 37 would benefit vehicular and pedestrian traffic in the town center area and would potentially help mitigate the peak-period congestion at this intersection to some extent.

Appendix A

Intersection Crash Rate Calculation
Weymouth Street at Pine/Sycamore Street, Holbrook

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Holbrook

COUNT DATE : 6/9/09

DISTRICT : 5

UNSIGNALIZED : X

SIGNALIZED :

~ INTERSECTION DATA ~

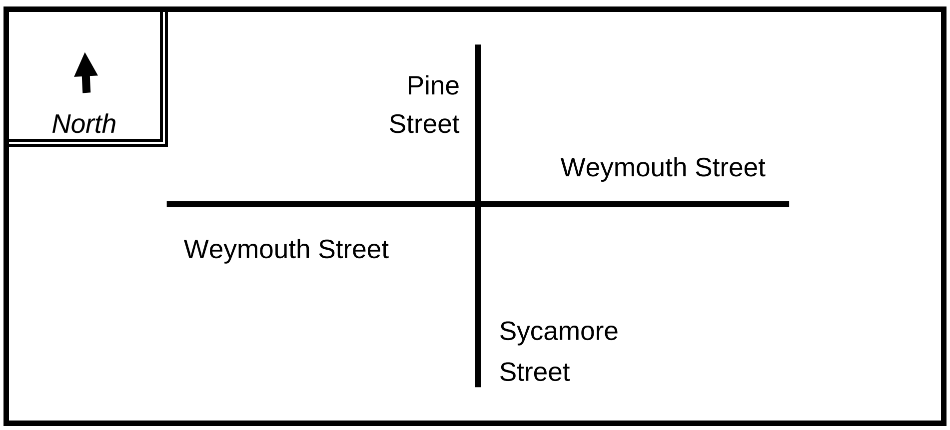
MAJOR STREET : Weymouth Street

MINOR STREET(S) : Pine Street

Sycamore Street

INTERSECTION DIAGRAM

(Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	EB	WB	NB	SB		
PEAK HOURLY VOLUMES (AM/PM) :	453	260	571	86		**1,370**

" K " FACTOR : **0.090**

INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **15,222**

TOTAL # OF CRASHES : 16

OF YEARS : 2

AVERAGE # OF CRASHES PER YEAR (**A**) : **8.00**

CRASH RATE CALCULATION : 1.44

RATE = (A * 1,000,000) / (V * 365)

Comments :

Project Title & Date: Safety and Operations Analyses at Selceted Intersections

Appendix B

AM/PM Peak Hour Intersection Capacity Analysis
Existing Traffic Conditions
Weymouth Street at Pine/Sycamore Street, Holbrook

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Volume (veh/h)	39	493	39	20	50	16	229	201	23	15	176	69
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			3%	
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hourly flow rate (vph)	41	519	41	21	53	17	241	212	24	16	185	73
Pedestrians					1			3				
Lane Width (ft)					16.0			12.0				
Walking Speed (ft/s)					4.0			4.0				
Percent Blockage					0			0				
Right turn flare (veh)												
Median type								None			None	
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	1005	996	224	1260	972	226	259			236		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	1005	996	224	1260	972	226	259			236		
tC, single (s)	7.1	6.5	6.2	7.1	6.5	6.2	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	72	0	95	0	74	98	82			99		
cM capacity (veh/h)	148	197	818	0	203	811	1304			1320		

Direction, Lane #	NB 1	SB 1	NE 1	SW 1
Volume Total	601	91	477	274
Volume Left	41	21	241	16
Volume Right	41	17	24	73
cSH	203	0	1304	1320
Volume to Capacity	2.96	Err	0.18	0.01
Queue Length 95th (ft)	1348	Err	17	1
Control Delay (s)	929.4	Err	5.1	0.6
Lane LOS	F	F	A	A
Approach Delay (s)	929.4	Err	5.1	0.6
Approach LOS	F	F		

Intersection Summary			
Average Delay	Err		
Intersection Capacity Utilization	81.7%	ICU Level of Service	D
Analysis Period (min)	15		

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Volume (veh/h)	56	177	38	49	380	65	33	216	60	40	206	34
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			3%	
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hourly flow rate (vph)	59	186	40	52	400	68	35	227	63	42	217	36
Pedestrians		1									1	
Lane Width (ft)		16.0									12.0	
Walking Speed (ft/s)		4.0									4.0	
Percent Blockage		0									0	
Right turn flare (veh)												
Median type								None			None	
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	917	666	261	782	680	235	253			292		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	917	666	261	782	680	235	253			292		
tC, single (s)	7.1	6.5	6.2	7.1	6.5	6.2	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	0	48	95	69	0	92	97			97		
cM capacity (veh/h)	0	359	779	168	352	807	1318			1275		

Direction, Lane #	NB 1	SB 1	NE 1	SW 1
Volume Total	285	520	325	295
Volume Left	59	52	35	42
Volume Right	40	68	63	36
cSH	0	340	1318	1275
Volume to Capacity	Err	1.53	0.03	0.03
Queue Length 95th (ft)	Err	729	2	3
Control Delay (s)	Err	280.5	1.1	1.4
Lane LOS	F	F	A	A
Approach Delay (s)	Err	280.5	1.1	1.4
Approach LOS	F	F		

Intersection Summary			
Average Delay	Err		
Intersection Capacity Utilization	59.0%	ICU Level of Service	B
Analysis Period (min)	15		

Appendix C

Summary of hourly traffic volumes
May 11-14, 2009
Weymouth Street at Pine/Sycamore Street, Holbrook

Live Search Maps

My Notes

FREE! Use **Live Search 411** to find movies, businesses & more: **800-CALL-411**.

HOLBROOK

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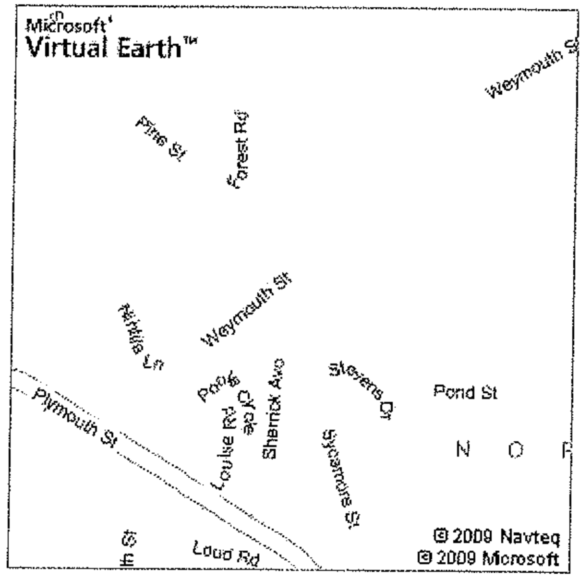

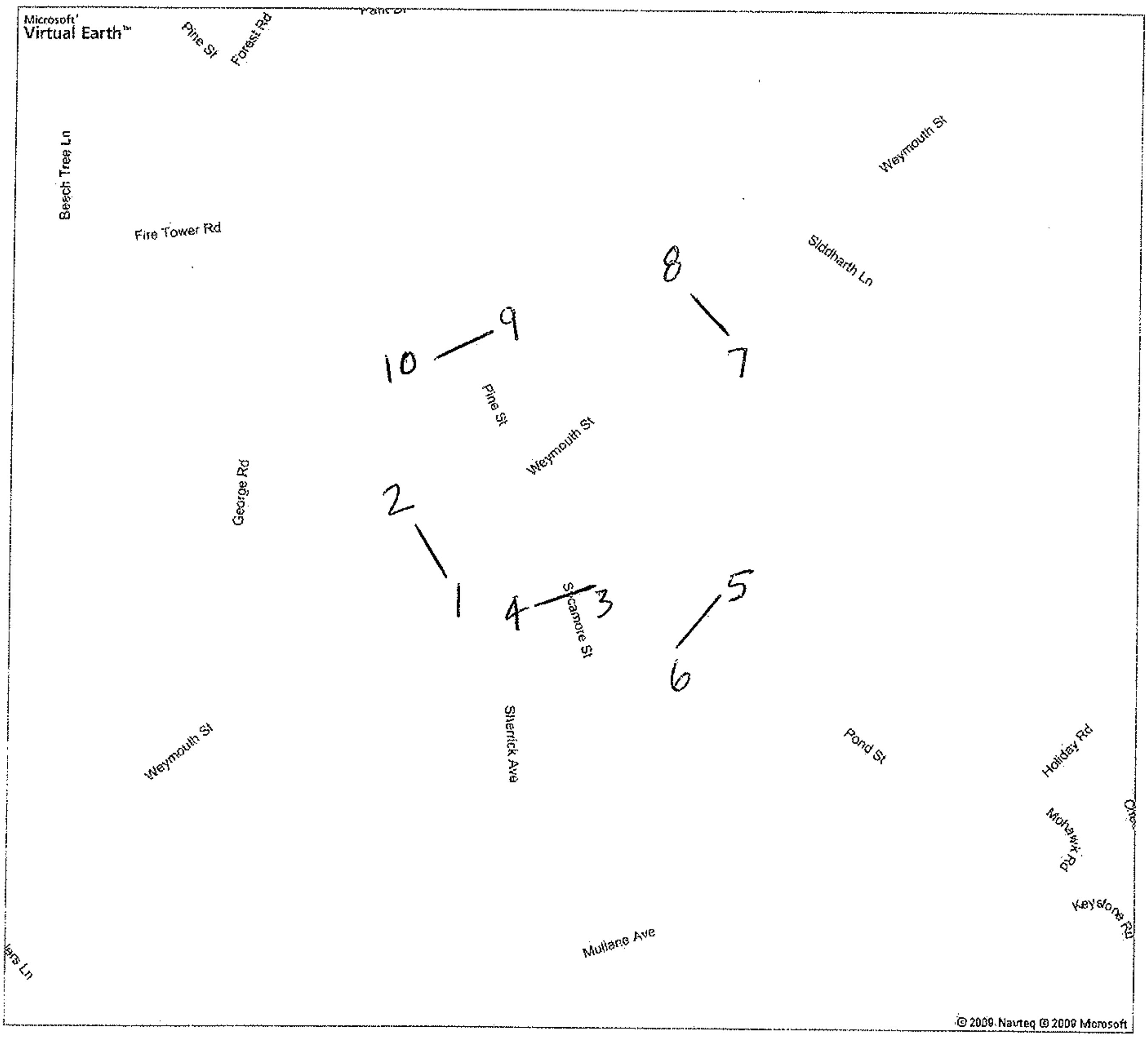

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 1 EB

Site Reference: 000000000893
Site ID: 000000000103
Location: WEYMOUTH ST., WEST OF PINE/SYCAMORE ST.
Direction: EAST

File: 103.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		13	20	24		19			19	57
02:00		11	16	12		13			13	39
03:00		6	7	6		6			6	19
04:00		1	4	2		2			2	7
05:00		17	16	18		17			17	51
06:00		58	67	64		63			63	189
07:00		191	206	208		201			201	605
08:00		433	471	477		460			460	1381
09:00		386	359	319		354			354	1064
10:00		161	201	206		189			189	568
11:00		161	170			165			165	331
12:00		168	184			176			176	352
13:00		181	184			182			182	365
14:00	185	189	176			183			183	550
15:00	243	241	242			242			242	726
16:00	268	266	262			265			265	796
17:00	278	277	260			271			271	815
18:00	289	313	251			284			284	853
19:00	232	250	239			240			240	721
20:00	171	175	190			178			178	536
21:00	115	129	153			132			132	397
22:00	95	97	105			99			99	297
23:00	89	65	86			80			80	240
24:00	27	39	49			38			38	115
'OTALS	1992	3828	3918	1336	0	3859	0	0	3859	11074
. AVG WKDY	51.6	99.1	101.5	34.6						
. AVG WEEK	51.6	99.1	101.5	34.6						
.M Times		08:00	08:00	08:00		08:00			08:00	
.M Peaks		433	471	477		460			460	
'M Times	18:00	18:00	16:00			18:00			18:00	
'M Peaks	289	313	262			284			284	

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EB 3859
WB 3392
COMB AWD 7251
FAC .91 (.99)
COMB ADT 6,500

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 2 WB

Site Reference: 000000000895
Site ID: 000000000204
Location: WEYMOUTH ST., WEST OF PINE/SYCAMORE ST.
Direction: WEST

File: 204.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		24	19	29		24			24	72
02:00		6	11	15		10			10	32
03:00		5	8	9		7			7	22
04:00		14	12	9		11			11	35
05:00		14	18	14		15			15	46
06:00		44	42	53		46			46	139
07:00		151	153	165		156			156	469
08:00		260	243	220		241			241	723
09:00		320	213	233		255			255	766
10:00		172	171	174		172			172	517
11:00		155	154			154			154	309
12:00		180	155			167			167	335
13:00		198	190			194			194	388
14:00	180	195	192			189			189	567
15:00	208	222	186			205			205	616
16:00	251	272	251			258			258	774
17:00	258	271	284			271			271	813
18:00	287	284	325			298			298	896
19:00	219	223	238			226			226	680
20:00	154	140	168			154			154	462
21:00	123	124	141			129			129	388
22:00	91	89	108			96			96	288
23:00	59	63	69			63			63	191
24:00	48	52	54			51			51	154
'OTALS	1878	3478	3405	921	0	3392	0	0	3392	9682
. AVG WKDY	55.3	102.5	100.3	27.1						
. AVG WEEK	55.3	102.5	100.3	27.1						
.M Times		09:00	08:00	09:00		09:00			09:00	
.M Peaks		320	243	233		255			255	
'M Times	18:00	18:00	18:00			18:00			18:00	
'M Peaks	287	284	325			298			298	

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 3 NB

Site Reference: 000000000444
Site ID: 000000301402
Location: SYCAMORE ST., BTWN POND & SHERRICK AVE
Direction: NORTH

File: 301402.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		13	9	15		12			12	37
02:00		5	6	5		5			5	16
03:00		2	5	7		4			4	14
04:00		9	15	8		10			10	32
05:00		25	23	27		25			25	75
06:00		129	125	126		126			126	380
07:00		444	439	433		438			438	1316
08:00		517	574	531		540			540	1622
09:00		428	528	518		491			491	1474
10:00		225	240	221		228			228	686
11:00		182	199	176		185			185	557
12:00		180	165			172			172	345
13:00		192	171			181			181	363
14:00	150	164	179			164			164	493
15:00	178	176	207			187			187	561
16:00	184	193	176			184			184	553
17:00	172	199	162			177			177	533
18:00	209	222	215			215			215	646
19:00	175	193	215			194			194	583
20:00	153	114	143			136			136	410
21:00	74	94	99			89			89	267
22:00	61	70	69			66			66	200
23:00	44	40	56			46			46	140
24:00	17	35	30			27			27	82
'OTALS	1417	3851	4050	2067	0	3902	0	0	3902	11385
. AVG WKDY	36.3	98.6	103.7	52.9						
. AVG WEEK	36.3	98.6	103.7	52.9						
.M Times		08:00	08:00	08:00		08:00			08:00	
.M Peaks		517	574	531		540			540	
'M Times	18:00	18:00	18:00			18:00			18:00	
'M Peaks	209	222	215			215			215	

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NB 3902
SB 4447
COMB AWD 8349
FAC .91 (.99)
COMB ADT 7,500

Mass Highway Department
WEEKLY SUMMARY FOR LANE 2
Starting: 5/11/2009

STA. 4SB

Site Reference: 000000000444
Site ID: 000000301402
Location: SYCAMORE ST., BTWN POND & SHERRICK AVE
Direction: SOUTH

File: 301402.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		15	40	34		29			29	89
02:00		10	19	11		13			13	40
03:00		8	6	10		8			8	24
04:00		4	8	2		4			4	14
05:00		8	8	11		9			9	27
06:00		13	15	16		14			14	44
07:00		148	148	169		155			155	465
08:00		352	428	400		393			393	1180
09:00		228	308	298		278			278	834
10:00		96	129	121		115			115	346
11:00		139	158	146		147			147	443
12:00		123	185			154			154	308
13:00		198	205			201			201	403
14:00	196	200	227			207			207	623
15:00	266	257	261			261			261	784
16:00	406	362	355			374			374	1123
17:00	455	465	491			470			470	1411
18:00	466	499	476			480			480	1441
19:00	398	372	396			388			388	1166
20:00	250	293	280			274			274	823
21:00	170	183	230			194			194	583
22:00	134	130	142			135			135	406
23:00	74	85	85			81			81	244
24:00	60	75	54			63			63	189
'OTALS	2875	4263	4654	1218	0	4447	0	0	4447	13010
. AVG WKDY	64.6	95.8	104.6	27.3						
. AVG WEEK	64.6	95.8	104.6	27.3						
.M Times		08:00	08:00	08:00		08:00			08:00	
.M Peaks		352	428	400		393			393	
'M Times	18:00	18:00	17:00			18:00			18:00	
'M Peaks	466	499	491			480			480	

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 5 NB

Site Reference: 000000000806
Site ID: 000000000501
Location: POND ST., SOUTH OF SYCAMORE ST.
Direction: NORTH

File: 501.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		2	3	2		2			2	7
02:00		0	4	1		1			1	5
03:00		0	0	2		0			0	2
04:00		0	2	0		0			0	2
05:00		6	3	5		4			4	14
06:00		15	14	11		13			13	40
07:00		44	41	43		42			42	128
08:00		61	62	61		61			61	184
09:00		38	41	46		41			41	125
10:00		34	39	31		34			34	104
11:00		30	41	33		34			34	104
12:00		37	32			34			34	69
13:00		49	37			43			43	86
14:00	31	50	32			37			37	113
15:00	28	32	39			33			33	99
16:00	44	36	41			40			40	121
17:00	41	43	34			39			39	118
18:00	39	40	42			40			40	121
19:00	44	37	29			36			36	110
20:00	30	30	32			30			30	92
21:00	15	24	22			20			20	61
22:00	11	17	9			12			12	37
23:00	7	5	9			7			7	21
24:00	8	8	9			8			8	25
:OTALS	298	638	617	235	0	611	0	0	611	1788
; AVG WKDY	48.7	104.4	100.9	38.4						
; AVG WEEK	48.7	104.4	100.9	38.4						
\M Times		08:00	08:00	08:00		08:00			08:00	
\M Peaks		61	62	61		61			61	
'M Times	16:00	14:00	18:00			13:00			13:00	
'M Peaks	44	50	42			43			43	

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NB 611
SB 711
COMB AWD 1322
FAC 1.00
COMB ADT 1,300

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 6 SB

Site Reference: 000000000557
Site ID: 000000000602
Location: POND ST., SOUTH OF SYCAMORE ST.
Direction: SOUTH

File: 602.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		1	6	7		4			4	14
02:00		0	6	2		2			2	8
03:00		0	1	3		1			1	4
04:00		0	3	0		1			1	3
05:00		2	2	2		2			2	6
06:00		4	4	6		4			4	14
07:00		10	13	18		13			13	41
08:00		25	31	23		26			26	79
09:00		28	22	23		24			24	73
10:00		22	39	38		33			33	99
11:00		44	37	26		35			35	107
12:00		35	43			39			39	78
13:00		58	39			48			48	97
14:00	35	38	37			36			36	110
15:00	53	53	56			54			54	162
16:00	56	50	62			56			56	168
17:00	59	70	49			59			59	178
18:00	60	62	74			65			65	196
19:00	58	49	49			52			52	156
20:00	52	55	56			54			54	163
21:00	38	43	37			39			39	118
22:00	20	40	32			30			30	92
23:00	21	25	15			20			20	61
24:00	9	16	19			14			14	44
'OTALS	461	730	732	148	0	711	0	0	711	2071
. AVG WKDY	64.8	102.6	102.9	20.8						
AVG WEEK	64.8	102.6	102.9	20.8						
.M Times		11:00	12:00	10:00		12:00			12:00	
.M Peaks		44	43	38		39			39	
'M Times	18:00	17:00	18:00			18:00			18:00	
'M Peaks	60	70	74			65			65	

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 7 EB

Site Reference: 000000000536
Site ID: 000000000703
Location: WEYMOUTH ST., EAST OF PINE/SYCAMORE ST.
Direction: EAST

File: 703.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		7	10	16		11			11	33
02:00		11	11	9		10			10	31
03:00		6	4	4		4			4	14
04:00		2	4	4		3			3	10
05:00		17	15	14		15			15	46
06:00		61	69	65		65			65	195
07:00		165	166	164		165			165	495
08:00		222	259	256		245			245	737
09:00		244	258	241		247			247	743
10:00		144	173	171		162			162	488
11:00		140	160			150			150	300
12:00		153	148			150			150	301
13:00		152	146			149			149	298
14:00	159	153	145			152			152	457
15:00	216	209	207			210			210	632
16:00	221	239	227			229			229	687
17:00	253	236	242			243			243	731
18:00	239	289	254			260			260	782
19:00	199	205	215			206			206	619
20:00	125	126	124			125			125	375
21:00	94	80	120			98			98	294
22:00	66	76	71			71			71	213
23:00	58	52	63			57			57	173
24:00	15	27	31			24			24	73
'OTALS	1645	3016	3122	944	0	3051	0	0	3051	8727
AVG WKDY	53.9	98.8	102.3	30.9						
AVG WEEK	53.9	98.8	102.3	30.9						
.M Times		09:00	08:00	08:00		09:00			09:00	
.M Peaks		244	259	256		247			247	
'M Times	17:00	18:00	18:00			18:00			18:00	
M Peaks	253	289	254			260			260	

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EB 3051
WB 3144
COMB AWD 6195
FAC .91 (.99)
COMB ADT 5,600

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 8 WB

Site Reference: 000000000653
Site ID: 000000000804
Location: WEYMOUTH ST., EAST OF PINE/SYCAMORE ST.
Direction: WEST

File: 804.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		16	21	23		20			20	60
02:00		8	11	12		10			10	31
03:00		5	10	5		6			6	20
04:00		14	10	10		11			11	34
05:00		11	14	13		12			12	38
06:00		40	37	44		40			40	121
07:00		143	151	143		145			145	437
08:00		274	256	230		253			253	760
09:00		259	211	232		234			234	702
10:00		158	161	148		155			155	467
11:00		139	122			130			130	261
12:00		159	168			163			163	327
13:00		169	178			173			173	347
14:00	164	176	176			172			172	516
15:00	190	197	161			182			182	548
16:00	265	262	234			253			253	761
17:00	264	267	284			271			271	815
18:00	257	253	288			266			266	798
19:00	204	175	212			197			197	591
20:00	126	139	147			137			137	412
21:00	120	110	134			121			121	364
22:00	84	79	97			86			86	260
23:00	54	67	63			61			61	184
24:00	44	46	48			46			46	138
'OTALS	1772	3166	3194	860	0	3144	0	0	3144	8992
AVG WKDY	56.3	100.6	101.5	27.3						
AVG WEEK	56.3	100.6	101.5	27.3						
M Times		08:00	08:00	09:00		08:00			08:00	
M Peaks		274	256	232		253			253	
M Times	16:00	17:00	18:00			17:00			17:00	
M Peaks	265	267	288			271			271	

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 9 NB

Site Reference: 000000000492
Site ID: 000000000901
Location: PINE ST., NORTH OF WEYMOUTH ST.
Direction: NORTH

File: 901.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		11	10	15		12			12	36
02:00		1	5	6		4			4	12
03:00		1	7	3		3			3	11
04:00		8	10	6		8			8	24
05:00		17	17	25		19			19	59
06:00		116	116	119		117			117	351
07:00		414	407	402		407			407	1223
08:00		667	640	630		645			645	1937
09:00		575	533	513		540			540	1621
10:00		226	258	235		239			239	719
11:00		155	179			167			167	334
12:00		173	174			173			173	347
13:00		170	180			175			175	350
14:00	160	174	178			170			170	512
15:00	184	156	185			175			175	525
16:00	194	185	167			182			182	546
17:00	182	205	157			181			181	544
18:00	191	213	182			195			195	586
19:00	165	161	182			169			169	508
20:00	142	123	146			137			137	411
21:00	77	102	97			92			92	276
22:00	62	63	65			63			63	190
23:00	48	42	52			47			47	142
24:00	19	29	29			25			25	77
TOTALS	1424	3987	3976	1954	0	3945	0	0	3945	11341
% AVG WKDY	36	101	100.7	49.5						
% AVG WEEK	36	101	100.7	49.5						
AM Times		08:00	08:00	08:00		08:00			08:00	
AM Peaks		667	640	630		645			645	
PM Times	16:00	18:00	15:00			18:00			18:00	
PM Peaks	194	213	185			195			195	

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NB 3945
SB 3488
COMB AWD 7433
FAC .91 (.99)
COMB ADT 6,700

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 5/11/2009

STA. 10 SB

Site Reference: 000000000499
Site ID: 000000001002
Location: PINE ST., NORTH OF WEYMOUTH ST.
Direction: SOUTH

File: 1002.prn
City: HOLBROOK
County: VOL

TIME	MON 11	TUE 12	WED 13	THU 14	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		14	30	28		24			24	72
02:00		5	11	11		9			9	27
03:00		7	4	6		5			5	17
04:00		5	7	4		5			5	16
05:00		4	4	5		4			4	13
06:00		17	16	22		18			18	55
07:00		51	49	54		51			51	154
08:00		100	92	91		94			94	283
09:00		113	114	112		113			113	339
10:00		81	124	114		106			106	319
11:00		109	147			128			128	256
12:00		118	155			136			136	273
13:00		172	188			180			180	360
14:00	181	180	186			182			182	547
15:00	246	222	228			232			232	696
16:00	344	335	312			330			330	991
17:00	433	421	460			438			438	1314
18:00	417	512	484			471			471	1413
19:00	358	346	359			354			354	1063
20:00	213	239	222			224			224	674
21:00	147	140	185			157			157	472
22:00	112	116	111			113			113	339
23:00	50	61	67			59			59	178
24:00	61	62	44			55			55	167
OTALS	2562	3430	3599	447	0	3488	0	0	3488	10038
AVG WKDY	73.4	98.3	103.1	12.8						
AVG WEEK	73.4	98.3	103.1	12.8						
M Times		12:00	12:00	10:00		12:00			12:00	
M Peaks		118	155	114		136			136	
M Times	17:00	18:00	18:00			18:00			18:00	
M Peaks	433	512	484			471			471	

Appendix D

AM/PM Peak Hour Intersection Capacity Analysis
Traffic Signal Option
Under Existing Traffic Conditions
Weymouth Street at Pine/Sycamore Street, Holbrook

Lane Group	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Volume (vph)	39	493	39	20	50	16	229	201	23	15	176	69
Confl. Peds. (#/hr)	3					3	1					1
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	2%	2%	2%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			4			8	
Permitted Phases	2			6			4			8		
Detector Phase	2	2		6	6		4	4		8	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	20.0	20.0		20.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	25.0	25.0	0.0	25.0	25.0	0.0	30.0	30.0	0.0	30.0	30.0	0.0
Total Split (%)	31.3%	31.3%	0.0%	31.3%	31.3%	0.0%	37.5%	37.5%	0.0%	37.5%	37.5%	0.0%
Yellow Time (s)	3.5	3.5		3.5	3.5		3.5	3.5		3.5	3.5	
All-Red Time (s)	1.5	1.5		1.5	1.5		1.5	1.5		1.5	1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	None	None		None	None		Min	Min		Min	Min	
Act Effct Green (s)		20.3			20.3			25.4			25.4	
Actuated g/C Ratio		0.35			0.35			0.43			0.43	
v/c Ratio		0.84			0.15			0.85			0.37	
Control Delay		33.1			14.5			34.8			13.7	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		33.1			14.5			34.8			13.7	
LOS		C			B			C			B	
Approach Delay		33.1			14.5			34.8			13.7	
Approach LOS		C			B			C			B	

Intersection Summary	
Cycle Length: 80	
Actuated Cycle Length: 58.8	
Natural Cycle: 110	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.85	
Intersection Signal Delay: 28.8	Intersection LOS: C
Intersection Capacity Utilization 84.2%	ICU Level of Service E
Analysis Period (min) 15	

Splits and Phases: 1: Sycamore & Weymouth

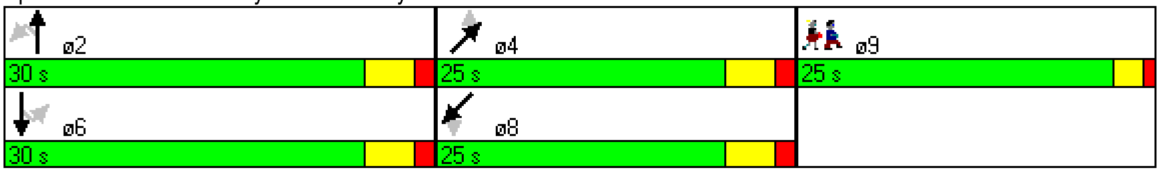
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	25.0
Total Split (s)	25.0
Total Split (%)	31%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Volume (vph)	56	177	38	49	380	65	33	216	60	40	206	34
Confl. Peds. (#/hr)			1	1					1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			4			8	
Permitted Phases	2			6			4			8		
Detector Phase	2	2		6	6		4	4		8	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		21.0	21.0		21.0	21.0	
Total Split (s)	30.0	30.0	0.0	30.0	30.0	0.0	25.0	25.0	0.0	25.0	25.0	0.0
Total Split (%)	37.5%	37.5%	0.0%	37.5%	37.5%	0.0%	31.3%	31.3%	0.0%	31.3%	31.3%	0.0%
Yellow Time (s)	3.5	3.5		3.5	3.5		3.5	3.5		3.5	3.5	
All-Red Time (s)	1.5	1.5		1.5	1.5		1.5	1.5		1.5	1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Min	Min		Min	Min		None	None		None	None	
Act Effct Green (s)		18.4			18.4			14.9			14.9	
Actuated g/C Ratio		0.39			0.39			0.32			0.32	
v/c Ratio		0.41			0.66			0.58			0.54	
Control Delay		14.0			18.7			20.1			19.5	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		14.0			18.7			20.1			19.5	
LOS		B			B			C			B	
Approach Delay		14.0			18.7			20.1			19.5	
Approach LOS		B			B			C			B	

Intersection Summary	
Cycle Length: 80	
Actuated Cycle Length: 46.7	
Natural Cycle: 70	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.66	
Intersection Signal Delay: 18.2	Intersection LOS: B
Intersection Capacity Utilization 60.6%	ICU Level of Service B
Analysis Period (min) 15	

Splits and Phases: 1: Sycamore & Weymouth



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	25.0
Total Split (s)	25.0
Total Split (%)	31%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix E

AM/PM Peak Hour Intersection Capacity Analysis
Traffic Signal Option
Under Projected 2030 Traffic Conditions
Weymouth Street at Pine/Sycamore Street, Holbrook

Lane Group	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Volume (vph)	39	493	39	20	50	16	229	201	23	15	176	69
Confl. Peds. (#/hr)	3					3	1					1
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	110%	110%	110%	110%	110%	110%	110%	110%	110%	110%	110%	110%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	2%	2%	2%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			4			8	
Permitted Phases	2			6			4			8		
Detector Phase	2	2		6	6		4	4		8	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	20.0	20.0		20.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	29.0	29.0	0.0	29.0	29.0	0.0	36.0	36.0	0.0	36.0	36.0	0.0
Total Split (%)	32.2%	32.2%	0.0%	32.2%	32.2%	0.0%	40.0%	40.0%	0.0%	40.0%	40.0%	0.0%
Yellow Time (s)	3.5	3.5		3.5	3.5		3.5	3.5		3.5	3.5	
All-Red Time (s)	1.5	1.5		1.5	1.5		1.5	1.5		1.5	1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	None	None		None	None		Min	Min		Min	Min	
Act Effct Green (s)		24.3			24.3			31.3			31.3	
Actuated g/C Ratio		0.35			0.35			0.45			0.45	
v/c Ratio		0.91			0.17			0.93			0.39	
Control Delay		41.5			16.4			45.8			14.8	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		41.5			16.4			45.8			14.8	
LOS		D			B			D			B	
Approach Delay		41.5			16.4			45.8			14.8	
Approach LOS		D			B			D			B	

Intersection Summary	
Cycle Length: 90	
Actuated Cycle Length: 68.8	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.93	
Intersection Signal Delay: 36.3	Intersection LOS: D
Intersection Capacity Utilization 91.3%	ICU Level of Service F
Analysis Period (min) 15	

Splits and Phases: 1: Sycamore & Weymouth

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	25.0
Total Split (s)	25.0
Total Split (%)	28%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

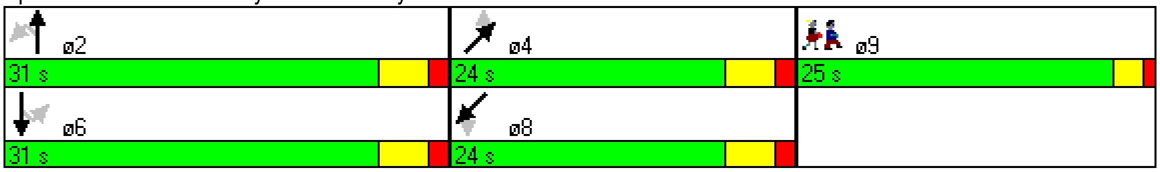
Intersection Summary

Lane Group	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Volume (vph)	56	177	38	49	380	65	33	216	60	40	206	34
Confl. Peds. (#/hr)			1	1					1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	110%	110%	110%	110%	110%	110%	110%	110%	110%	110%	110%	110%
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			4			8	
Permitted Phases	2			6			4			8		
Detector Phase	2	2		6	6		4	4		8	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		21.0	21.0		21.0	21.0	
Total Split (s)	31.0	31.0	0.0	31.0	31.0	0.0	24.0	24.0	0.0	24.0	24.0	0.0
Total Split (%)	38.8%	38.8%	0.0%	38.8%	38.8%	0.0%	30.0%	30.0%	0.0%	30.0%	30.0%	0.0%
Yellow Time (s)	3.5	3.5		3.5	3.5		3.5	3.5		3.5	3.5	
All-Red Time (s)	1.5	1.5		1.5	1.5		1.5	1.5		1.5	1.5	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Min	Min		Min	Min		None	None		None	None	
Act Effct Green (s)		21.2			21.2			18.2			18.2	
Actuated g/C Ratio		0.40			0.40			0.35			0.35	
v/c Ratio		0.46			0.72			0.59			0.55	
Control Delay		15.3			21.3			22.0			21.4	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		15.3			21.3			22.0			21.4	
LOS		B			C			C			C	
Approach Delay		15.3			21.3			22.0			21.4	
Approach LOS		B			C			C			C	

Intersection Summary

Cycle Length: 80
Actuated Cycle Length: 52.5
Natural Cycle: 80
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.72
Intersection Signal Delay: 20.3 Intersection LOS: C
Intersection Capacity Utilization 65.9% ICU Level of Service C
Analysis Period (min) 15

Splits and Phases: 1: Sycamore & Weymouth



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	25.0
Total Split (s)	25.0
Total Split (%)	31%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix F

AM/PM Peak Hour Intersection Capacity Analysis
Modern Roundabout Option
Under Existing Traffic Conditions
Weymouth Street at Pine/Sycamore Street, Holbrook

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Right Turn Channelized												
Volume (veh/h)	39	493	39	20	50	16	229	201	23	15	176	69
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hourly flow rate (vph)	41	519	41	21	53	17	241	212	24	16	185	73
Approach Volume (veh/h)		601			91			477			274	
Crossing Volume (veh/h)		474			242			89			801	
High Capacity (veh/h)		953			1146			1291			732	
High v/c (veh/h)		0.63			0.08			0.37			0.37	
Low Capacity (veh/h)		772			944			1076			578	
Low v/c (veh/h)		0.78			0.10			0.44			0.47	

Intersection Summary			
Maximum v/c High	0.63		
Maximum v/c Low	0.78		
Intersection Capacity Utilization	81.7%	ICU Level of Service	D

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Right Turn Channelized												
Volume (veh/h)	56	177	38	49	380	65	33	216	60	40	206	34
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hourly flow rate (vph)	59	186	40	52	400	68	35	227	63	42	217	36
Approach Volume (veh/h)		285			520			325			295	
Crossing Volume (veh/h)		314			318			494			280	
High Capacity (veh/h)		1083			1079			938			1112	
High v/c (veh/h)		0.26			0.48			0.35			0.27	
Low Capacity (veh/h)		888			884			759			914	
Low v/c (veh/h)		0.32			0.59			0.43			0.32	

Intersection Summary			
Maximum v/c High	0.48		
Maximum v/c Low	0.59		
Intersection Capacity Utilization	59.0%	ICU Level of Service	B

Appendix G

AM/PM Peak Hour Intersection Capacity Analysis
Modern Roundabout Option
Under projected 2030 Traffic Conditions
Weymouth Street at Pine/Sycamore Street, Holbrook

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Right Turn Channelized												
Volume (veh/h)	39	493	39	20	50	16	229	201	23	15	176	69
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hourly flow rate (vph)	45	571	45	23	58	19	265	233	27	17	204	80
Approach Volume (veh/h)		661			100			525			301	
Crossing Volume (veh/h)		521			266			98			881	
High Capacity (veh/h)		918			1124			1282			686	
High v/c (veh/h)		0.72			0.09			0.41			0.44	
Low Capacity (veh/h)		741			925			1068			537	
Low v/c (veh/h)		0.89			0.11			0.49			0.56	

Intersection Summary			
Maximum v/c High	0.72		
Maximum v/c Low	0.89		
Intersection Capacity Utilization	88.8%	ICU Level of Service	E

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Right Turn Channelized												
Volume (veh/h)	56	177	38	49	380	65	33	216	60	40	206	34
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hourly flow rate (vph)	65	205	44	57	440	75	38	250	69	46	239	39
Approach Volume (veh/h)		314			572			358			324	
Crossing Volume (veh/h)		345			350			543			308	
High Capacity (veh/h)		1056			1052			902			1087	
High v/c (veh/h)		0.30			0.54			0.40			0.30	
Low Capacity (veh/h)		864			860			726			892	
Low v/c (veh/h)		0.36			0.66			0.49			0.36	

Intersection Summary			
Maximum v/c High	0.54		
Maximum v/c Low	0.66		
Intersection Capacity Utilization	64.2%	ICU Level of Service	C

MEMORANDUM

To: **Larry Dunkin, Milford Town Planner** **February 17, 2011**
Joseph Frawley, MassDOT Highway District 3

From: **Chen-Yuan Wang and Efi Pagitsas**

Re: **Safety and Operations Analyses at Selected Boston Region MPO Intersections: Prospect Street at Water Street in Milford**

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersection of Prospect Street (Route 140) at Water Street in Milford. It contains the following sections:

- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Preliminary Analysis of Traffic Signal Warrants
- Analysis of Traffic Signal Alternative
- Review of Roundabout Alternative
- Improvement Recommendations and Discussion

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

INTERSECTION LAYOUT AND TRAFFIC CONTROL

The intersection is unsignalized and located in the western section of the town, near the Hopedale/Milford border. Prospect Street, a two-lane roadway running in the north-south direction, is the major street of the intersection. It is a part of Route 140 that serves as a principal urban arterial running from Central Massachusetts (Grafton) to Southeast Massachusetts (New Bedford). Water Street, the minor street of the intersection, is a two-lane minor urban arterial running in the east-west direction and connecting Route 16 in the downtown area and Route 140 at this intersection. West of the intersection, Water Street becomes Williams Street and connects to Freedom Street, which leads to the central area of Hopedale.

Figure 1 shows the intersection layout and the area nearby. Both approaches of Prospect Street near the intersection widen to add an exclusive left-turn lane, which has a storage length of about 100 feet in the northbound direction and about 150 feet in the southbound direction. Both approaches of Water Street remain a single lane that is shared by all movements. A crosswalk is installed only on the south side of the intersection (across the Prospect Street northbound

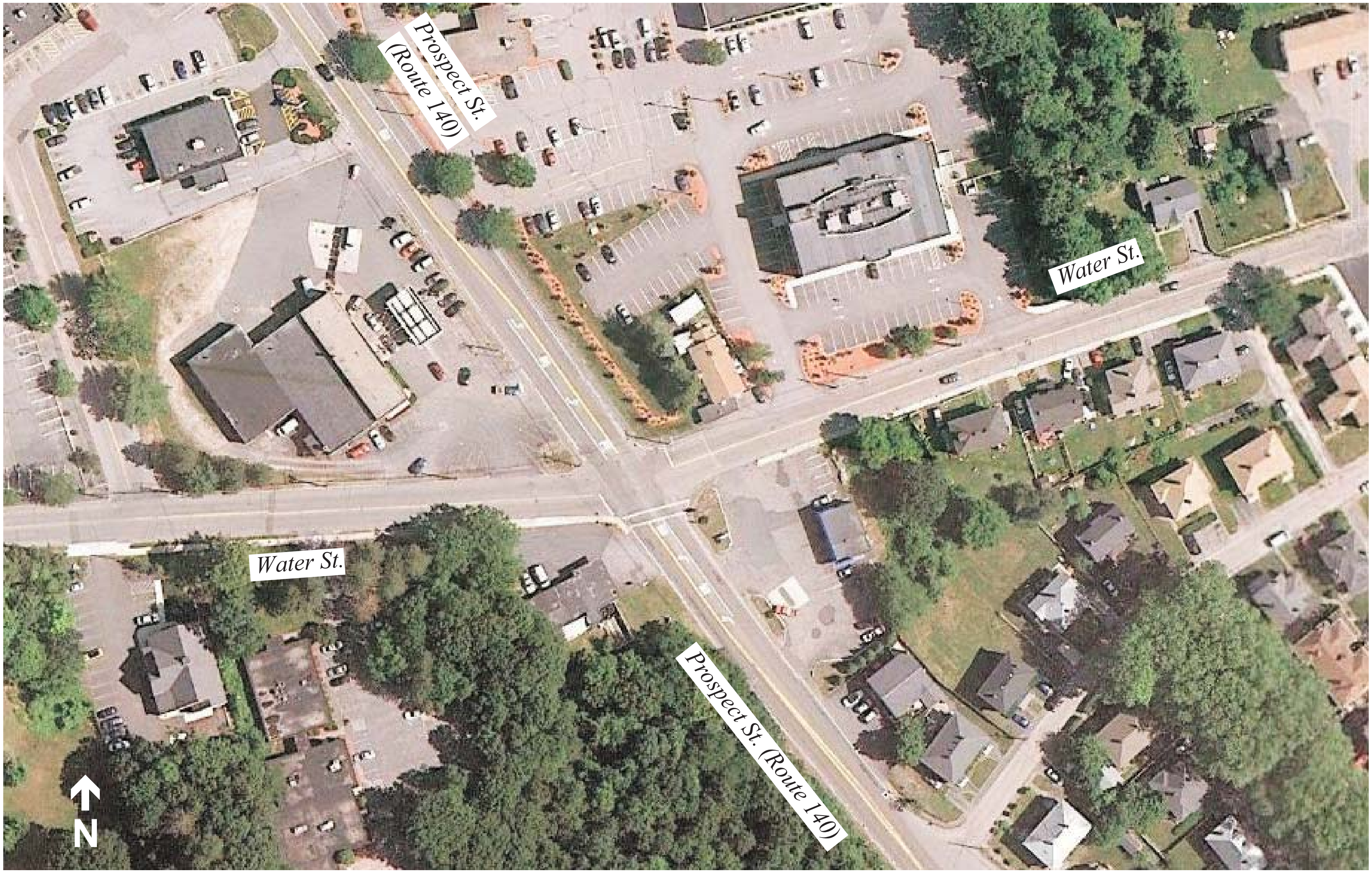


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FIGURE 1
Prospect Street at Water Street, Milford

Safety and Operations Improvements at Selected Intersections

approach). Sidewalks are installed on all approaches near the intersection. Away from the intersection, they are installed only on the east side of Prospect Street and on the south side of Water Street and Williams Street. No bike lanes are in place on any of the approaches. There are pedestrian-crossing warning signs facing Prospect Street traffic located at both ends of the crosswalk. As the intersection is not equipped with traffic signals, no pedestrian signals or push buttons are provided.

Currently the intersection is under a two-way stop control on Water Street and Williams Street, with a 24-by-24-foot stop sign placed on both approaches. In addition, an intersection traffic-control beacon mounted on a post about 7 to 8 feet tall is placed on the southwest corner of the intersection. The beacon contains four single-section signal faces: two flashing yellow beacons facing Prospect Street traffic, and two flashing red beacons facing Water Street traffic. The signal face has a diameter of about 8 inches.

The intersection is adjacent to a busy commercial section of Route 140. Its land uses are mixed, with commercial, office, and residential developments. At the intersection, there are a gas station and a dry cleaner on the northwest corner, a flower shop on the southwest corner, a small restaurant on the northeast corner, and an auto service shop on the southeast corner. North of the intersection, commercial and office developments, including Shaw's, Walgreens, Bank of America, Rite Aid Pharmacy, and other shops and professional services sprawl on both sides of Prospect Street until the signalized intersection at West Street. Slightly away from the intersection on Water Street a medical service building is located on the east side and an office park is located on the west side. Further away from the intersection are single- and multiple-family residences on Water Street and mainly vacant land on Williams Street. South of the intersection on Prospect Street are single-family residences on the east side and woodlands on the west side.

In addition to the surrounding mixed land uses, the intersection is situated on sloped terrain. Approaching the intersection from the north, Prospect Street goes very slightly downhill, while from the south it goes continuously uphill starting from Route 16, about half a mile away. Water Street goes gently uphill toward the intersection from the east and gently downhill from the west. A windshield survey indicated that the sight distances to the intersection are short from the downhill approaches. The sight line to the south of drivers near the stop line on the westbound Water Street approach is obstructed by several signs, commercial and traffic signs, on the southeast corner.

ISSUES AND CONCERNS

Comments from Milford town officers, including the Police Department, indicate that the Town is concerned about the consistently high number of crashes over the years. A review of the recent crash data indicates that the intersection has a high number of crashes and a crash rate higher than the average for unsignalized intersections in the area (see the next section for further analyses).

The section of Route 140 (Prospect Street) adjacent to the intersection carries a traffic volume of about 12,000 (south of the intersection) to 13,000 vehicles (north of the intersection) per weekday in both directions. During peak periods, heavy traffic on Prospect Street deters the traffic on Water Street from entering the intersection. Field observations indicated that during the evening peak hour, the Water Street westbound approach frequently has five to ten vehicles backed up from the stop line. The congested conditions may compel motorists on Water Street to enter the intersection without waiting for safe traffic gaps.

Meanwhile, traffic control devices at this intersection may not be sufficient to alert drivers about approaching a stop-controlled intersection. As the intersection is located in rolling terrain and surrounded by commercial developments, drivers encountering these complicated conditions may have difficulty paying attention to the stop control even during the off-peak traffic periods. The flashing beacon signals are somewhat helpful. However, they are small and are located on a corner at a low height; they therefore are visible only from the Water Street eastbound approach. They are not conspicuous from other approaches, especially from the uphill approaches of Prospect Street and Water Street.

The issues and concerns for this intersection can be summarized as follows:

- High number of crashes and high crash rate
- Traffic congestion on the minor-street approaches during peak hours
- Short sight distance from the uphill approaches
- Insufficient traffic control devices to alert drivers
- No pedestrian signals for pedestrians crossing Prospect Street

CRASH DATA ANALYSIS

Based on the 2006-2008 MassDOT Registry of Motor Vehicles Division crash data, Table 1 shows that on average about 10 crashes occurred at the intersection each year. About one-third resulted in personal injuries (including one fatality), and about two-thirds of the total crashes involved property damage only or were not reported. The crash types, not including data that were not reported, consist of about 55% angle collisions, 20% sideswipe collisions, 10% rear-end collisions, and 10% head-on or single-vehicle collisions. No crashes involved pedestrians or bicycles. About 30% of the total crashes occurred during peak periods. About 30% of the total crashes happened when the roadway pavement was wet or icy.

Crash rate[1] is another effective tool for examining the relative safety of a particular location. Based on the 2006-2008 crash data and the recently collected traffic volume data, the crash rate for this intersection is calculated as 1.68 (see Appendix A for the calculation). This recent crash rate is still higher than the average rate for the unsignalized locations in MassDOT Highway Division District 3, which is estimated to be 0.68.[2]

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1 Crash rates are estimated based on crash frequency (crashes per year) and vehicle exposure (traffic volumes or miles traveled). Crash rates are expressed as “crashes per million entering vehicles” for intersection locations and as “crashes per million miles traveled” for roadway segments.

2 The average crash rates estimated by the MassDOT Highway Division (as of January 29, 2010) are based upon 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. The most recent average crash rates, which are updated on a nearly annual basis, are based on all entries in the database, not just those entries made within the past year.

TABLE 1
Summary of MassDOT Crash Data (2006-2008)

Statistics Period		2006	2007	2008	3-Year	Annual
Total Number of Crashes		8	11	10	29	10
Severity	Property Damage Only	4	5	4	13	4
	Personal Injury	2	3	3	8	3
	Fatality	0	1	0	1	0
	Not Reported	2	2	3	7	2
Collision Type	Angle	4	3	3	10	3
	Rear-end	1	1	0	2	1
	Sideswipe	1	1	2	4	1
	Head-on	0	0	1	1	0
	Single Vehicle	0	1	0	1	0
	Not Reported	2	5	4	11	4
Involved Pedestrian(s)		0	0	0	0	0
Involved Cyclist(s)		0	0	0	0	0
Occurred during Weekday Peak Periods*		3	2	3	8	3
Wet or Icy Pavement Conditions		2	3	4	9	3
Dark/Lighted Conditions		0	1	2	3	1

* Peak Periods defined as 7:00 - 10:00 AM and 3:30- 6:30 PM

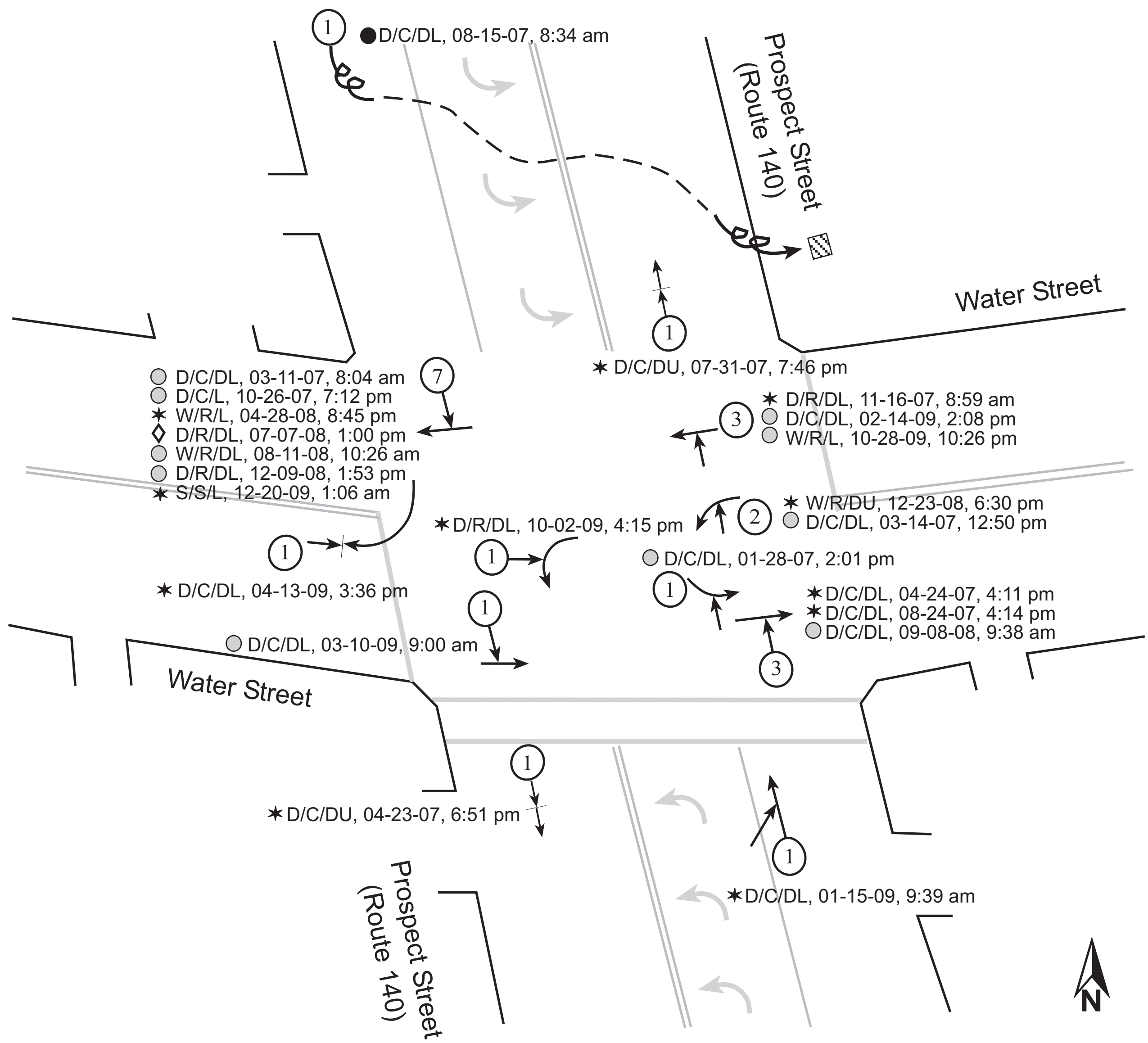
The Milford Police Department also provided collision reports for the most recent three years, from 2007 to 2009. Based on the reports, staff constructed the collision diagram for the intersection (see Figure 2) and a summary of the reports corresponding to the collision diagram (see Table 2).

The collision diagram shows a high number of angle collisions (about 70% of all collisions), which resulted from conflicts between vehicles entering the intersection from Water Street (stop controlled) and those traveling on Prospect Street (free of controls). It should be noted that three of the crashes do not appear to be related to the intersection operations. The two rear-end collisions on Prospect Street might have been caused by traffic from the nearby driveways. The single fatal out-of-control-vehicle collision in 2007 was not caused by traffic operations or roadway conditions but was due to the driver's illness.

Several factors could contribute to the angle collisions, including drivers from Water Street failing to wait for sufficient traffic gaps on Prospect Street, traffic congestion on Water Street pushing drivers to behave aggressively, drivers on Prospect Street traveling at a high speed and failing to slow down in time to avoid the collisions, as well as drivers' lack of attention to the traffic and roadway conditions.

Drivers approaching this intersection have to handle a complicated and sometimes-busy traffic conditions and may violate the law, often by not paying attention to the stop control. The collision diagram clearly shows a majority of oblique- and right-angle collisions that involved vehicles traveling on the stop-control approaches.

FIGURE 2
Collision Diagram
January 1, 2007, through December 31, 2009
Prospect Street at Water Street, Milford



SYMBOLS		PAVEMENT/WEATHER/LIGHTING		TYPES OF COLLISIONS
	Moving vehicle	D	Dry	Head-on
	Backing vehicle	W	Wet	Angle
	Pedestrian or bicycle	S	Snowy, icy	Rear-end
	Out-of-control vehicle	--	Other	Sideswipe
	Fixed object	C	Clear	
	Property damage only	R	Rainy/foggy/cloudy	
	Injury	S	Snow/sleet	
	Fatality	--	Other	
	No damage or injury	DL	Daylight	
	Not reported	L	Dark, lights	
	Number of accidents	N	Dark, no lights	
		DU	Dusk	
		DW	Dawn	

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TABLE 2
Summary of Crash Reports from Milford Police Department (2007-2009)

Statistics Period		2007	2008	2009	3-Year	Annual
Total Number of Crashes		10	6	7	23	8
Severity	Property Damage Only	6	2	4	12	4
	Personal Injury	3	3	3	9	3
	Fatality	1	0	0	1	0
	Not Reported	0	1	0	1	0
Collision Type	Angle	7	6	5	18	6
	Rear-end	2	0	0	2	1
	Sideswipe	0	0	1	1	0
	Head-on	0	0	1	1	0
	Single Vehicle	1	0	0	1	0
	Not Reported	0	0	0	0	0
Involved Pedestrian(s)		0	0	0	0	0
Involved Cyclist(s)		0	0	0	0	0
Occurred during Weekday Peak Periods*		4	3	4	11	4
Wet or Icy Pavement Conditions		0	3	2	5	2
Dark/Lighted Conditions		3	2	2	7	2

* Peak periods are defined as 7:00-10:00 AM and 3:30-6:30 PM.
Note: All 2007 crashes in this table are included in Table 1 (MassDOT Crash Data 2006-2008).
All 2008 crashes, except two (7/7/2008 and 12/23/2008), in this table are included in Table 1.
None of the 2009 crashes in this table are included in Table 1.

INTERSECTION CAPACITY ANALYSIS

MPO staff collected turning movement counts at the intersection on June 3, 2010. The data were recorded in 15-minute intervals for the peak traffic periods in the morning, from 7:00 to 9:00, and in the evening, from 4:00 to 6:00. The intersection carried about 1,180 vehicles in the morning peak hour, from 7:30 to 8:30, and about 1,420 vehicles in the evening peak hour, from 4:00 to 5:00 (see Table 3). Six pedestrians and four pedestrians were observed during the AM and PM peak hour, respectively. No cyclists were observed in the AM peak hour, and one westbound through cyclist was observed in the PM peak hour (not shown in Table 3).

TABLE 3
AM and PM Peak-Hour Traffic Volumes and Pedestrian Crossings

Street name		Prospect Street						Water Street						Total
Direction		Northbound			Southbound			Eastbound			Westbound			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	Turning volume	37	358	31	71	412	30	11	35	73	14	22	82	1176
	Approach volume	426			513			119			118			
	Ped. crossings	2			1			1			2			6
PM peak hour	Turning volume	58	448	35	83	448	32	12	42	49	34	31	104	1416
	Approach volume	581			563			103			169			
	Ped. crossings	2			0			2			0			4

Based on the turning movement counts and the signal timings measured on the site, the intersection capacity was analyzed by using an intersection capacity analysis program, Synchro.[3] The intersection was modeled as an unsignalized intersection with a stop control on Water Street. As Table 4 shows, the operations on Water Street were found to operate at level of service (LOS) D with an average delay of about half a minute in the AM peak hour, and to operate at LOS F with an average delay of about one to one and half minutes in the PM peak hour. The criteria for the level of service are based on Highway Capacity Manual 2000.[4] The LOS analysis indicates that drivers on Water Street experience some acceptable delays in the AM peak hour but experience undesirable delays in the PM peak hour. Detailed analysis settings and results for both the AM and PM peak hour are included in Appendix B.

TABLE 4
Intersection Capacity Analysis, Existing Conditions

Street name		**Prospect Street**						**Water Street**					
Direction		**Northbound**			**Southbound**			**Eastbound**			**Westbound**		
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
AM peak hour	**LOS**	**A**			**A**			**D**			**D**		
	Delay (sec/veh)	1			1			31			28		
PM peak hour	**LOS**	**A**			**A**			**F**			**F**		
	Delay (sec/veh)	1			1			57			109		

PRELIMINARY ANALYSIS OF TRAFFIC SIGNAL WARRANTS

According to Manual for Uniform Traffic Control Devices(MUTCD),[5] an engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location should be performed to determine whether installation of a traffic control signal is justified at a particular location. The investigation should include applicable factors contained in the following traffic signal warrants and other factors related to existing operations and safety at the study location:

1. Eight-Hour Vehicular Volume Warrant
2. Four-Hour Vehicular Volume Warrant
3. Peak-Hour Warrant
4. Pedestrian Volume Warrant
5. School Crossing Warrant
6. Coordinated Signal System Warrant
7. Crash Experience Warrant
8. Roadway Network Warrant
9. Intersection Near a Grade Crossing

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3 Synchro is developed and distributed by Trafficware, Ltd. It can perform capacity analysis and traffic simulation (when combined with SimTraffic) for an individual intersection or a series of intersections.

4 Transportation Research Board, *Highway Capacity Manual 2000*, Nation Research Council, Washington D. C., 2000.

5 Federal Highway Administration, U.S. Department of Transportation, *Chapter 4C. Traffic Control Signal Needs*, 2009 Edition, December 2009.

A traffic control signal should not be installed unless one or more of the factors reflected in these warrants are met. Moreover, the satisfaction of a warrant or warrants in itself does not justify signal installation unless an engineering study indicates that the installation will improve the overall safety and/or operation of the intersection.

In this study, we performed a preliminary analysis of the applicable traffic signal warrants based on available traffic data. The applicable factors for this intersection are contained in Warrants 1, 2, and 7. Warrant 3 is intended for unusual cases, such as office complexes, manufacturing plants, industrial complexes, or high-occupancy-vehicle facilities that attract or discharge large numbers of vehicles over a short time. The intersection is regarded as a stand-alone location, not a part of a coordinated traffic system, where pedestrian volume is low and is not close to any schools or near a grade crossing. Therefore Warrants 3, 4, 5, 6, 8, and 9 were not tested.

Table 5 shows the examination of Warrants 1, 2, and 7 based on hourly volumes of an average day, which were derived from three mid-week days' 24-hour automatic traffic counts. The counts were collected by MassDOT's Highway Division in the week of June 7, 2010; the volumes were considered typical for the season or even slightly higher than average (see Appendix C for the detailed summary of hourly volumes from all the approaches at the intersection).

TABLE 5
Summary of Hourly Volumes and Warrant Fulfillment

Hourly Period Starting	Prospect St. (main street)		Water/Williams St. (minor street)		Sum of main street	Higher of minor street	Volumes above the minimum requirement		
	EB	WB	SB	NB			Warrant 1	Warrant 2	Warrant 7
6:00	50	71	23	26	121	26			
7:00	167	267	56	60	434	60			X
8:00	349	422	114	90	771	114	X		X
9:00	399	475	138	111	874	138	X		X
10:00	408	467	133	106	875	133	X		X
11:00	421	444	110	116	865	116	X		X
12:00	452	443	144	125	895	144	X		X
13:00	479	482	142	133	961	142	X		X
14:00	479	463	117	144	942	144	X		X
15:00	510	537	142	145	1047	145	X	X	X
16:00	562	559	136	154	1121	154	X	X	X
17:00	548	532	139	155	1080	155	X	X	X
18:00	540	504	124	144	1044	144	X	X	X
19:00	452	430	95	106	882	106	X		X

Note: **Warrant 1 is fulfilled.** It requires that the traffic conditions (observed vehicular volumes higher than the specified minimum volumes) exist for each of any 8 hours of an average day. Conditions B was applied in this case.
Warrant 2 is fulfilled. It requires that the traffic conditions (minimum volumes specified differently from Warrant 1) exist for each of any 4 hours of an average day.
Warrant 7 (Crash Experience) is fulfilled. It requires that the traffic conditions (vehicular volumes higher than 80 percent of the volumes specified in Warrant 1 Condition B), in addition to the requirement of five or more correctable crashes in recent 12-month period.

The analysis indicates that the intersection meets the conditions required by Warrants 1 (Eight-Hour Vehicular Volume Warrant) and 2 (Four-Hour Vehicular Volume Warrant). Warrant 7 is also satisfied, as the traffic conditions meet the required criteria and the 2008 crashes include five angle collisions that are susceptible to correction.

ANALYSIS OF TRAFFIC SIGNAL ALTERNATIVE

The preliminary traffic signal warrants analysis shows that the required traffic conditions exist for Warrants 1, 2 and 7 to be satisfied at this intersection. This section will examine if and how a traffic signal control would work at this intersection.

Synchro tests of the installation of a traffic signal control indicate that under the existing layout the intersection would operate at an overall level of service (LOS) B in both the AM and PM peak hours, with all individual approaches running at a desirable LOS B or better (see Table 6). The signal was modeled as a three-phase operation, with the north-south approaches led by protected and permissive left turns, under a total cycle of 67 seconds consisting of 45 seconds of traffic phases and an on-call exclusive pedestrian signal phase of 22 seconds (see Appendix D for details of the analysis for both AM and PM peak hours).

TABLE 6
Intersection Capacity Analysis
Traffic Signal Option under Existing Traffic Conditions

Street name		**Prospect Street**						**Water Street**						**Overall**
Direction		**Northbound**			**Southbound**			**Eastbound**			**Westbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	LOS	**A**	**B**		**A**	**B**		**B**			**B**			**B**
	Delay (sec/veh)	7	14		7	14		19			17			14
PM peak hour	LOS	**A**	**B**		**A**	**B**		**B**			**B**			**B**
	Delay (sec/veh)	8	20		9	19		17			19			18

In addition, a future-year scenario of 15% growth over a 20-year planning horizon was tested for the traffic signal option. The growth assumption is based on a review of the traffic projections at the intersection from the recent Boston Region MPO transportation-planning model. As shown in Table 7, the signalized intersection, without any major geometric design modifications, would still operate at a desirable LOS B in the AM peak hour and LOS C in the PM peak hour under the projected traffic conditions (see Appendix E for details of the analysis results).

The above analyses show that a traffic signal would operate acceptably at this intersection. The traffic signal would interrupt traffic on Prospect Street at intervals to permit traffic from Water Street to proceed. Traffic operations on Water Street would be significantly improved with much reduced delays. Although delays on Prospect Street would increase somewhat, it would still maintain a desirable level of service for both approaches.

In addition, the signal is expected to reduce the frequency and severity of certain types of crashes, especially right-angle collisions. Currently the flashing beacon is located at a corner of the

TABLE 7
Intersection Capacity Analysis
Traffic Signal Option under 2030 Projected Traffic Conditions

Street name		**Prospect Street**						**Water Street**						**Overall**
Direction		**Northbound**			**Southbound**			**Eastbound**			**Westbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	LOS	**A**	**B**		**A**	**B**		**C**			**B**			**B**
	Delay (sec/veh)	7	15		7	15		20			18			15
PM peak hour	LOS	**A**	**C**		**B**	**C**		**B**			**C**			**C**
	Delay (sec/veh)	8	25		11	21		18			23			21

intersection. The future overhead signal indications would increase the awareness and visibility of the intersection, especially from the uphill approaches. These measures are further discussed in the section on recommendations and discussion.

REVIEW OF ROUNDABOUT ALTERNATIVE

Another improvement option considered for this intersection is the installation of a modern roundabout. Modern roundabouts have the advantages of slowing down traffic, reducing crash severity, and requiring minimal maintenance costs. This section will evaluate whether a modern roundabout would work for this intersection.

Synchro tests of a single-lane roundabout under the existing traffic conditions indicate that a modern roundabout would operate satisfactorily in both AM and PM peak hours. All the approaches would operate under 85% of the estimated capacity, which is regarded as the threshold for roundabout operations.[6] Detailed analyses of individual approaches for both peak hours are shown in Appendix F.

In addition, a future-year scenario of 15% growth over a 20-year planning horizon was tested for the single-lane roundabout option. The assumed roundabout intersection would still operate acceptably, with volume-to-capacity ratios under 85% for all approaches in both of the peak hours under the projected traffic conditions.

The above analyses show that a modern roundabout at this location is operationally feasible under the existing and projected traffic conditions. However, further review of the geometric design elements and the surrounding land use characteristics indicates that the roundabout option is not favorable for this intersection.

As the future roundabout would be located in the middle of a principal urban arterial with a prevailing traffic speed of 35 MPH or higher within a limited space, the following basic design elements were considered:[7]

[6] Federal Highway Administration, U.S. Department of Transportation, *Roundabouts: An Informational Guide, Chapter 4: Operation,* FHWA-RD-00-67, June 2000.
[7] Federal Highway Administration, U.S. Department of Transportation, *Roundabouts: An Informational Guide, Chapter 6: Geometric Design,* FHWA-RD-00-67, June 2000.

- Single entry/exit lane from all approaches
- 25 MPH maximum speed of the entry design
- 115 to 130 feet inscribed circle diameter
- Raised and extended splitter islands with crosswalk cuts
- Up to 20,000 vehicles daily service volumes

Based on these design elements, the roundabout conversion would likely require some land-takings at and near the intersection.[8] In addition, the vertical curves on both streets could complicate the roundabout maneuver during snowy or icy conditions. It would also require sufficient distance on Prospect Street for vehicles to slow down from 35 MPH to 25 MPH. Last but not least, it would not be compatible with the existing surroundings, where signalized intersections already exist north and south of this intersection and adjacent commercial developments require several access/egress driveways near the intersection. Therefore, the modern roundabout option is considered to be unfavorable at this location.

OTHER IMPROVEMENT ALTERNATIVES

In the study review session, some improvement ideas costing less than the traffic signal and the roundabout alternatives and focusing on reducing the severity of collisions were discussed:

- Make Prospect Street (Route 140) a single shared through-left lane by removing the left-turn lane in both directions (which would potentially help eliminate the major safety issue of the queued left-turning traffic blocking the sight lines for the Water Street traffic)
- Prohibit left turns at the intersection (presumably drivers could use the signalized intersection to the north to make the necessary movements)
- Make the intersection a four-way stop operation

A quick review found that the first and the third ideas would have significant impacts on the capacity of Route 140 and have uncertain safety benefits as traffic congestion on Route 140 potentially would increase the number of crashes at the intersection. The second idea is also not feasible, as the Town indicated that there are no sufficient alternative routes in the current street system for the left turners if they are prohibited from turning left at this intersection. For these reasons, these three ideas were not considered for this intersection.

IMPROVEMENT RECOMMENDATIONS AND DISCUSSION

The above safety and operations analyses indicate that the existing two-way stop control is not effective for the roadway and traffic conditions at this intersection. To improve safety and operations at this intersection, this study reviewed two major improvement alternatives: (1) to install a traffic signal in place of the STOP control, and (2) to convert the intersection to a modern roundabout. The conversion to a roundabout would involve design modifications with potential land takings and was considered unfavorable through a review of the existing roadway and land use conditions.

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[8] A review of the State Roadway Inventory file indicates that near the intersection, Prospect Street has a 40-foot right-of-way (ROW), Water Street has a 50-foot ROW, and Williams Street has a 40-foot ROW. The intersection space is insufficient for accommodating an inscribed circle of 115 to 130 feet in diameter.

The installation of a traffic signal was analyzed as justified and was determined to be operationally acceptable. The preliminary traffic signal warrants analysis shows that the required traffic conditions of Warrants 1, 2, and 7 are all satisfied for this intersection. The capacity analyses of the signalized intersection under the existing layout indicate that Water Street traffic operations would be significantly improved, with much reduced delays, and Prospect Street would still maintain a desirable level of service (LOS) with slightly increased delays. The intersection would operate at a desirable overall LOS B with a reduced average delay per vehicle.

In addition, the signal would reduce conflicts between Prospect Street and Water Street traffic and thus reduce the frequency and severity of certain types of crashes (mainly right-angle collisions). More significantly, it would improve the pedestrian safely at this intersection as it could stop all the traffic at intervals and provide an exclusive signal phase for pedestrians to cross the intersection. We therefore recommend the installation of a traffic signal at this intersection with the following major features:

- Install a fully actuated traffic signal system with pedestrian signal heads
- Install overhead signal indications supported by mast arms, which can be clearly viewed from all approaches
- Maintain the existing 100- and 150-foot storage lengths for the northbound and the southbound left-turn pockets
- Install pedestrian signal heads and push buttons at all corners of the intersection
- Install crosswalks on the three approaches that lack crosswalks (there is an existing crosswalk on the northbound approach)
- Install wheelchair ramps that meet ADA (American with Disabilities Act)/AAB (Massachusetts Architectural Access Board) standards at all corners of the intersection
- Upgrade any substandard sidewalks connected to the intersection
- Consolidate or modify the driveways of the nearby commercial developments so that they would not be too close to the intersection's functional (turning) areas
- Widen the shoulders on Route 140 to a minimum of 4 feet to accommodate bicycles[9]

The State Roadway Inventory file indicates that Prospect Street (Route 140) in the vicinity of the intersection has a right-of-way width of about 40 feet. It appears to be insufficient for the inclusion of a 4-foot shoulder on both sides of Route 140. The right-of-way impacts of this and the potential sidewalk upgrades should be further examined in the functional design stage for this intersection.

At this preliminary planning stage, the total cost of the signal installation and the intersection reconstruction can be roughly estimated as $500,000 to $750,000 barring no land-taking costs. Currently Prospect Street (Route 140) is under the jurisdiction of MassDOT, and Water Street is owned by the Town of Milford. The implementation would require the town to work closely with MassDOT through the project implantation process (see Appendix G). The Town can prepare the Project Need Form (PNF) and Project Initiation Form (PIF) for improvements to be implemented at this location, as an important part of the Needs Identification/Project Initiation process, to gather public consensus for a conceptual design. The MassDOT Highway Division District office will assist the Town in preparing these forms. In addition, the Town will have to request

[9] This is required by MassDOT's engineering directive E-09-005, unless the project is small enough to be exempt from the design criteria.

that the Boston Region MPO place any proposed project for this location in the Transportation Improvement Program.

In the short term, the following measures can help to improve the existing traffic operations:

- Replace the existing 24-by-24-foot stop signs with 30-by-30-foot signs
- Install a solar powered flashing red beacon on the top of the new stop sign on the Water Street westbound approach
- Relocate the traffic signs and commercial signs on the southeast corner of the intersection[10]
- Install an intersection-ahead warning sign (W2-1)[11] on the northbound approach about 500 feet from the intersection

These short-term measures would increase drivers' awareness of and attention to the traffic conditions and regulations at the intersection.

[10] There are two traffic signs at the location. The pedestrian crossing warning sign can be relocated about 15 to 20 feet further south. The "Left Lane Must Turn Left" sign is too close to the intersection and should be relocated about 100 feet from the intersection.
[11] Federal Highway Administration, U.S. Department of Transportation, *Chapter 2C. Warning Signs*, 2009 Edition, December 2009.

Appendix A

Intersection Crash Rate Calculation
Prospect Street at Water Street, Milford

MassDOT Highway — Moving Massachusetts Forward.

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Milford COUNT DATE : 6/3/10

DISTRICT : 3 UNSIGNALIZED : X SIGNALIZED :

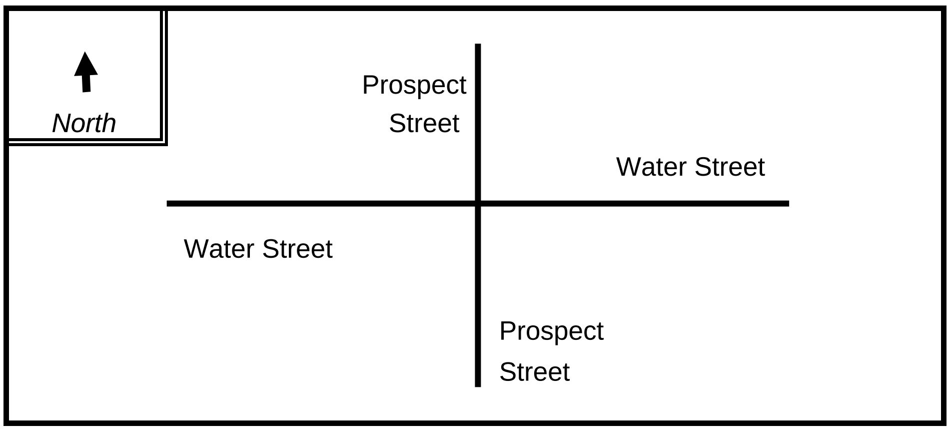
~ INTERSECTION DATA ~

MAJOR STREET : Prospect Street (Route 140)

MINOR STREET(S) : Water Street

Williams 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) :	581	563	103	169		**1,416**

" K " FACTOR : **0.090** INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **15,733**

TOTAL # OF CRASHES : 29 # OF YEARS : 3 AVERAGE # OF CRASHES PER YEAR (**A**) : **9.67**

CRASH RATE CALCULATION : 1.68

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

Comments : MassDOT District 3 Average Rate = 0.68

Project Title & Date: Safety and Operations Analyses at Selceted Intersections

Appendix B

AM/PM Peak Hour Intersection Capacity Analysis
Existing Traffic Conditions
Prospect Street at Water Street, Milford

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	11	35	73	14	22	82	37	358	31	71	412	30
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Hourly flow rate (vph)	12	40	83	16	25	93	42	407	35	81	468	34
Pedestrians		1			2			2			1	
Lane Width (ft)		12.0			12.0			12.0			12.0	
Walking Speed (ft/s)		4.0			4.0			4.0			4.0	
Percent Blockage		0			0			0			0	
Right turn flare (veh)												
Median type								None			None	
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	1245	1176	488	1245	1175	427	503			444		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	1245	1176	488	1245	1175	427	503			444		
tC, single (s)	7.1	6.5	6.2	7.1	6.5	6.2	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	88	76	86	83	85	85	96			93		
cM capacity (veh/h)	103	169	576	96	169	624	1050			1104		

Direction, Lane #	EB 1	WB 1	NB 1	NB 2	SB 1	SB 2
Volume Total	135	134	42	442	81	502
Volume Left	12	16	42	0	81	0
Volume Right	83	93	0	35	0	34
cSH	270	290	1050	1700	1104	1700
Volume to Capacity	0.50	0.46	0.04	0.26	0.07	0.30
Queue Length 95th (ft)	65	58	3	0	6	0
Control Delay (s)	30.9	27.7	8.6	0.0	8.5	0.0
Lane LOS	D	D	A		A	
Approach Delay (s)	30.9	27.7	0.7		1.2	
Approach LOS	D	D				

Intersection Summary			
Average Delay	6.7		
Intersection Capacity Utilization	46.9%	ICU Level of Service	A
Analysis Period (min)	15		

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	12	42	49	34	31	104	58	488	35	83	448	32
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Hourly flow rate (vph)	13	45	52	36	33	111	62	519	37	88	477	34
Pedestrians		2						2				
Lane Width (ft)		12.0						12.0				
Walking Speed (ft/s)		4.0						4.0				
Percent Blockage		0						0				
Right turn flare (veh)												
Median type								None			None	
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	1442	1352	498	1391	1350	538	513			556		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	1442	1352	498	1391	1350	538	513			556		
tC, single (s)	7.1	6.5	6.2	7.1	6.5	6.2	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	80	65	91	49	74	80	94			91		
cM capacity (veh/h)	63	129	573	71	129	543	1051			1004		

Direction, Lane #	EB 1	WB 1	NB 1	NB 2	SB 1	SB 2
Volume Total	110	180	62	556	88	511
Volume Left	13	36	62	0	88	0
Volume Right	52	111	0	37	0	34
cSH	172	186	1051	1700	1004	1700
Volume to Capacity	0.64	0.97	0.06	0.33	0.09	0.30
Queue Length 95th (ft)	90	196	5	0	7	0
Control Delay (s)	57.1	109.2	8.6	0.0	8.9	0.0
Lane LOS	F	F	A		A	
Approach Delay (s)	57.1	109.2	0.9		1.3	
Approach LOS	F	F				

Intersection Summary			
Average Delay	18.1		
Intersection Capacity Utilization	58.6%	ICU Level of Service	B
Analysis Period (min)	15		

Appendix C

Summary of hourly traffic volumes
June 7, 2010
Prospect Street at Water Street, Milford

STA, 1 NB

Site Reference: 000000000544
Site ID: 000000000101
Location: RTE. 140 SOUTH OF WATER/WILLIAMS STS.
Direction: NORTH

File: 101.prn
City: MILFORD
County: VOL N.B.

TIME	MON 7	TUE 8	WED 9	THU 10	FRI 11	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		37	46	44	57	46			46	184
02:00		27	19	16	26	22			22	88
03:00		16	8	13	13	12			12	50
04:00		10	5	5	5	6			6	25
05:00		17	14	25	24	20			20	80
06:00		45	50	48	57	50			50	200
07:00		166	179	157	166	167			167	668
08:00		341	365	339	353	349			349	1398
09:00		391	403	381	424	399			399	1599
10:00		398	400	427		408			408	1225
11:00		412	419	433		421			421	1264
12:00	466	447	466	432		452			452	1811
13:00	455	502	475	486		479			479	1918
14:00	513	472	493	438		479			479	1916
15:00	525	516	503	499		510			510	2043
16:00	556	561	585	549		562			562	2251
17:00	544	588	572	490		548			548	2194
18:00	535	557	529	540		540			540	2161
19:00	438	459	428	483		452			452	1808
20:00	399	365	354	424		385			385	1542
21:00	276	318	298	308		300			300	1200
22:00	181	160	172	183		174			174	696
23:00	101	105	94	104		101			101	404
24:00	78	87	73	89		81			81	327
TOTALS	5067	6997	6950	6913	1125	6963	0	0	6963	27052
% AVG WKDY	72.7	100.4	99.8	99.2	16.1					
% AVG WEEK	72.7	100.4	99.8	99.2	16.1					
AM Times	12:00	12:00	12:00	11:00	09:00	12:00			12:00	
AM Peaks	466	447	466	433	424	452			452	
PM Times	16:00	17:00	16:00	16:00		16:00			16:00	
PM Peaks	556	588	585	549		562			562	

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NB 6963
SB 6742
COMB AWD 13705
FAC .90 (.97)
COMB ADT 12,000

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 6/7/2010

STA. 1SB

Site Reference: 000000000689
Site ID: 000000000102
Location: RTE. 140 SOUTH OF WATER/WILLIAMS STS.
Direction: SOUTH

File: 102.prn
City: MILFORD
County: VOL S.B.

TIME	MON 7	TUE 8	WED 9	THU 10	FRI 11	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		22	36	17	29	26			26	104
02:00		6	15	15	17	13			13	53
03:00		15	9	8	13	11			11	45
04:00		10	6	8	8	8			8	32
05:00		23	20	24	25	23			23	92
06:00		77	76	68	70	72			72	291
07:00		284	286	265	266	275			275	1101
08:00		429	427	415	418	422			422	1689
09:00		468	442	446	427	445			445	1783
10:00		440	424	433		432			432	1297
11:00		437	403	429		423			423	1269
12:00	406	410	478	464		439			439	1758
13:00	474	486	439	455		463			463	1854
14:00	469	407	421	422		429			429	1719
15:00	520	519	509	493		510			510	2041
16:00	524	499	483	476		495			495	1982
17:00	510	532	504	517		515			515	2063
18:00	483	479	463	505		482			482	1930
19:00	423	371	412	432		409			409	1638
20:00	316	303	335	315		317			317	1269
21:00	242	254	220	266		245			245	982
22:00	161	135	138	152		146			146	586
23:00	91	103	80	107		95			95	381
24:00	48	43	44	54		47			47	189
TOTALS	4667	6752	6670	6786	1273	6742	0	0	6742	26148
% AVG WKDY	69.2	100.1	98.9	100.6	18.8					
% AVG WEEK	69.2	100.1	98.9	100.6	18.8					
AM Times	12:00	09:00	12:00	12:00	09:00	09:00			09:00	
AM Peaks	406	468	478	464	427	445			445	
PM Times	16:00	17:00	15:00	17:00		17:00			17:00	
PM Peaks	524	532	509	517		515			515	

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 6/22/2010

STA. 2 NB

Site Reference: 000000000560
Site ID: 000000000201
Location: RTE. 140 NORTH OF WATER ST.
Direction: NORTH

File: 201.prn
City: MILFORD
County: VOL N.B.

TIME	MON	TUE 22	WED 23	THU 24	FRI 25	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00			43	53	55	50			50	151
02:00			29	39	40	36			36	108
03:00			13	20	19	17			17	52
04:00			9	11	15	11			11	35
05:00			24	24	25	24			24	73
06:00			71	83	65	73			73	219
07:00			182	177	161	173			173	520
08:00			353	330	329	337			337	1012
09:00			446	460	441	449			449	1347
10:00			444	480	452	458			458	1376
11:00		442	520	510		490			490	1472
12:00		474	509	497		493			493	1480
13:00		537	517	534		529			529	1588
14:00		479	549	549		525			525	1577
15:00		498	560	516		524			524	1574
16:00		538	551	546		545			545	1635
17:00		584	569	601		584			584	1754
18:00		577	562	579		572			572	1718
19:00		443	479	526		482			482	1448
20:00		390	462	412		421			421	1264
21:00		329	379	326		344			344	1034
22:00		258	262	260		260			260	780
23:00		130	150	172		150			150	452
24:00		94	103	106		101			101	303
TOTALS	0	5773	7786	7811	1602	7648	0	0	7648	22972
% AVG WKDY		75.4	101.8	102.1	20.9					
% AVG WEEK		75.4	101.8	102.1	20.9					
AM Times		12:00	11:00	11:00	10:00	12:00			12:00	
AM Peaks		474	520	510	452	493			493	
PM Times		17:00	17:00	17:00		17:00			17:00	
PM Peaks		584	569	601		584			584	

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NB 7648
SB 7085
COMB AWD 14733
FAC .90 (.97)
COMB ADT 12,900

STA. 2 SB

Site Reference: 000000000516
Site ID: 000000000202
Location: RTE. 140 NORTH OF WATER ST.
Direction: SOUTH

File: 202.prn
City: MILFORD
County: VOL S.B.

TIME	MON 7	TUE 8	WED 9	THU 10	FRI 11	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		22	35	19	32	27			27	108
02:00		9	15	11	18	13			13	53
03:00		15	11	6	10	10			10	42
04:00		9	5	7	8	7			7	29
05:00		23	24	23	26	24			24	96
06:00		78	82	65	62	71			71	287
07:00		277	275	254	265	267			267	1071
08:00		436	425	400	428	422			422	1689
09:00		503	448	478	474	475			475	1903
10:00		471	453	436	511	467			467	1871
11:00		450	420	462		444			444	1332
12:00	418	426	460	469		443			443	1773
13:00	474	513	441	500		482			482	1928
14:00	493	455	452	453		463			463	1853
15:00	538	542	532	536		537			537	2148
16:00	565	577	547	550		559			559	2239
17:00	531	538	523	537		532			532	2129
18:00	496	507	492	524		504			504	2019
19:00	453	394	421	453		430			430	1721
20:00	336	341	359	330		341			341	1366
21:00	272	274	242	278		266			266	1066
22:00	169	140	149	162		155			155	620
23:00	102	98	77	106		95			95	383
24:00	57	47	46	56		51			51	206
TOTALS	4904	7145	6934	7115	1834	7085	0	0	7085	27932
% AVG WKDY	69.2	100.8	97.8	100.4	25.8					
% AVG WEEK	69.2	100.8	97.8	100.4	25.8					
AM Times	12:00	09:00	12:00	09:00	10:00	09:00			09:00	
AM Peaks	418	503	460	478	511	475			475	
PM Times	16:00	16:00	16:00	16:00		16:00			16:00	
PM Peaks	565	577	547	550		559			559	

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 6/7/2010

STA.3 EB

Site Reference: 000000000803
Site ID: 000000000303
Location: WILLIAMS ST. WEST OF RTE. 140 .
Direction: EAST

File: 303.prn
City: MILFORD
County: VOL E.B.

TIME	MON 7	TUE 8	WED 9	THU 10	FRI 11	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		9	4	8	7	7			7	28
02:00		1	3	3	3	2			2	10
03:00		5	1	1	3	2			2	10
04:00		4	1	2	0	1			1	7
05:00		6	10	6	6	7			7	28
06:00		25	20	23	25	23			23	93
07:00		59	58	57	50	56			56	224
08:00		114	109	117	118	114			114	458
09:00		134	136	154	131	138			138	555
10:00		125	153	121		133			133	399
11:00		102	117	113		110			110	332
12:00	162	124	140	152		144			144	578
13:00	151	141	142	134		142			142	568
14:00	128	125	118	98		117			117	469
15:00	152	151	145	121		142			142	569
16:00	127	148	139	133		136			136	547
17:00	127	157	145	127		139			139	556
18:00	140	111	116	132		124			124	499
19:00	93	77	98	112		95			95	380
20:00	100	85	57	55		74			74	297
21:00	53	64	53	64		58			58	234
22:00	26	28	30	39		30			30	123
23:00	14	15	25	20		18			18	74
24:00	7	15	7	7		9			9	36
TOTALS	1280	1825	1827	1799	343	1821	0	0	1821	7074
% AVG WKDY	70.2	100.2	100.3	98.7	18.8					
% AVG WEEK	70.2	100.2	100.3	98.7	18.8					
AM Times	12:00	09:00	10:00	09:00	09:00	12:00			12:00	
AM Peaks	162	134	153	154	131	144			144	
PM Times	15:00	17:00	15:00	13:00		13:00			13:00	
PM Peaks	152	157	145	134		142			142	

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EB 1821
WB 1976
COMB AWD 3797
FAC .90(.98)
COMB ADT 3,300

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 6/7/2010

STA. 3 WB

Site Reference: 000000000736
Site ID: 000000000304
Location: WILLIAMS ST. WEST OF RTE. 140 .
Direction: WEST

File: 304.prn
City: MILFORD
County: VOL W.B.

TIME	MON 7	TUE 8	WED 9	THU	FRI	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		11	15			13			13	26
02:00		2	4			3			3	6
03:00		4	1			2			2	5
04:00		2	0			1			1	2
05:00		3	2			2			2	5
06:00		7	8			7			7	15
07:00		29	28			28			28	57
08:00		77	90			83			83	167
09:00		123	106			114			114	229
10:00		110	133			121			121	243
11:00		104	119			111			111	223
12:00	132	131	124			129			129	387
13:00	137	123	126			128			128	386
14:00	145	160	137			147			147	442
15:00	153	147	155			151			151	455
16:00	164	178	185			175			175	527
17:00	190	185	176			183			183	551
18:00	180	158				169			169	338
19:00	148	116				132			132	264
20:00	114	107				110			110	221
21:00	74	87				80			80	161
22:00	50	50				50			50	100
23:00	22	21				21			21	43
24:00	16	17				16			16	33
TOTALS	1525	1952	1409	0	0	1976	0	0	1976	4886
% AVG WKDY	77.1	98.7	71.3							
% AVG WEEK	77.1	98.7	71.3							
AM Times	12:00	12:00	10:00			12:00			12:00	
AM Peaks	132	131	133			129			129	
PM Times	17:00	17:00	16:00			17:00			17:00	
PM Peaks	190	185	185			183			183	

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 6/7/2010

STA. 4 EB

Site Reference: 000000000452
Site ID: 000000000403
Location: WATER ST. EAST OF RTE. 140 .
Direction: EAST

File: 403.prn
City: MILFORD
County: VOL E.B.

TIME	MON 7	TUE 8	WED 9	THU 10	FRI 11	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		7	3	6	13	7			7	29
02:00		5	6	1	4	4			4	16
03:00		5	1	1	2	2			2	9
04:00		3	2	2	3	2			2	10
05:00		6	11	9	8	8			8	34
06:00		23	23	22	21	22			22	89
07:00		57	52	47	49	51			51	205
08:00		93	78	79	80	82			82	330
09:00		120	101	122	110	113			113	453
10:00		132	129	120	118	124			124	499
11:00	124	106	109	131		117			117	470
12:00	147	139	136	151		143			143	573
13:00	143	173	125	156		149			149	597
14:00	140	136	126	103		126			126	505
15:00	143	137	151	155		146			146	586
16:00	157	162	145	179		160			160	643
17:00	141	143	130	145		139			139	559
18:00	133	157	151	143		146			146	584
19:00	111	101	97	128		109			109	437
20:00	109	124	116	102		112			112	451
21:00	101	110	88	86		96			96	385
22:00	62	66	56	62		61			61	246
23:00	30	26	31	25		28			28	112
24:00	23	19	14	24		20			20	80
TOTALS	1564	2050	1881	1999	408	1967	0	0	1967	7902
% AVG WKDY	79.5	104.2	95.6	101.6	20.7					
% AVG WEEK	79.5	104.2	95.6	101.6	20.7					
AM Times	12:00	12:00	12:00	12:00	10:00	12:00			12:00	
AM Peaks	147	139	136	151	118	143			143	
PM Times	16:00	13:00	15:00	16:00		16:00			16:00	
PM Peaks	157	173	151	179		160			160	

u5

EB 1967
WB 1961
COMB AWD 3928
FAC .90(.98)
COMB ADT 3,500

Mass Highway Department
WEEKLY SUMMARY FOR LANE 1
Starting: 6/7/2010

STA. 4 WB

Site Reference: 000000000587
Site ID: 000000000404
Location: WATER ST. EAST OF RTE. 140 .
Direction: WEST

File: 404.prn
City: MILFORD
County: VOL W.B.

TIME	MON 7	TUE 8	WED 9	THU 10	FRI 11	WKDAY AVG	SAT	SUN	WEEK AVG	TOTAL
01:00		13	15	12	14	13			13	54
02:00		5	6	8	9	7			7	28
03:00		6	1	5	8	5			5	20
04:00		4	1	0	4	2			2	9
05:00		5	8	9	6	7			7	28
06:00		27	29	25	23	26			26	104
07:00		56	58	57	71	60			60	242
08:00		98	77	88	98	90			90	361
09:00		116	118	110	103	111			111	447
10:00		100	102	108	115	106			106	425
11:00	123	102	119	122		116			116	466
12:00	119	121	136	127		125			125	503
13:00	140	150	125	119		133			133	534
14:00	151	155	137	136		144			144	579
15:00	139	147	152	143		145			145	581
16:00	148	161	156	152		154			154	617
17:00	154	154	138	174		155			155	620
18:00	143	140	128	166		144			144	577
19:00	102	108	99	118		106			106	427
20:00	109	107	87	123		106			106	426
21:00	96	104	83	87		92			92	370
22:00	60	61	62	54		59			59	237
23:00	38	35	32	34		34			34	139
24:00	23	15	23	24		21			21	85
TOTALS	1545	1990	1892	2001	451	1961	0	0	1961	7879
% AVG WKDY	78.7	101.4	96.4	102	22.9					
% AVG WEEK	78.7	101.4	96.4	102	22.9					
AM Times	11:00	12:00	12:00	12:00	10:00	12:00			12:00	
AM Peaks	123	121	136	127	115	125			125	
PM Times	17:00	16:00	16:00	17:00		17:00			17:00	
PM Peaks	154	161	156	174		155			155	

Appendix D

AM/PM Peak Hour Intersection Capacity Analysis
Traffic Signal Alternative
Under Existing Traffic Conditions
Prospect Street at Water Street, Milford

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	11	35	73	14	22	82	37	358	31	71	412	30
Confl. Peds. (#/hr)	1		2	2		1	1		2	2		1
Confl. Bikes (#/hr)												
Peak Hour Factor	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	3%	3%	3%	4%	4%	4%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			pm+pt			pm+pt		
Protected Phases		2			6		7	4		3	8	
Permitted Phases	2			6			4			8		
Detector Phase	2	2		6	6		7	4		3	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		2.0	4.0		2.0	4.0	
Minimum Split (s)	9.0	9.0		9.0	9.0		8.0	9.0		8.0	9.0	
Total Split (s)	11.0	11.0	0.0	11.0	11.0	0.0	8.0	26.0	0.0	8.0	26.0	0.0
Total Split (%)	16.4%	16.4%	0.0%	16.4%	16.4%	0.0%	11.9%	38.8%	0.0%	11.9%	38.8%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		2.0	3.0		2.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	4.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag							Lead	Lag		Lead	Lag	
Lead-Lag Optimize?							Yes	Yes		Yes	Yes	
Recall Mode	None	None		None	None		None	Max		None	Max	
Act Effct Green (s)		6.2			6.2		28.5	26.4		29.3	28.1	
Actuated g/C Ratio		0.13			0.13		0.61	0.56		0.63	0.60	
v/c Ratio		0.48			0.47		0.08	0.43		0.14	0.46	
Control Delay		18.6			17.0		6.6	13.7		6.7	13.8	
Queue Delay		0.0			0.0		0.0	0.0		0.0	0.0	
Total Delay		18.6			17.0		6.6	13.7		6.7	13.8	
LOS		B			B		A	B		A	B	
Approach Delay		18.6			17.0			13.1			12.9	
Approach LOS		B			B			B			B	

Intersection Summary	
Cycle Length: 67	
Actuated Cycle Length: 46.8	
Natural Cycle: 65	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 0.48	
Intersection Signal Delay: 13.9	Intersection LOS: B
Intersection Capacity Utilization 48.6%	ICU Level of Service A
Analysis Period (min) 15	

Splits and Phases: 3: Water Street & Prospect Street

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	33%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	12	42	49	34	31	104	58	488	35	83	448	32
Confl. Peds. (#/hr)			2	2			2					2
Confl. Bikes (#/hr)												
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	2%	2%	2%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			pm+pt			pm+pt		
Protected Phases		2			6		7	4		3	8	
Permitted Phases	2			6			4			8		
Detector Phase	2	2		6	6		7	4		3	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		2.0	4.0		2.0	4.0	
Minimum Split (s)	9.0	9.0		9.0	9.0		8.0	9.0		8.0	9.0	
Total Split (s)	13.0	13.0	0.0	13.0	13.0	0.0	8.0	24.0	0.0	8.0	24.0	0.0
Total Split (%)	19.4%	19.4%	0.0%	19.4%	19.4%	0.0%	11.9%	35.8%	0.0%	11.9%	35.8%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		2.0	3.0		2.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	4.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag							Lead	Lag		Lead	Lag	
Lead-Lag Optimize?							Yes	Yes		Yes	Yes	
Recall Mode	None	None		None	None		None	Min		None	Min	
Act Effct Green (s)		7.5			7.5		26.0	22.7		26.0	22.7	
Actuated g/C Ratio		0.16			0.16		0.54	0.47		0.54	0.47	
v/c Ratio		0.37			0.55		0.14	0.64		0.23	0.60	
Control Delay		16.9			18.8		7.8	19.6		8.6	18.7	
Queue Delay		0.0			0.0		0.0	0.0		0.0	0.0	
Total Delay		16.9			18.8		7.8	19.6		8.6	18.7	
LOS		B			B		A	B		A	B	
Approach Delay		16.9			18.8			18.4			17.2	
Approach LOS		B			B			B			B	

Intersection Summary	
Cycle Length: 67	
Actuated Cycle Length: 48.3	
Natural Cycle: 70	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 0.64	
Intersection Signal Delay: 17.9	Intersection LOS: B
Intersection Capacity Utilization 60.2%	ICU Level of Service B
Analysis Period (min) 15	

Splits and Phases: 3: Water Street & Prospect Street

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	33%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix E

AM/PM Peak Hour Intersection Capacity Analysis
Traffic Signal Alternative
Under Projected 2030 Traffic Conditions
Prospect Street at Water Street, Milford

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	11	35	73	14	22	82	37	358	31	71	412	30
Confl. Peds. (#/hr)	1		2	2		1	1		2	2		1
Confl. Bikes (#/hr)												
Peak Hour Factor	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Growth Factor	115%	115%	115%	115%	115%	115%	115%	115%	115%	115%	115%	115%
Heavy Vehicles (%)	3%	3%	3%	3%	3%	3%	4%	4%	4%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			pm+pt			pm+pt		
Protected Phases		2			6		7	4		3	8	
Permitted Phases	2			6			4			8		
Detector Phase	2	2		6	6		7	4		3	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		2.0	4.0		2.0	4.0	
Minimum Split (s)	9.0	9.0		9.0	9.0		8.0	9.0		8.0	9.0	
Total Split (s)	11.0	11.0	0.0	11.0	11.0	0.0	8.0	26.0	0.0	8.0	26.0	0.0
Total Split (%)	16.4%	16.4%	0.0%	16.4%	16.4%	0.0%	11.9%	38.8%	0.0%	11.9%	38.8%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		2.0	3.0		2.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	4.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag							Lead	Lag		Lead	Lag	
Lead-Lag Optimize?							Yes	Yes		Yes	Yes	
Recall Mode	None	None		None	None		None	Max		None	Max	
Act Effct Green (s)		6.3			6.3		27.8	25.8		28.6	27.5	
Actuated g/C Ratio		0.14			0.14		0.61	0.56		0.62	0.60	
v/c Ratio		0.52			0.51		0.10	0.50		0.18	0.53	
Control Delay		20.1			17.8		6.7	15.3		7.0	15.3	
Queue Delay		0.0			0.0		0.0	0.0		0.0	0.0	
Total Delay		20.1			17.8		6.7	15.3		7.0	15.3	
LOS		C			B		A	B		A	B	
Approach Delay		20.1			17.8			14.6			14.2	
Approach LOS		C			B			B			B	

Intersection Summary	
Cycle Length: 67	
Actuated Cycle Length: 45.8	
Natural Cycle: 75	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 0.53	
Intersection Signal Delay: 15.3	Intersection LOS: B
Intersection Capacity Utilization 53.6%	ICU Level of Service A
Analysis Period (min) 15	

Splits and Phases: 3: Water Street & Prospect Street

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	33%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	12	42	49	34	31	104	58	488	35	83	448	32
Confl. Peds. (#/hr)			2	2			2					2
Confl. Bikes (#/hr)												
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Growth Factor	115%	115%	115%	115%	115%	115%	115%	115%	115%	115%	115%	115%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	2%	2%	2%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			pm+pt			pm+pt		
Protected Phases		2			6		7	4		3	8	
Permitted Phases	2			6			4			8		
Detector Phase	2	2		6	6		7	4		3	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		2.0	4.0		2.0	4.0	
Minimum Split (s)	9.0	9.0		9.0	9.0		8.0	9.0		8.0	9.0	
Total Split (s)	13.0	13.0	0.0	13.0	13.0	0.0	8.0	24.0	0.0	8.0	24.0	0.0
Total Split (%)	19.4%	19.4%	0.0%	19.4%	19.4%	0.0%	11.9%	35.8%	0.0%	11.9%	35.8%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		2.0	3.0		2.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	4.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag							Lead	Lag		Lead	Lag	
Lead-Lag Optimize?							Yes	Yes		Yes	Yes	
Recall Mode	None	None		None	None		None	Min		None	Min	
Act Effct Green (s)		7.9			7.9		26.7	22.4		27.6	24.2	
Actuated g/C Ratio		0.16			0.16		0.53	0.45		0.55	0.48	
v/c Ratio		0.43			0.63		0.19	0.78		0.33	0.67	
Control Delay		18.3			23.4		8.2	25.0		10.6	20.7	
Queue Delay		0.0			0.0		0.0	0.0		0.0	0.0	
Total Delay		18.3			23.4		8.2	25.0		10.6	20.7	
LOS		B			C		A	C		B	C	
Approach Delay		18.3			23.4			23.3			19.2	
Approach LOS		B			C			C			B	

Intersection Summary	
Cycle Length: 67	
Actuated Cycle Length: 50.3	
Natural Cycle: 80	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 0.78	
Intersection Signal Delay: 21.3	Intersection LOS: C
Intersection Capacity Utilization 67.0%	ICU Level of Service C
Analysis Period (min) 15	

Splits and Phases: 3: Water Street & Prospect Street

Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	33%
Yellow Time (s)	2.0
All-Red Time (s)	1.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix F

AM/PM Peak Hour Intersection Capacity Analysis
Modern Roundabout Alternative
Under Existing Traffic Conditions
Prospect Street at Water Street, Milford

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Right Turn Channelized												
Volume (veh/h)	11	35	73	14	22	82	37	358	31	71	412	30
Peak Hour Factor	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Hourly flow rate (vph)	13	40	83	16	25	93	42	407	35	81	468	34
Approach Volume (veh/h)		135			134			484			583	
Crossing Volume (veh/h)		565			461			133			83	
High Capacity (veh/h)		886			963			1248			1298	
High v/c (veh/h)		0.15			0.14			0.39			0.45	
Low Capacity (veh/h)		713			780			1037			1082	
Low v/c (veh/h)		0.19			0.17			0.47			0.54	

Intersection Summary			
Maximum v/c High	0.45		
Maximum v/c Low	0.54		
Intersection Capacity Utilization	58.8%	ICU Level of Service	B

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Right Turn Channelized												
Volume (veh/h)	12	42	49	34	31	104	58	488	35	83	448	32
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Hourly flow rate (vph)	13	45	52	36	33	111	62	519	37	88	477	34
Approach Volume (veh/h)		110			180			618			599	
Crossing Volume (veh/h)		601			594			146			131	
High Capacity (veh/h)		861			866			1236			1250	
High v/c (veh/h)		0.13			0.21			0.50			0.48	
Low Capacity (veh/h)		690			695			1026			1039	
Low v/c (veh/h)		0.16			0.26			0.60			0.58	

Intersection Summary			
Maximum v/c High	0.50		
Maximum v/c Low	0.60		
Intersection Capacity Utilization	68.2%	ICU Level of Service	C

Appendix G

MassDOT Project Implementation Process

The following description of the implementation process is based on Chapter 2 of the *MassDOT Highway Division's Project Development and Design Guide (2005)*. The text below borrows heavily from that document.

1 NEEDS IDENTIFICATION

For each of the locations at which an improvement is to be implemented, MassDOT Highway Division leads an effort to define the problem, establishes project goals and objectives, and defines the scope of the planning needed for implementation. To that end, it has to complete a Project Need Form (PNF), which states in general terms the deficiencies or needs related to the transportation facility or location. The PNF documents the problems and explains why corrective action is needed. For this study, the information defining the need for the project will be drawn primarily, perhaps exclusively, from the present report. Also, at this point in the process, MassDOT Highway Division meets with potential participants, such as the Boston Region Metropolitan Planning Organization (MPO) and community members, to allow for an informal review of the project.

The PNF is reviewed by the MassDOT Highway Division district office whose jurisdiction includes the location of the proposed project. MassDOT Highway Division also sends the PNF to the MPO, for informational purposes. The outcome of this step determines whether the project requires further planning, whether it is already well supported by prior planning studies, and, therefore, whether it is ready to move forward into the design phase, or whether it should be dismissed from further consideration.

2 PLANNING

This phase will likely not be required for the implementation of the improvements proposed in this planning study, as this planning report should constitute the outcome of this step. However, in general, the purpose of this implementation step is for the project proponent to identify issues, impacts, and approvals that may need to be obtained, so that the subsequent design and permitting processes are understood.

The level of planning needed will vary widely, based on the complexity of the project. Typical tasks include: define the existing context, confirm project need, establish goals and objectives, initiate public outreach, define the project, collect data, develop and analyze alternatives, make recommendations, and provide documentation. Likely outcomes include consensus on the project definition to enable it to move forward into environmental documentation (if needed) and design, or a recommendation to delay the project or dismiss it from further consideration.

3 PROJECT INITIATION

At this point in the process, the proponent, MassDOT Highway Division, fills out, for each improvement, a Project Initiation Form (PIF), which is reviewed by its Project Review Committee (PRC) and the MPO. The PRC is composed of the Chief

Engineer, each District Highway Director, and representatives of the Project Management, Environmental, Planning, Right-of-Way, Traffic, and Bridge departments, and the Capital Expenditure Program Office (CEPO). The PIF documents the project type and description, summarizes the project planning process, identifies likely funding and project management responsibility, and defines a plan for interagency and public participation. First the PRC reviews and evaluates the proposed project based on the Executive Office of Transportation and Public Works's statewide priorities and criteria. If the result is positive, MassDOT Highway Division moves the project forward to the design phase, and to programming review by the MPO. The PRC may provide a Project Management Plan to define roles and responsibilities for subsequent steps. The MPO review includes project evaluation based on the MPO's regional priorities and criteria. The MPO may assign project evaluation criteria score, a Transportation Improvement Program (TIP) year, a tentative project category, and a tentative funding category.

4 ENVIRONMENTAL, DESIGN, AND RIGHT-OF-WAY PROCESS

This step has four distinct but closely integrated elements: public outreach, environmental documentation and permitting (if required), design, and right-of-way acquisition (if required). The outcome of this step is a fully designed and permitted project ready for construction. However, a project does not have to be fully designed in order for the MPO to program it in the TIP.

5 PROGRAMMING

Programming, which typically begins during the design phase, can actually occur at any time during the process, from planning to design. In this step, which is distinct from project initiation, where the MPO receives preliminary information on the proposed project, the proponent requests that the MPO place the project in the region's TIP. The MPO considers the project in terms of regional needs, evaluation criteria, and compliance with the regional Transportation Plan and decides whether to place it in the draft TIP for public review and then in the final TIP.

6 PROCUREMENT

Following project design and programming, MassDOT Highway Division publishes a request for proposals. It then reviews the bids and awards the contract to the qualified bidder with the lowest bid.

7 CONSTRUCTION

After a construction contract is awarded, MassDOT Highway Division and the contractor develop a public participation plan and a management plan for the construction process.

8 PROJECT ASSESSMENT

The purpose of this step is to receive constituents' comments on the project development process and the project's design elements. MassDOT Highway Division can apply what is learned in this process to future projects.

MEMORANDUM

To: **Martha White, Natick Town Administrator** **February 17, 2011**
Eric Nascimento, MassDOT Highway Division District 3

From: **Chen-Yuan Wang and Efi Pagitsas**

Re: **Safety and Operations Analyses at Selected Boston Region MPO Intersections: West Central Street (Route 135) at Speen Street in Natick**

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersection of West Central Street (Route 135) at Speen Street in Natick. It contains the following sections:

- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Analyses of Improvement Alternatives
- Improvement Recommendations and Discussion

The memorandum also includes a collection of technical appendices that contain methods and data applied in the study and detailed reports of the intersection capacity analysis.

INTERSECTION LAYOUT AND TRAFFIC CONTROL

This is a signalized intersection where two major regional roadways meet. It is located in the central-western section of Natick about a mile west of the town center. West Central Street, a two-lane roadway running in the east-west direction, is the major street of the intersection. It is a part of State Route 135, a principal arterial in eastern Massachusetts that runs from Route 128/Interstate 95 (I-95) in Dedham to the town center of Northborough west of Interstate 495 through several communities between the two major highways.

Speen Street, a two-lane roadway running in the north-south direction, is classified as an urban minor arterial north of the intersection and as an urban collector south of the intersection. It runs from Old Connecticut Path in Framingham, intersecting Route 30, Route 9, and Route 135 (at this intersection), to Coolidge Street in South Natick, where further south it connects to Route 16/Route 27 in Sherborn. It serves Natick Mall, Home Depot, and several other commercial developments between Route 9 and Route 30. Speen Street is also a major access road to the MassTurnpike (Interstate 90), as I-90 Exit 13 (Natick/Framingham Exit) is located just west of its intersection with Route 30.

Figure 1 shows the intersection layout and the area nearby. Approaching the intersection, both approaches of West Central Street widen to include an exclusive left-turn lane that has a storage space about 100 feet long. Speen Street widens to include a continuous left-turn lane, starting from its railroad bridge section about 400 feet north of the intersection. The northbound approach of Speen Street remains a single lane shared by all movements.

Crosswalks are installed across the eastbound and the southbound approaches. Sidewalks exist on all corners of the intersection. They continue on both sides of Speen Street north of the intersection. There are no sidewalks south of the intersection. They exist only on the north side of West Central Street east of the intersection and only on the south side west of the intersection.

The intersection traffic signal appears to be new and is fully actuated by approaching traffic. Overhead signal heads are appropriately placed and supported by a cable system. The signal cycles also include an on-call exclusive pedestrian phase that lasts about 26 seconds. Pedestrian signal heads with push buttons and audible indications are placed at both ends of the existing crosswalks. Right turns on red are allowed on all approaches except the northbound approach.

The land uses in the intersection vicinity are mainly single-family residential mixed with commercial developments, office parks, public transportation, and public waters and lands. The Massachusetts Bay Transportation Authority (MBTA) Framingham/Worcester Commuter Rail Line runs parallel to Route 135 north of the intersection. West Natick Station, on the line, is located on Route 135 about half a mile west of this intersection. Lake Cochituate, a popular state park, occupies a large area west of Speen Street. Fiske Pond, a reservoir owned by the Massachusetts Department of Conservation and Recreation (DCR), is located immediately south of Route 135 near the intersection. The land use on both sides of Speen Street is mainly single-family houses until the area north of Route 9. At the intersection, the northeast quadrant is occupied by a retail store (CVS), and the other three quadrants are conservation lands with open waters (portions of Fiske Pond).

West Central Street (Route 135) in the intersection vicinity has a speed limit of 40 miles per hour (MPH). Speen Street has a speed limit of 35 MPH in the northern section and 25 MPH south of the intersection. The southern section of Speen Street is narrow, as both of sides have adjacent wet lands and Fiske Pond.

ISSUES AND CONCERNS

A review of the recent crash data from 2006 to 2008 indicates that the intersection has a high number of crashes and a crash rate much higher than other signalized intersections in the area (see the next section for further analysis).

The intersection is congested during peak periods on almost all approaches, depending on the peak direction. As a principal arterial in the region, traffic on West Central Street is heavy in both directions during peak periods, especially the eastbound direction in the AM peak periods. As a major north-south arterial leading to many commercial developments and transportation facilities in the area, Speen Street north of the intersection carries even more traffic than either side of West Central Street at the intersection. This section of Speen Street is especially congested during the PM peak hour.

CTPS

FIGURE 1
West Central Street (Route 135) at Speen Street, Natick

Safety and Operations Improvements at Selected Intersections

The issues and concerns for this intersection can be summarized as follows:

- High number of crashes and high crash rate at the intersection
- Traffic congestion during peak hours
- Limited space for geometry modifications due to the adjacent conservation lands
- No pedestrian sidewalks on Speen Street south of the intersection

CRASH DATA ANALYSIS

Based on the 2006–2008 MassDOT Registry of Motor Vehicles Division crash data, Table 1 shows that on average about 30 crashes occurred at the intersection each year. About 15% of the total crashes resulted in personal injuries. The crash types consist of about 45% rear-end collisions, nearly 40% angle collisions, and about 15% other types. No crashes involved pedestrians or bicyclists. One-third (33%) of the total crashes occurred during weekday peak periods. A quarter (25%) of the total crashes occurred in wet or icy conditions. About 20% of the total crashes occurred in dark conditions. The relatively high percentage of crashes occurring during peak periods was possibly caused by the congested conditions at the intersection.

TABLE 1
Summary of Crash Data (2006–2008)

Statistics Period		2006	2007	2008	2006–08	Average
Total number of crashes		34	33	26	93	31
Severity	Property damage only	25	31	20	76	25
	Personal injury	7	1	6	14	5
	Fatality	0	0	0	0	0
	Not reported	2	1	0	3	1
Collision Type	Angle	14	14	7	35	12
	Rear-end	14	15	13	42	14
	Sideswipe	3	2	1	6	2
	Head-on	1	0	2	3	1
	Single vehicle	0	2	2	4	1
	Not reported	2	0	1	3	1
Crashes involving pedestrian(s)		0	0	0	0	0
Crashes involving cyclist(s)		0	0	0	0	0
Occurred during weekday peak periods*		14	10	7	31	10
Wet or icy pavement conditions		6	10	7	23	8
Dark/lighted conditions		6	9	3	18	6

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

Crash rate[1] is another effective tool for examining the relative safety of a particular location. Based on the above data and the recently collected traffic volume data, the crash rate for this intersection is calculated as 2.90 (see Appendix A for the calculation sheet). The rate is much

[1] Crash rates normalize crash frequency (crashes per year) by vehicle exposure (traffic volumes or miles traveled). Crash rates are expressed as "crashes per million entering vehicles" for intersection locations and as "crashes per million miles traveled" for roadway segments.

higher than the average rate for the signalized locations in MassDOT Highway Division's District 3, which is estimated to be 0.93.[2]

INTERSECTION CAPACITY ANALYSIS

Boston Region MPO staff collected pedestrian, bicyclist, and vehicular turning movement counts at the intersection on June 8, 2010. The data were recorded in 15-minute intervals for the peak traffic periods in the morning, from 7:00 to 9:00, and in the evening, from 4:00 to 6:00. It should be noted that during that time the southbound section of Speen Street south of the intersection was closed.[3] After consultation with the town officers, we decided to proceed with this study using adjustments of the counts at this intersection based on available turning movement counts from traffic studies in recent years.

Table 2 shows the adjusted turning movements on all approaches in both the AM and PM peak hours. The AM peak hour is identified as 7:15 to 8:15, and the PM peak hour is from 5:00 to 6:00, based on the 2010 counts. The intersection is estimated to carry about 2,400 vehicles in the AM peak hour and about 2,650 vehicles in the PM peak hour. Six and 22 pedestrians were observed in the AM and the PM peak hour, respectively. Nine and 13 bicyclists were observed in the AM and PM peak hour, respectively (not shown in Table 2). They all appeared to be commuters and most of them traveled on Route 135 and Speen Street north of the intersection.

TABLE 2
AM and PM Peak-Hour Traffic Volumes and Pedestrian Crossings

Street name		**West Central Street**						**Speen Street**						**Total**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	Turning volume	339	426	15	50	266	145	5	477	53	175	250	149	2410
	Approach volume	840			461			535			574			
	Pedestrian crossings	3			0			0			3			6
PM peak hour	Turning volume	290	340	20	90	327	120	11	317	47	250	605	221	2638
	Approach volume	650			537			375			1076			
	Pedestrian crossings	10			10			0			2			22

Based on the adjusted turning-movement counts and the signal timings measured at the site, the intersection capacity was analyzed using an intersection capacity analysis program, Synchro.[4] The program indicated that the intersection operates at an overall level of service (LOS) E with an average delay of over one minute per vehicle in the AM peak hour and at LOS F with an average delay of over two minutes per vehicle in the PM peak hour (see Table 3). The level-of-

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[2] The average crash rates estimated by the MassDOT Highway Division are based upon a database that contains intersection crash rates submitted to the Highway Division as part of a review process for an environmental impact report or functional design report. The most recent average crash rates, which are updated on a nearly yearly basis, are based on all entries in the database, not just those entries made within the past year.

[3] A Fiske Pond culvert underneath Speen Street just south of the intersection was damaged during a rain storm in March 2010. The southbound section was closed to avoid further damage and for drivers' safety.

[4] Synchro is developed and distributed by Trafficware, Ltd. It can perform capacity analysis and traffic simulation (when combined with SimTraffic) for an individual intersection or a series of intersections.

service criteria are based on the Highway Capacity Manual 2000.[5] Detailed analysis settings and results for both the AM and PM peak hour are included in Appendix B.

TABLE 3
Intersection Capacity Analysis, Existing Conditions

<table>
<tr><th colspan="2">Street name</th><th colspan="6">West Central Street</th><th colspan="6">Speen Street</th><th rowspan="3">Overall</th></tr>
<tr><th colspan="2">Direction</th><th colspan="3">Eastbound</th><th colspan="3">Westbound</th><th colspan="3">Northbound</th><th colspan="3">Southbound</th></tr>
<tr><th colspan="2">Turning movement</th><td>LT</td><td>TH</td><td>RT</td><td>LT</td><td>TH</td><td>RT</td><td>LT</td><td>TH</td><td>RT</td><td>LT</td><td>TH</td><td>RT</td></tr>
<tr><td rowspan="2">AM peak hour</td><td>LOS</td><td>F</td><td colspan="2">D</td><td>C</td><td colspan="2">E</td><td colspan="3">E</td><td>D</td><td colspan="2">C</td><td>E</td></tr>
<tr><td>Delay (sec/veh)</td><td>199</td><td colspan="2">39</td><td>29</td><td colspan="2">69</td><td colspan="3">58</td><td>47</td><td colspan="2">29</td><td>74</td></tr>
<tr><td rowspan="2">PM peak hour</td><td>LOS</td><td>F</td><td colspan="2">C</td><td>C</td><td colspan="2">D</td><td colspan="3">F</td><td>E</td><td colspan="2">F</td><td>F</td></tr>
<tr><td>Delay (sec/veh)</td><td>86</td><td colspan="2">29</td><td>23</td><td colspan="2">51</td><td colspan="3">400</td><td>58</td><td colspan="2">153</td><td>133</td></tr>
</table>

As the analysis shows, traffic on the eastbound (EB) left turns endures extensive delays in both the AM and PM peak hours due to the insufficient capacity of the single turning lane. All the movements in the northbound (NB) approach endure extensive delays in the PM peak hour, when its opposite approach carries an extremely high traffic volume. Apparently, the existing intersection layout and signal timing plan do not provide sufficient capacity to meet traffic demand at the intersection.

ANALYSES OF IMPROVEMENT ALTERNATIVES

The intersection locates in a limited space because it is surrounded by conservation lands. It appears that the current layout and signal sequence are appropriate for the high traffic demand in the limited space. The crash data analysis indicates that a high proportion (one-third) of crashes occurred during peak periods. Mitigating traffic congestion during peak periods would be an effective way to enhance the intersection safety.

Currently the actuated traffic signal at the intersection operates in four traffic phases: (1) southbound (SB) left-turn and through phase, (2) northbound/southbound (NB/SB) all movements (left turns permitted), (3) leading eastbound/westbound (EB/WB) left-turn protected phase, and (4) eastbound/westbound (EB/WB) all movements (left turns permitted). The phasing plan also includes a 26-second on-call exclusive pedestrian phase.[6] Stopwatch measurements at the site indicate a somewhat different maximum cycle length (including the pedestrian phase) in the AM and PM peak hour, ranging from 140 seconds to 154 seconds.[7]

As there is limited space for expansion, we basically tested two simple alternatives for improving traffic operations at the intersection:

1) Retime the signals with the current phasing sequence and intersection layout
2) Add an exclusive WB right-turn lane with the current phasing sequence

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5 Transportation Research Board, *Highway Capacity Manual 2000*, National Research Council, Washington D.C., 2000

6 The pedestrian phase time is sufficient. Based on a 4-second start-up time and a 3.5-feet-per-second walking speed, the time required to cross the longer southbound approach (about 60 feet) is calculated as 22 seconds.

7 It should be noted that the measurements were taken when SB Speen Street south of the intersection was closed. The may not represent the usual setting of the signal.

Synchro tests of signal timing optimization indicate that a maximum cycle length of 150 seconds (including a 26-second exclusive pedestrian phase) would be appropriate for the intersection phasing plan. Alternative 1 represents the results of the optimization tests based on the adjusted turning movement counts.

The only area available for expansion for increasing the intersection capacity is the northeast quadrant where the CVS parking lot is currently located. Alternative 2 was developed in an attempt to utilize the open space to accommodate the relatively high volume of WB right turns and consequently to increase the overall capacity. It was tested under the same maximum cycle length and phasing sequence as Alternative 1.

Table 4 summarizes the intersection capacity analyses for the two alternatives. Detailed analysis settings and results for both the AM and PM peak hours for the alternatives are included in Appendices C and D separately. As Table 4 shows, retiming the traffic signal and rebalancing the phase times based on the approaching traffic (Alternative 1) would somewhat improve traffic operations at the intersection. Adding a right-turn exclusive lane (Alternative 2) would significantly improve traffic operations in both the AM and PM peak hours, with reduced overall intersection delays. It would operate at LOS D in the AM peak hour and LOS E in the PM peak hour, considered acceptable for an urbanized intersection.

TABLE 4
Intersection Capacity Analyses of Improvement Alternatives

Street name		**West Central Street**		**Speen Street**		**Overall**
Approach		**Eastbound**	**Westbound**	**Northbound**	**Southbound**	
AM peak hour	Existing	F/115	E/65	E/58	C/35	E/74
	Alternative 1	E/66	F/88	E/63	D/44	E/64
	Alternative 2	D/55	D/54	D/51	C/30	D/48
PM peak hour	Existing	D/55	D/47	F/>180	F/131	F/133
	Alternative 1	F/101	F/96	E/66	E/58	E/78
	Alternative 2	E/78	E/73	C/32	D/42	E/56

Note Performance measures: Level of Service (A to F)/Average Delay (seconds per vehicle)
Alternative 1: Retime the signals with the current phasing sequence and intersection layout
Alternative 2: Add an exclusive WB right-turn lane with the current phasing sequence

In addition, a future-year scenario of 10% growth over a 20-year planning horizon was tested for the two alternatives.[8] Synchro tests show that under the 2030 projected traffic conditions Alternative 1 would deteriorate to LOS F with an average delay of about one and half minutes in the AM peak hour and nearly two minutes in the PM peak hour. Alternative 2 would still operate at LOS E, with an average delay of nearly one minute in the AM peak hour and one and a quarter minutes in the PM peak hour under the projected traffic conditions.

The above analyses indicate that adding a WB right-turn lane would significantly improve traffic operations at the intersection. A brief review of the intersection aerial photograph indicates that

8 The growth assumption is based on a review of the traffic projections at the intersection from the Boston Region MPO transportation-planning model.

Alternative 2 is potentially feasible by acquiring a strip of the lawn area along the north side of West Central Street. The exclusive right-turn lane should be channelized with a refuge island for pedestrians and bicyclists. The distance for pedestrians to cross the southbound approach would potentially be reduced with the installation of the refuge island. Meanwhile, bicyclists would have a place to stay while waiting for the signal change. The island should be designed with curb cuts or ramps for easy access by pedestrians and bicyclists.

IMPROVEMENT RECOMMENDATIONS AND DISCUSSION

The intersection is the junction of two major regional roadways. It is very congested during the AM and PM peak hours and has a high number of crashes and a crash rate much higher than other signalized intersections in the area. The crash data analysis indicates that a high proportion (one-third) of crashes occurred during peak periods. Mitigating traffic congestion during peak periods would be an effective way to enhance the intersection's safety.

As the intersection is situated in a limited space surrounded by conservation lands, there are few options for increasing its capacity. This study basically examined two improvement alternatives:

1) Retime the signals with the current phasing sequence and intersection layout
2) Add an exclusive WB right-turn lane with the current phasing sequence

The Synchro operations analyses show that Alternative 1 would somewhat improve traffic operations at the intersection, with reduced overall intersection delays in both the AM and PM peak hours. Alternative 2 would significantly improve traffic operations, with much reduced overall intersection delays, and the intersection would operate at an acceptable LOS D in the AM peak hour and LOS E in the PM peak hour.

Currently Speen Street south of the intersection is completely closed (in both directions) and the culvert replacement and roadway reconstruction work is underway. According to Town staff, a sidewalk along the west side of Speen Street will be installed as part of the roadway reconstruction. The sidewalk will be very beneficial to the area's residents as it provides a connection to the adjacent sidewalks at the intersection. It would also enhance the pedestrian safety on Speen Street.

Alternative 1 shows that the intersection's signal timing appears to have room for adjustments to enhance traffic operations. The Speen Street culvert/roadway reconstruction is expected to be completed in the spring of 2012. We recommend that once the traffic is back to normal after completion of the project, the intersection signal should be retimed with updated turning movements.

In the long run, we recommend Alternative 2. It would improve traffic operations significantly at the intersection. The alternative should include the following major features:

- Channelize the exclusive right-turn lane to provide a refuge island (with curb cuts or ramps) for pedestrians and bicyclists
- Provide a minimum of 4-foot shoulders for bicycle accommodation
- Upgrade the existing sidewalks

The distance for pedestrians to cross the southbound approach would potentially be reduced with the installation of the refuge island. Meanwhile, bicyclists would have a place to stay while waiting for the signal change.

At this preliminary planning stage, it appears that the improvement alternative can only be feasible if a major portion of the lawn area along the north side of West Central Street is obtainable.[9] Assuming no cost for land takings, the total cost of the installation of an exclusive right-turn exclusive lane with a refuge island[10] and the construction of adjacent shoulders and sidewalks is roughly estimated as $150,000 to $200,000. Currently West Central Street (Route 135) is under the jurisdiction of MassDOT, and Speen Street is administered by the Town of Natick. The implementation would require the Town to work closely with MassDOT through the project implantation process (see Appendix E).

[9] Town staff indicated that the land acquisition may be feasible in light of a previous agreement with the CVS developer. However, it would require at least 16 feet in width of the lawn area, as MassDOT now mandates a 4-foot shoulder for bicycle accommodation and upgraded sidewalks for any new projects.

[10] The lane is assumed to be 150 feet long (including the taper) and 12 feet wide. The refuge island is assumed to be about 100 to 150 square feet. The more precise size of the installation should be identified in the functional design stage.

Appendix A

Intersection Crash Rate Calculation
West Central Street at Speen Street, Natick

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Natick COUNT DATE : 6/8/10

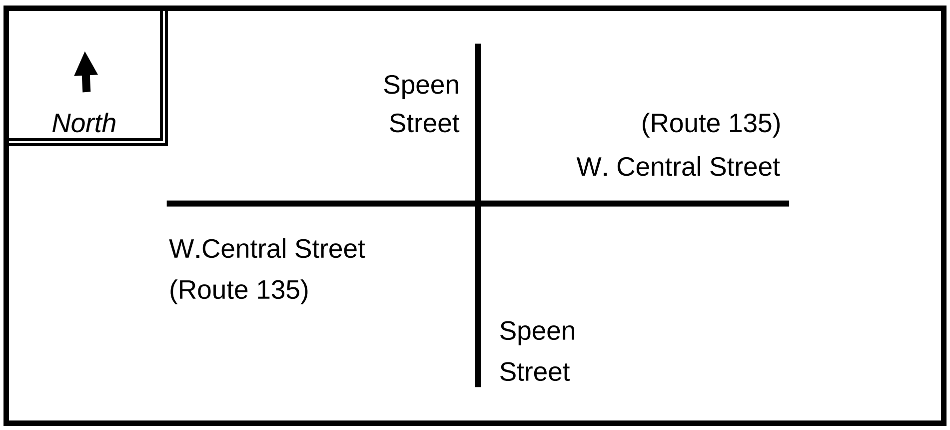
DISTRICT : 3 UNSIGNALIZED : [ ] SIGNALIZED : X

~ INTERSECTION DATA ~

MAJOR STREET : West Central Street (Route 135)

MINOR STREET(S) : Speen Street

INTERSECTION DIAGRAM
(Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	EB	WB	NB	SB		
PEAK HOURLY VOLUMES (AM/PM) :	650	537	375	1,076		**2,638**

" K " FACTOR : **0.090** INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **29,311**

TOTAL # OF CRASHES : 93 # OF YEARS : 3 AVERAGE # OF CRASHES PER YEAR (**A**) : **31.00**

CRASH RATE CALCULATION : **2.90** RATE = $\frac{(A * 1{,}000{,}000)}{(V * 365)}$

Comments : MassDOT Highway District 3 Average Rate = 0.93

Project Title & Date: Safety and Operations Analyses at Selceted Intersections

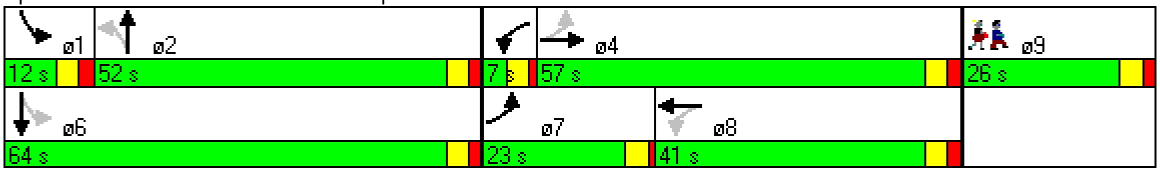
Appendix B

AM/PM Peak Hour Intersection Capacity Analysis
Existing Traffic Conditions
West Central Street at Speen Street, Natick

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	399	426	15	50	266	145	5	477	53	175	250	149
Confl. Peds. (#/hr)	3					3	3					3
Confl. Bikes (#/hr)			3			3			1			
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	5%	5%	5%	5%	5%	5%	6%	6%	6%	5%	5%	5%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt			pm+pt			Perm			pm+pt		
Protected Phases	7	4		3	8			2		1	6	
Permitted Phases	4			8			2			6		
Detector Phase	7	4		3	8		2	2		1	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0		3.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	9.0	21.0		7.0	21.0		21.0	21.0		9.0	21.0	
Total Split (s)	23.0	57.0	0.0	7.0	41.0	0.0	52.0	52.0	0.0	12.0	64.0	0.0
Total Split (%)	14.9%	37.0%	0.0%	4.5%	26.6%	0.0%	33.8%	33.8%	0.0%	7.8%	41.6%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.0	2.0		1.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag	Lead	Lag		Lead	Lag		Lag	Lag		Lead		
Lead-Lag Optimize?	Yes	Yes		Yes	Yes		Yes	Yes		Yes		
Recall Mode	Max	Min		Max	Min		None	None		None	None	
Act Effct Green (s)	60.2	52.2		40.1	36.1			47.2		59.2	59.2	
Actuated g/C Ratio	0.46	0.39		0.30	0.27			0.36		0.45	0.45	
v/c Ratio	1.33	0.65		0.23	0.91			0.89		0.76	0.54	
Control Delay	199.4	39.0		28.7	69.3			58.3		47.2	29.4	
Queue Delay	0.0	0.0		0.0	0.0			0.0		0.0	0.0	
Total Delay	199.4	39.0		28.7	69.3			58.3		47.2	29.4	
LOS	F	D		C	E			E		D	C	
Approach Delay		115.2			64.9			58.3			34.8	
Approach LOS		F			E			E			C	

Intersection Summary	
Cycle Length: 154	
Actuated Cycle Length: 132.2	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.33	
Intersection Signal Delay: 73.8	Intersection LOS: E
Intersection Capacity Utilization 111.9%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Route 135 & Speen Street



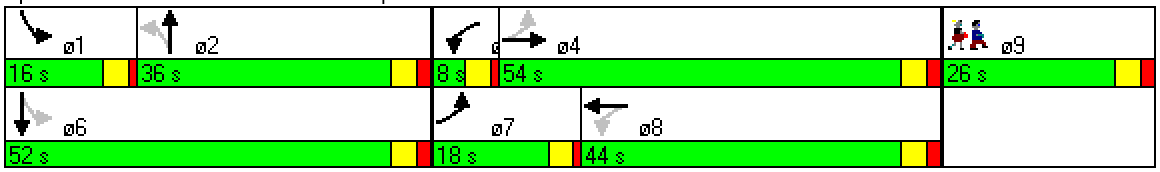
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	26.0
Total Split (s)	26.0
Total Split (%)	17%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	290	340	20	90	327	120	11	317	47	250	605	221
Confl. Peds. (#/hr)	10		2	2		10	10					10
Confl. Bikes (#/hr)			4			6						2
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	2%	2%	2%	2%	2%	2%	2%	2%	2%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt			pm+pt			Perm			pm+pt		
Protected Phases	7	4		3	8			2		1	6	
Permitted Phases	4			8			2			6		
Detector Phase	7	4		3	8		2	2		1	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0		3.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	9.0	21.0		7.0	21.0		21.0	21.0		9.0	21.0	
Total Split (s)	18.0	54.0	0.0	8.0	44.0	0.0	36.0	36.0	0.0	16.0	52.0	0.0
Total Split (%)	12.9%	38.6%	0.0%	5.7%	31.4%	0.0%	25.7%	25.7%	0.0%	11.4%	37.1%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.0	2.0		1.0	2.0		2.0	2.0		1.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag	Lead	Lag		Lead	Lag		Lag	Lag		Lead		
Lead-Lag Optimize?	Yes	Yes		Yes	Yes		Yes	Yes		Yes		
Recall Mode	Max	Min		Max	Min		None	None		None	None	
Act Effct Green (s)	56.3	47.3		42.2	37.2			31.2		48.3	47.3	
Actuated g/C Ratio	0.48	0.41		0.36	0.32			0.27		0.42	0.41	
v/c Ratio	1.03	0.52		0.29	0.84			1.79		0.89	1.25	
Control Delay	85.9	29.9		23.1	51.3			400.0		58.4	153.1	
Queue Delay	0.0	0.0		0.0	0.0			0.0		0.0	0.0	
Total Delay	85.9	29.9		23.1	51.3			400.0		58.4	153.1	
LOS	F	C		C	D			F		E	F	
Approach Delay		54.9			46.6			400.0			131.1	
Approach LOS		D			D			F			F	

Intersection Summary	
Cycle Length: 140	
Actuated Cycle Length: 116.3	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.79	
Intersection Signal Delay: 133.4	Intersection LOS: F
Intersection Capacity Utilization 122.4%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Route 135 & Speen Street



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	26.0
Total Split (s)	26.0
Total Split (%)	19%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

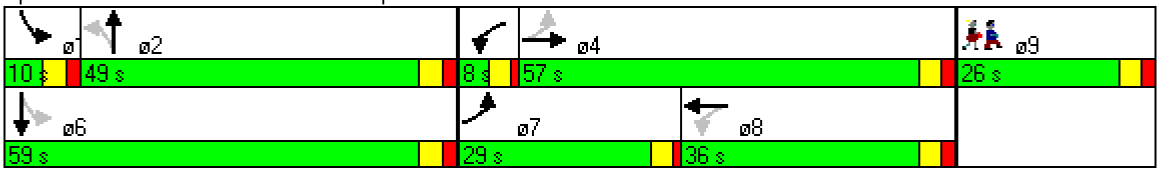
Appendix C

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 1
Retime the Signal with Existing Layout and Phasing Sequence
West Central Street at Speen Street, Natick

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	399	426	15	50	266	145	5	477	53	175	250	149
Confl. Peds. (#/hr)	3					3	3					3
Confl. Bikes (#/hr)			3			3			1			
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	5%	5%	5%	5%	5%	5%	6%	6%	6%	5%	5%	5%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt			pm+pt			Perm			pm+pt		
Protected Phases	7	4		3	8			2		1	6	
Permitted Phases	4			8			2			6		
Detector Phase	7	4		3	8		2	2		1	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0		3.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	9.0	21.0		7.0	21.0		21.0	21.0		9.0	21.0	
Total Split (s)	29.0	57.0	0.0	8.0	36.0	0.0	49.0	49.0	0.0	10.0	59.0	0.0
Total Split (%)	19.3%	38.0%	0.0%	5.3%	24.0%	0.0%	32.7%	32.7%	0.0%	6.7%	39.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.0	2.0		1.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag	Lead	Lag		Lead	Lag		Lag	Lag		Lead		
Lead-Lag Optimize?	Yes	Yes		Yes	Yes		Yes	Yes		Yes		
Recall Mode	Max	Min		Max	Min		None	None		None	None	
Act Effct Green (s)	61.2	52.2		36.1	31.1			44.2		54.2	54.2	
Actuated g/C Ratio	0.48	0.41		0.28	0.24			0.34		0.42	0.42	
v/c Ratio	1.07	0.63		0.20	1.02			0.93		0.89	0.58	
Control Delay	99.8	36.2		25.8	95.2			63.1		71.8	31.6	
Queue Delay	0.0	0.0		0.0	0.0			0.0		0.0	0.0	
Total Delay	99.8	36.2		25.8	95.2			63.1		71.8	31.6	
LOS	F	D		C	F			E		E	C	
Approach Delay		66.4			87.6			63.1			43.9	
Approach LOS		E			F			E			D	

Intersection Summary	
Cycle Length: 150	
Actuated Cycle Length: 128.2	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.07	
Intersection Signal Delay: 64.4	Intersection LOS: E
Intersection Capacity Utilization 111.9%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Route 135 & Speen Street



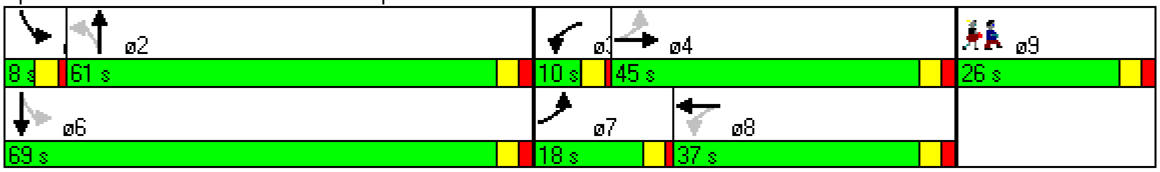
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	26.0
Total Split (s)	26.0
Total Split (%)	17%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	290	340	20	90	327	120	11	317	47	250	605	221
Confl. Peds. (#/hr)	10		2	2		10	10					10
Confl. Bikes (#/hr)			4			6						2
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Growth Factor	100%	100%	110%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	2%	2%	2%	2%	2%	2%	2%	2%	2%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt			pm+pt			Perm			pm+pt		
Protected Phases	7	4		3	8			2		1	6	
Permitted Phases	4			8			2			6		
Detector Phase	7	4		3	8		2	2		1	6	
Switch Phase												
Minimum Initial (s)	3.0	4.0		3.0	4.0		4.0	4.0		3.0	4.0	
Minimum Split (s)	7.0	21.0		7.0	21.0		21.0	21.0		7.0	21.0	
Total Split (s)	18.0	45.0	0.0	10.0	37.0	0.0	61.0	61.0	0.0	8.0	69.0	0.0
Total Split (%)	12.0%	30.0%	0.0%	6.7%	24.7%	0.0%	40.7%	40.7%	0.0%	5.3%	46.0%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.0	2.0		1.0	2.0		2.0	2.0		1.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag	Lead	Lag		Lead	Lag		Lag	Lag		Lead		
Lead-Lag Optimize?	Yes	Yes		Yes	Yes		Yes	Yes		Yes		
Recall Mode	Max	Min		Max	Min		None	None		None	None	
Act Effct Green (s)	51.2	40.2		39.2	32.1			56.2		65.3	64.3	
Actuated g/C Ratio	0.40	0.31		0.31	0.25			0.44		0.51	0.50	
v/c Ratio	1.25	0.68		0.41	1.08			0.94		0.70	1.01	
Control Delay	168.9	46.4		33.9	109.2			66.2		34.4	65.1	
Queue Delay	0.0	0.0		0.0	0.0			0.0		0.0	0.0	
Total Delay	168.9	46.4		33.9	109.2			66.2		34.4	65.1	
LOS	F	D		C	F			E		C	E	
Approach Delay		100.8			96.5			66.2			58.0	
Approach LOS		F			F			E			E	

Intersection Summary	
Cycle Length: 150	
Actuated Cycle Length: 128.2	
Natural Cycle: 145	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.25	
Intersection Signal Delay: 77.6	Intersection LOS: E
Intersection Capacity Utilization 122.4%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Route 135 & Speen Street



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	26.0
Total Split (s)	26.0
Total Split (%)	17%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

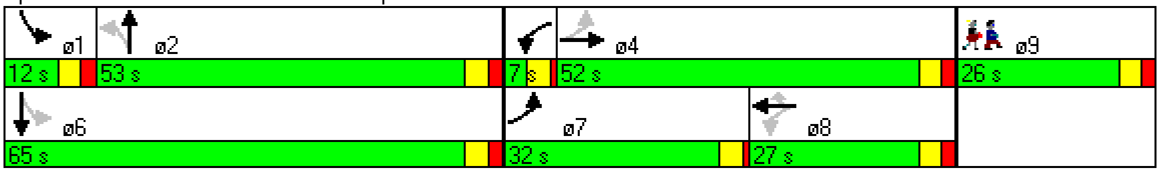
Appendix D

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 2
Add a WB Right-Turn Exclusive Lane with Existing Phasing Sequence
West Central Street at Speen Street, Natick

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	399	426	15	50	266	145	5	477	53	175	250	149
Confl. Peds. (#/hr)	3					3	3					3
Confl. Bikes (#/hr)			3			3			1			
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	5%	5%	5%	5%	5%	5%	6%	6%	6%	5%	5%	5%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt			pm+pt		Perm	Perm			pm+pt		
Protected Phases	7	4		3	8			2		1	6	
Permitted Phases	4			8		8	2			6		
Detector Phase	7	4		3	8	8	2	2		1	6	
Switch Phase												
Minimum Initial (s)	4.0	4.0		3.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	9.0	21.0		7.0	21.0	21.0	21.0	21.0		9.0	21.0	
Total Split (s)	32.0	52.0	0.0	7.0	27.0	27.0	53.0	53.0	0.0	12.0	65.0	0.0
Total Split (%)	21.3%	34.7%	0.0%	4.7%	18.0%	18.0%	35.3%	35.3%	0.0%	8.0%	43.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0	3.0	3.0	3.0		3.0	3.0	
All-Red Time (s)	1.0	2.0		1.0	2.0	2.0	2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	4.0	4.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag	Lead	Lag		Lead	Lag	Lag	Lag	Lag		Lead		
Lead-Lag Optimize?	Yes	Yes		Yes	Yes	Yes	Yes	Yes		Yes		
Recall Mode	Max	Min		Max	Min	Min	None	None		None	None	
Act Effct Green (s)	55.2	47.2		26.1	22.1	22.1		47.6		59.6	59.6	
Actuated g/C Ratio	0.43	0.37		0.20	0.17	0.17		0.37		0.47	0.47	
v/c Ratio	0.96	0.70		0.26	0.89	0.40		0.86		0.69	0.52	
Control Delay	68.9	42.0		34.1	82.0	10.9		51.2		38.7	26.4	
Queue Delay	0.0	0.0		0.0	0.0	0.0		0.0		0.0	0.0	
Total Delay	68.9	42.0		34.1	82.0	10.9		51.2		38.7	26.4	
LOS	E	D		C	F	B		D		D	C	
Approach Delay		54.8			54.4			51.2			30.2	
Approach LOS		D			D			D			C	

Intersection Summary	
Cycle Length: 150	
Actuated Cycle Length: 127.6	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.96	
Intersection Signal Delay: 48.0	Intersection LOS: D
Intersection Capacity Utilization 102.9%	ICU Level of Service G
Analysis Period (min) 15	

Splits and Phases: 3: Route 135 & Speen Street



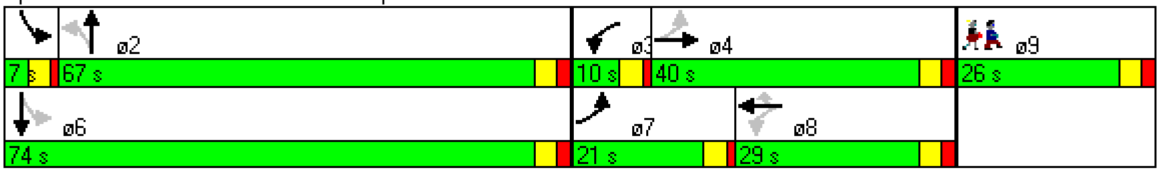
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	26.0
Total Split (s)	26.0
Total Split (%)	17%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	290	340	20	90	327	120	11	317	47	250	605	221
Confl. Peds. (#/hr)	10		2	2		10	10					10
Confl. Bikes (#/hr)			4			6						2
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	2%	2%	2%	2%	2%	2%	2%	2%	2%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt			pm+pt		Perm	Perm			pm+pt		
Protected Phases	7	4		3	8			2		1	6	
Permitted Phases	4			8		8	2			6		
Detector Phase	7	4		3	8	8	2	2		1	6	
Switch Phase												
Minimum Initial (s)	3.0	4.0		3.0	4.0	4.0	4.0	4.0		3.0	4.0	
Minimum Split (s)	7.0	21.0		7.0	21.0	21.0	21.0	21.0		7.0	21.0	
Total Split (s)	21.0	40.0	0.0	10.0	29.0	29.0	67.0	67.0	0.0	7.0	74.0	0.0
Total Split (%)	14.0%	26.7%	0.0%	6.7%	19.3%	19.3%	44.7%	44.7%	0.0%	4.7%	49.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0	3.0	3.0	3.0		3.0	3.0	
All-Red Time (s)	1.0	2.0		1.0	2.0	2.0	2.0	2.0		1.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	4.0	4.0	5.0	5.0	5.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag	Lead	Lag		Lead	Lag	Lag	Lag	Lag		Lead		
Lead-Lag Optimize?	Yes	Yes		Yes	Yes	Yes	Yes	Yes		Yes		
Recall Mode	Max	Min		Max	Min	Min	None	None		None	None	
Act Effct Green (s)	46.2	35.1		31.1	24.1	24.1		62.2		70.3	69.3	
Actuated g/C Ratio	0.36	0.27		0.24	0.19	0.19		0.49		0.55	0.54	
v/c Ratio	1.07	0.77		0.52	1.01	0.35		0.66		0.62	0.94	
Control Delay	105.9	54.9		43.2	102.9	13.9		32.3		27.8	45.8	
Queue Delay	0.0	0.0		0.0	0.0	0.0		0.0		0.0	0.0	
Total Delay	105.9	54.9		43.2	102.9	13.9		32.3		27.8	45.8	
LOS	F	D		D	F	B		C		C	D	
Approach Delay		77.6			73.0			32.3			41.6	
Approach LOS		E			E			C			D	

Intersection Summary	
Cycle Length: 150	
Actuated Cycle Length: 128.2	
Natural Cycle: 145	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.07	
Intersection Signal Delay: 55.6	Intersection LOS: E
Intersection Capacity Utilization 114.8%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Route 135 & Speen Street



Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	26.0
Total Split (s)	26.0
Total Split (%)	17%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix E

MassDOT Project Implementation Process

The following description of the implementation process is based on Chapter 2 of the *MassDOT Highway Division's Project Development and Design Guide (2005)*. The text below borrows heavily from that document.

1 NEEDS IDENTIFICATION

For each of the locations at which an improvement is to be implemented, MassDOT Highway Division leads an effort to define the problem, establishes project goals and objectives, and defines the scope of the planning needed for implementation. To that end, it has to complete a Project Need Form (PNF), which states in general terms the deficiencies or needs related to the transportation facility or location. The PNF documents the problems and explains why corrective action is needed. For this study, the information defining the need for the project will be drawn primarily, perhaps exclusively, from the present report. Also, at this point in the process, MassDOT Highway Division meets with potential participants, such as the Boston Region Metropolitan Planning Organization (MPO) and community members, to allow for an informal review of the project.

The PNF is reviewed by the MassDOT Highway Division district office whose jurisdiction includes the location of the proposed project. MassDOT Highway Division also sends the PNF to the MPO, for informational purposes. The outcome of this step determines whether the project requires further planning, whether it is already well supported by prior planning studies, and, therefore, whether it is ready to move forward into the design phase, or whether it should be dismissed from further consideration.

2 PLANNING

This phase will likely not be required for the implementation of the improvements proposed in this planning study, as this planning report should constitute the outcome of this step. However, in general, the purpose of this implementation step is for the project proponent to identify issues, impacts, and approvals that may need to be obtained, so that the subsequent design and permitting processes are understood.

The level of planning needed will vary widely, based on the complexity of the project. Typical tasks include: define the existing context, confirm project need, establish goals and objectives, initiate public outreach, define the project, collect data, develop and analyze alternatives, make recommendations, and provide documentation. Likely outcomes include consensus on the project definition to enable it to move forward into environmental documentation (if needed) and design, or a recommendation to delay the project or dismiss it from further consideration.

3 PROJECT INITIATION

At this point in the process, the proponent, MassDOT Highway Division, fills out, for each improvement, a Project Initiation Form (PIF), which is reviewed by its Project Review Committee (PRC) and the MPO. The PRC is composed of the Chief

Engineer, each District Highway Director, and representatives of the Project Management, Environmental, Planning, Right-of-Way, Traffic, and Bridge departments, and the Capital Expenditure Program Office (CEPO). The PIF documents the project type and description, summarizes the project planning process, identifies likely funding and project management responsibility, and defines a plan for interagency and public participation. First the PRC reviews and evaluates the proposed project based on the Executive Office of Transportation and Public Works's statewide priorities and criteria. If the result is positive, MassDOT Highway Division moves the project forward to the design phase, and to programming review by the MPO. The PRC may provide a Project Management Plan to define roles and responsibilities for subsequent steps. The MPO review includes project evaluation based on the MPO's regional priorities and criteria. The MPO may assign project evaluation criteria score, a Transportation Improvement Program (TIP) year, a tentative project category, and a tentative funding category.

4 ENVIRONMENTAL, DESIGN, AND RIGHT-OF-WAY PROCESS

This step has four distinct but closely integrated elements: public outreach, environmental documentation and permitting (if required), design, and right-of-way acquisition (if required). The outcome of this step is a fully designed and permitted project ready for construction. However, a project does not have to be fully designed in order for the MPO to program it in the TIP.

5 PROGRAMMING

Programming, which typically begins during the design phase, can actually occur at any time during the process, from planning to design. In this step, which is distinct from project initiation, where the MPO receives preliminary information on the proposed project, the proponent requests that the MPO place the project in the region's TIP. The MPO considers the project in terms of regional needs, evaluation criteria, and compliance with the regional Transportation Plan and decides whether to place it in the draft TIP for public review and then in the final TIP.

6 PROCUREMENT

Following project design and programming, MassDOT Highway Division publishes a request for proposals. It then reviews the bids and awards the contract to the qualified bidder with the lowest bid.

7 CONSTRUCTION

After a construction contract is awarded, MassDOT Highway Division and the contractor develop a public participation plan and a management plan for the construction process.

8 PROJECT ASSESSMENT

The purpose of this step is to receive constituents’ comments on the project development process and the project’s design elements. MassDOT Highway Division can apply what is learned in this process to future projects.

MEMORANDUM

To: **Ben Fehan**
Stoughton Town Engineer

February 17, 2011

From: **Chen-Yuan Wang and Efi Pagitsas**

Re: **Safety and Operations Analyses at Selected Boston Region MPO Intersections: Central Street at Pearl Street in Stoughton**

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersection of Central Street at Pearl Street in Stoughton. It contains the following sections:

- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Analyses of Improvement Alternatives
- Improvement Recommendations and Discussion

The memorandum also includes a collection of technical appendices that contain methods and data applied in the study and detailed reports of the intersection capacity analysis.

INTERSECTION LAYOUT AND TRAFFIC CONTROL

This signalized intersection is located about half a mile north of Stoughton Town Center. Central Street is a two-lane roadway that connects Route 24 in the east and Route 27 in the west and intersects Route 138 in the middle. Although it is classified as a minor urban arterial, it is the principal east-west roadway in the northern section of the town. Pearl Street, a two-lane roadway running from the town center to the Canton/Stoughton border in the north-south direction, functions as a minor urban arterial and serves mainly the neighborhood between Washington Street (Route 138) and Canton Street (Route 27).

Figure 1 shows the intersection layout and the area nearby. The Central Street eastbound approach remains a single lane shared by all movements, with a slightly flared area near the intersection. The Central Street westbound approach widens to include an exclusive left-turn lane and a shared lane for through traffic and right turns. Both approaches of Pearl Street have a single lane shared by all movements. There is a small traffic median (about 6 feet by 20 feet) on Central Street west of the intersection, which bears a traffic light post with signal indications for traffic from both the east and west approaches. Crosswalks are installed across all approaches except the westbound approach. Sidewalks exist on all corners of the intersection. Away from the intersection, they exist only on the north side of Central Street and the west side of Pearl Street.

CTPS

FIGURE 1
Central Street at Pearl Street, Stoughton

Safety and Operations Improvements at Selected Intersections

The traffic signal is pre-timed and operates in two traffic phases: (1) eastbound/westbound (EB/WB) all movements (left turns permitted), and (2) northbound/southbound (NB/SB) all movements (left turns permitted). Field measurements by a stopwatch indicated that each traffic signal cycle lasts about one minute (35 seconds for the EB/WB phase and 25 seconds for the NB/SB phase, including a 5-second clearance time for each phase). Right turns on red are allowed on all approaches. A regulatory sign of “Right Turn on Red after Full Stop” is installed for the southbound approach.

All the signal heads are post-mounted and positioned about 10 to 12 feet high. They are located on the four corners of the intersection and on the traffic median on Central Street. Although they provide each approach with two or more signal indications, they are not clearly visible from far away because of their low height.

The signal control also includes an on-call exclusive pedestrian phase that lasts about 20 seconds. There are pedestrian push buttons attached to the traffic signal post at the northwest corner and on a stand-alone low post at the other three corners. But there are no pedestrian signals and the pedestrian phase is indicated by the traffic signals. During the pedestrian phase, the traffic signals first show a steady yellow light and a steady red light lasting about 7 seconds (to indicate “Walk”) and then show a steady red light lasting about 13 seconds to indicate (“Flashing Don’t Walk”). This type of indication can be confusing to the pedestrians and drivers who are not familiar with it.

The land use in the vicinity of the intersection is mainly residential. There are also other uses, such as institutional, office, and commercial, on both streets. At the intersection, the southwest corner is an open lawn area own by the state (Stoughton District Court), while the other corners are occupied by private homes. West of the intersection, the district court main building and an elementary school (West Elementary School) are locate on Central Street. South of the intersection, Stoughton High School is located on Pearl Street about a quarter of a mile from the intersection. A middle school (O’Donnell Middle School) is also located just west of the high school, on Cushing Street. Because these schools are so close to this intersection, a school crossing guard is usually at the intersection to direct traffic during weekday school opening and closing hours.

Further away from the intersection, the east side of Central Street crossed Route 138, where many commercial developments are located, and reaches Route 24 in the east. The north side of Pearl Street becomes Pleasant Street in Canton, which connects with other streets and reaches Canton Center (and its commuter rail station) and Interstate 95 (I-95) in further west.

ISSUES AND CONCERNS

The intersection is congested during peak periods on almost all approaches, depending on the peak direction. Because Central Street is a major arterial in the north section of Stoughton, traffic there is heavy in both directions during peak periods. In general, the peak direction is eastbound in the morning and westbound in the evening. Traffic frequently backs up in both directions in the AM peak hour and mainly in the westbound direction in the PM peak hour. Pearl Street also has heavy traffic in both directions in the AM peak hour and mainly in the southbound direction in the PM peak hour. Due to the high proportion of left turns, southbound traffic frequently backs up during peak hours.

Recent turning movement counts (see Table 2 in the intersection capacity analysis section) indicate high westbound right-turn and southbound left-turn volumes at this intersection. The right turns are about 30% to 40% of the total westbound volume, and the left turns are about 50% to 60% of the total southbound volume. There is extensive traffic flowing from Central Street east of the intersection to Pearl Street north of the intersection, and vice versa. Drivers use the intersection and its north and east legs as an alternative path to reach Canton Center, I-95, Route 138 South, Route 24, and other major routes.

A review of the recent crash data from 2006 to 2008 indicates that the intersection has a high number of crashes and a crash rate much higher than other signalized intersections in the area. In addition, accident reports from the Stoughton Police Department show that several crashes involved a moving vehicle hitting the traffic median on Central Street or the nearby roadside light post. The collision diagram analysis indicates that the median and its adjacent light post form a narrow passage and appear to be hazardous to some drivers, especially those from the south making a left turn or those from the east traveling at a high speed (see the next section for further analysis).

The issues and concerns for this intersection can be summarized as follows:

- High number of crashes and high crash rate at the intersection
- Outdated traffic signal system
- No standard pedestrian signal indications
- Questionable location of the traffic median on Central Street
- Traffic congestion during peak hours, especially on Central Street
- High proportion of WB right turns and SB left turns causing traffic queues

CRASH DATA ANALYSIS

Based on the 2006–2008 MassDOT Registry of Motor Vehicles Division crash data, Table 1 shows that on average 16 crashes occurred at the intersection each year. Nearly 30% of the total crashes resulted in personal injury. The crash types consist of about 30% angle collisions, 30% rear-end collisions, nearly 30% single-vehicle collisions, and about 10% other types, including "unknown." Two crashes out of the 48 total crashes in the three-year period involved pedestrians. No crashes involved bicyclists. About 10% of the total crashes occurred during weekday peak periods; about 25% of them occurred in wet or icy conditions; and about 30% of them occurred in dark conditions.

Crash rate[1] is another effective tool for examining the relative safety of a particular location. Based on the above data and the recently collected traffic volume data, the crash rate for this intersection is calculated as 1.70 (see Appendix A for the calculation sheet). The rate is much higher than the average rate for the signalized locations in MassDOT Highway Division's District 5, which is estimated to be 0.77.[2]

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[1] Crash rates normalize crash frequency (crashes per year) by vehicle exposure (traffic volumes or miles traveled). Crash rates are expressed as "crashes per million entering vehicles" for intersection locations and as "crashes per million miles traveled" for roadway segments.

[2] The average crash rates estimated by the MassDOT Highway Division are based upon a database that contains intersection crash rates submitted to the Highway Division as part of a review process for an environmental

TABLE 1
Summary of Crash Data (2006–2008)

Statistics Period		2006	2007	2008	2006–08	Average
Total number of crashes		20	15	13	48	16
Severity	Property damage only	13	9	6	28	9
	Personal injury	5	3	6	14	5
	Fatality	0	0	0	0	0
	Not reported	2	3	1	6	2
Collision Type	Angle	8	4	3	15	5
	Rear-end	3	8	4	15	5
	Sideswipe	1	0	0	1	0
	Head-on	2	0	0	2	1
	Single vehicle	4	3	6	13	4
	Not reported	2	0	0	2	1
Crashes involving pedestrian(s)		1	0	1	2	1
Crashes involving cyclist(s)		0	0	0	0	0
Occurred during weekday peak periods*		3	1	1	5	2
Wet or icy pavement conditions		4	5	3	12	4
Dark/lighted conditions		5	6	4	15	5

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

The Town of Stoughton also provided crash reports for the most recent three years, from 2007 to 2009.[3] Based on the reports, staff constructed the collision diagram for the intersection (see Figure 2). The diagram shows that various types of collisions occurred in and around the Intersection, and a relatively high number (over 30%) of crashes involved a moving vehicle hitting either the traffic median (and/or the light post dwelling on it) on Central Street or the adjacent light post on the north side of the street.

The two fixed objects in effect form a narrow passage that is difficult for westbound vehicles to enter, either from Central Street or from Pearl Street. It is especially difficult for the vehicles from Pearl Street turning left into Central Street, as the roadside light post is close to the left-turn path if the vehicles do not slow down and therefore make a wide-radius turn (in order to avoid hitting the median). The three crashes that involved hitting the roadside light post are very likely such a case. For large trucks or buses, it is even more difficult to make the left turn without hitting either object.

The analysis indicates that the traffic median (and its adjacent traffic light post) appears to be hazardous to drivers from the south or from the east of the intersection. It also hinders large trucks, buses, and emergency vehicles making turns at the intersection. The traffic median should be removed and replaced by pavement markings, if necessary. Meanwhile, the post-mounted traffic signals on the median and on the northwest corner should be hung from a cable system or a mast arm extended from the roadside.

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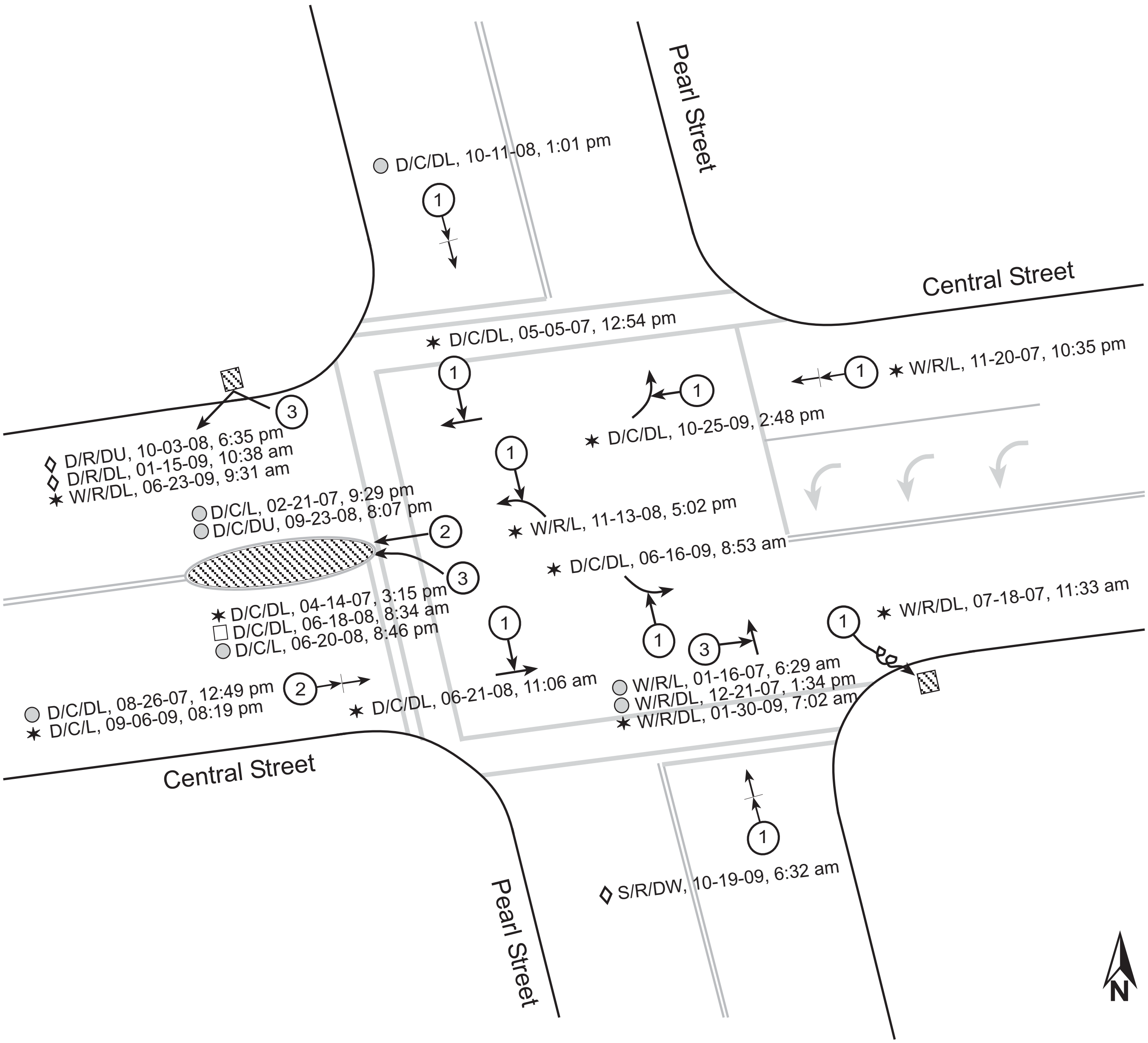
impact report or functional design report. The most recent average crash rates, which are updated on a nearly yearly basis, are based on all entries in the database, not just those entries made within the past year.

3 These are reports filed by Stoughton Police Department. They do not include some of the crashes in the MassDOT Registry Division database, as some drivers might have notified the police and filed the reports only with the insurance companies.

FIGURE 2
Collision Diagram
January 1, 2007, through December 31, 2009
Central Street at Pearl Street, Stoughton



SYMBOLS		PAVEMENT/WEATHER/LIGHTING		TYPES OF COLLISIONS
	Moving vehicle	D	Dry	
	Backing vehicle	W	Wet	Head-on
	Pedestrian or bicycle	S	Snowy, icy	Angle
	Out-of-control vehicle	--	Other	Rear-end
	Fixed object	C	Clear	Sideswipe
	Property damage only	R	Rainy/foggy/cloudy	Right angle
	Injury	S	Snow/sleet	
	Fatality	--	Other	
	No damage or injury	DL	Daylight	
	Not reported	L	Dark, lights	
#	Number of accidents	N	Dark, no lights	
		DU	Dusk	CTPS
		DW	Dawn	

The MassDOT Registry Division's crash data show that there were two crashes involving pedestrians and that resulted in personal injuries. The first case was a westbound through vehicle that collided with a pedestrian at noontime on a raining Sunday (September 3, 2006). The second case was a vehicle going straight (direction unknown) colliding with a pedestrian at round 1:30 PM on a cloudless Wednesday (November 26, 2008). No further information can be found for these two cases, as no police reports were available. With no pedestrian signals at this intersection, the exclusive pedestrian phase indicated by traffic signals could be confusing for the pedestrians and drivers who are not familiar with the particular indications. As it is located in residential neighborhood and adjacent to school, the intersection should be equipped with standard pedestrian signals.

INTERSECTION CAPACITY ANALYSIS

Staff collected turning-movement counts at the intersection on May 18, 2010. The data were recorded in 15-minute intervals for the peak traffic periods in the morning, from 7:00 to 9:00, and in the evening, from 4:00 to 6:00. The intersection carried about 2,350 vehicles in the morning peak hour, from 7:15 to 8:15, and about 2,300 vehicles in the evening peak hour, from 5:00 to 6:00 (see Table 2). About 25 and 10 pedestrians were observed during the AM peak hour and the PM peak hour, respectively. About 5 bicyclists, who appeared to be high school students, went through the intersection in the AM peak hour. No bicyclists were observed in the PM peak hour.

TABLE 2
AM and PM Peak-Hour Traffic Volumes and Pedestrian Crossings

Street name		**Central Street**						**Pearl Street**						**Total**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	Turning volume	10	623	65	88	437	333	74	268	60	222	131	14	2325
	Approach volume	698			858			402			367			
	Pedestrian crossings	12			0			6			6			24
PM peak hour	Turning volume	13	472	55	45	545	251	60	203	54	306	246	23	2273
	Approach volume	540			841			317			575			
	Pedestrian crossings	6			0			2			1			9

Based on the turning-movement counts and the signal timings measured at the site, the intersection capacity was analyzed using an intersection capacity analysis program, Synchro.[4] The program evaluates that it operates at an overall level of service (LOS) F with an average delay of over two minutes per vehicle in both the AM and PM peak hours (see Table 3). The level of service criteria are based on the Highway Capacity Manual 2000.[5] Detailed analysis settings and results for both the AM and PM peak hour are included in Appendix B.

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[4] Synchro is developed and distributed by Trafficware, Ltd. It can perform capacity analysis and traffic simulation (when combined with SimTraffic) for an individual intersection or a series of intersections.

[5] Transportation Research Board, *Highway Capacity Manual 2000*, National Research Council, Washington D.C., 2000

TABLE 3
Intersection Capacity Analysis, Existing Conditions

Street name		**Central Street**						**Pearl Street**						**Overall**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	LOS	**F**			**C**	**F**		**D**			**F**			**F**
	Delay (sec/veh)	151			24	81		42			> 180			124
PM peak hour	LOS	**E**			**B**	**E**		**C**			**F**			**F**
	Delay (sec/veh)	69			14	72		29			> 180			146

As the analysis shows, traffic on the EB/WB approaches endures extensive delays in the AM peak hour, especially the EB approach. Traffic on the SB approach endures significant delays due to the high proportion of left turns in the approach. The existing intersection capacity apparently is not sufficient in handling the existing traffic conditions.

ANALYSES OF IMPROVEMENT ALTERNATIVES

To improve traffic operations at this intersection, we examined a number of traffic signal and geometric design strategies. The analyses were performed progressively, from simple to more involved modifications in the improvement alternatives. As mentioned earlier, the intersection capacity was evaluated using the Synchro optimization and simulation software.

A basic assumption for all the alternatives is a fully actuated traffic signal system with pedestrian signal heads and push buttons in place of the existing outdated system. With the actuated signal system, the traffic signal cycle length would be extended from the existing 60 seconds to 80 seconds in order to reduce lost time due to signal changing during peak hours. An on-call exclusive pedestrian phase of 22 seconds[6] was also assumed for all the alternatives. The alternatives tested for this intersection include:

1) Operate the upgraded signal system under the existing intersection layout and phasing sequence (two-phase EB/WB and NB/SB operation with left turns permitted)
2) Modify the WB approach to an LT(left-turn)/TH (through) shared lane and an exclusive RT (right-turn) lane, and operate the upgraded signal system under the existing phasing sequence
3) Modify the WB approach to an LT/TH shared lane and a TH/RT shared lane, and operate the upgraded signal system under the existing phasing sequence
4) Add an exclusive LT lane to the SB approach, and operate the upgraded signal system under the existing phasing sequence
5) Modify the WB approach to an LT/TH shared lane and an exclusive RT lane, add an exclusive LT lane to the SB approach, and operate the upgraded signal system under the existing phasing sequence

[6] The pedestrian phase would be increased to 22 seconds from the existing 20 seconds in order to cover a crossing distance of at least 60 feet, based on a walking speed of 3.5 feet per second in addition to a “walk” indication time of 4 seconds. The widest existing crossing distance is estimated as about 50 feet. The additional 10 feet would be considered for the potential modifications of the intersection layout.

6) Modify the WB approach to an LT/TH shared lane and a TH/RT shared lane, add an exclusive LT lane to the SB approach, and operate the upgraded signal system under the existing phasing sequence

Alternatives 4, 5, and 6 basically are Alternatives 1, 2, and 3 with the addition of an SB-LT exclusive lane to each. We also tested other alternatives. They are not included, as they would expand the intersection to a large extent and are much less feasible than the above six alternatives.

Table 4 summarizes the intersection capacity analyses for both the AM and PM peak hours for the six alternatives (detailed analysis settings and results for the alternatives are included in Appendices C to H separately). Alternative 1 shows that the intersection operations would be improved by simply upgrading the signal system, especially the operations on Central Street. Changing the WB approach to accommodate its high right-turn volume (Alternative 2) would improve Central Street traffic operations and the overall intersection operation noticeably. Changing the WB approach to two shared lanes (Alternative 3) would also improve Central Street traffic operations and the overall intersection operation, especially in the PM peak hour.

TABLE 4
Intersection Capacity Analyses of Improvement Alternatives

Street name		**Central Street**		**Pearl Street**		**Overall**
Approach		**Eastbound**	**Westbound**	**Northbound**	**Southbound**	
AM peak hour	Existing	F/151	F/81	D/42	F/ >180	F/124
	Alternative 1	E/62	E/58	D/44	F/ >180	F/91
	Alternative 2	D/52	D/40	D/35	F/179	E/65
	Alternative 3	D/53	C/26	D/35	F/179	E/60
	Alternative 4	D/45	D/52	D/45	F/151	E/65
	Alternative 5	D/52	D/40	C/33	E/80	D/49
	Alternative 6	D/53	C/26	C/33	E/80	D/44
PM peak hour	Existing	E/68	E/72	C/29	F/ >180	F/146
	Alternative 1	D/52	E/64	C/30	F/ >180	F/125
	Alternative 2	D/46	D/37	C/23	F/178	E/73
	Alternative 3	D/54	C/35	B/19	F/108	E/56
	Alternative 4	D/52	E/64	C/29	F/107	E/67
	Alternative 5	C/33	C/29	C/24	E/62	D/38
	Alternative 6	D/36	C/27	C/22	D/48	C/34

Note Performance measures: Level of Service (A to F)/Average Delay (seconds per vehicle)
Alternative 1: Operate the upgraded signal system under the existing intersection layout and phasing sequence
Alternative 2: Modify the WB approach to an LT/TH lane and an RT lane, with the upgraded signal system
Alternative 3: Modify the WB approach to an LT/TH lane and a TH/RT lane, with the upgraded signal system
Alternative 4: Add an LT lane on the SB approach, with the improvements of Alternative 1
Alternative 5: Add an LT lane on the SB Approach, with the improvements of Alternative 2
Alternative 6: Add an LT lane on the SB Approach, with the improvements of Alternative 3

Alternative 2 would likely be constructed within the existing WB approach layout with no major intersection modifications. Alternative 3 would potentially require some land takings, as it calls for two receiving lanes on the WB departure approach and a slight realignment of Central Street. Currently the section of Central Street west of the intersection appears to have space (the lawn area belongs to Stoughton District Court) available on the south side. The State Road Inventory File indicates that this section of Central Street has a surface width of 24 feet with a right-of-way (ROW) width of 40 feet. To maintain the existing sidewalk on the south side and a 2-foot shoulder on each side, this alternative would very likely require some land takings. The feasibility of Alternative 3 should be further examined in the functional design stage.

The Synchro tests indicate that the SB approach in the first three alternatives would still operate at an unacceptable LOS F with extensive delays. Adding an LT exclusive lane on the SB approach without other modifications (Alternative 4) would improve traffic operations mainly on the SB approach and somewhat on the EB and WB approaches. Adding an LT lane on the SB approach and changing the WB approach lane configuration (Alternatives 5 and 6) would improve traffic operations significantly on all the approaches. Based on the Synchro tests' queue length estimation, this modification would require at least 250 feet of left turn storage space on the SB approach. That would require an expansion of the entire section of Pearl Street from McEvoy Circle to the intersection.

From the aerial photograph of the vicinity, there appears to be little room for the expansion, as both sides of Pearl Street are occupied by private homes. The State Road Inventory File indicates that this section of Pearl Street (owned by the town) has a surface width of 28 feet with a right-of-way (ROW) width of 50 feet. Given the existing 6-foot-wide sidewalk on the west side and a 2-foot shoulder on each side, there may be room for an additional lane with the configuration of two 10-foot lanes approaching the intersection. The feasibility of adding the LT lane should be carefully examined in the future functional design stage, as it could have some impacts on the residential areas north of the intersection.

IMPROVEMENT RECOMMENDATIONS AND DISCUSSION

The intersection has a high number of crashes and a crash rate much higher than other signalized intersections in the area. The above safety and operations analyses found a number of deficiencies related to the existing signal system and the intersection layout that might have been the causes of some crashes in recent years. The traffic median on Central Street is found to be hazardous for drivers from the south and from the east. However, it houses major signal indications for Central Street traffic and can not be removed unless the signals are converted to overhead signal indications.

Meanwhile, the intersection is highly congested during the AM and PM peak hours. To improve traffic operations, the study examined a number of traffic signal and geometric design strategies. The alternatives tested for this intersection include:

1) Operate the upgraded signal system under the existing intersection layout
2) Modify the WB approach to an LT/TH shared lane and an exclusive RT lane, and operate the upgraded signal system under the existing phasing sequence
3) Modify the WB approach to an LT/TH shared lane and a TH/RT shared lane, and operate the upgraded signal system under the existing phasing sequence

4) Add an exclusive LT lane to the SB approach, and operate the upgraded signal system under the existing phasing sequence
5) Modify the WB approach to an LT/TH shared lane and an exclusive RT lane, add an exclusive LT lane to the SB approach, and operate the upgraded signal system under the existing phasing sequence
6) Modify the WB approach to an LT/TH shared lane and a TH/RT shared lane, add an exclusive LT lane to the SB approach, and operate the upgraded signal system under the existing phasing sequence

The study found that Alternatives 3, 4, 5, and 6 would likely require land takings and have some impacts on the surrounding areas. Alternatives 1 and 2 are more feasible than the other alternatives. Alternative 2 is operationally more favorable than Alternative 1, as it would noticeably improve traffic operations, with reduced delays on all approaches. In terms of traffic safety, Alternative 1 is more favorable than Alternative 2, as the WB left turns in Alternative 2 would be under more pressure with the lost waiting (storage) space. Meanwhile, Alternative 2 could potentially induce somewhat more traffic bound for Canton Center/I-95 traffic with the increase of EB-RT capacity.

At this preliminary planning stage, we recommend Alternative 1 for this intersection. It is essential to upgrade the outdated signal system. Although the intersection would likely still operate at an undesirable LOS F during peak hours, its operations and safety would improve noticeably from the existing conditions. The new signal system should include the following major features:

- Install a fully actuated traffic signal system with standard pedestrian signals and push buttons
- Replace the existing post-mounted signals with overhead signal indications supported by a cable system or mast arms, which can be clearly viewed on all approaches from a distance
- Remove the traffic median on Central Street, and replace it with hatched pavement markings if necessary
- Maintain the existing crosswalks and sidewalks at the intersection
- Include a pre-emption function for emergency vehicles[7]
- Install wheelchair ramps with ADA (American with Disabilities Act)/AAB(Massachusetts Architectural Access Board) standards at all corners of the intersection
- Install accessible (audible) countdown pedestrian signals
- Improve lighting conditions at the intersection[8]

Meanwhile, we recommend including Alternatives 2 to 6 for further examination in the future functional design stage for the intersection. Based on the Town's suggestions (see Appendix I), the following issues should be included in the design scope:

---

[7] Most of the major intersections in the town are already equipped with this function in connection with fire engines and other emergency vehicles. The upgraded signals at this intersection should be incorporated into the system.

[8] The crash data for recent years show that 30% of the intersection crashes occurred in dark conditions. Currently the intersection has only one street light, over its southeast corner. Additional lighting would potentially reduce the number of crashes in darkness.

- Scheduling public hearings to receive public input
- Consideration of private parking needs and access
- Drainage improvements
- Potential coordination with nearby traffic signals
- Pavement marking coordination with the nearby roadways

Assuming no land takings, the total cost of the signal installation (including its support system) and the necessary intersection modifications can be roughly estimated as $500,000 to $750,000. Both streets and the intersection are under the jurisdiction of the Town of Stoughton. The Town can seek funding support from the state by working closely with MassDOT Highway District 5 through the project implementation process (see Appendix J).

In the immediate term, before the signal system is updated, the safety at this intersection can be enhanced by (1) making sure a comprehensive school crossing guard protection is always in place at this location during school hours, and (2) placing pedestrian crossing warning signs on both of the Central Street approaches.

Appendix A

Intersection Crash Rate Calculation
Central Street at Pearl Street, Stoughton

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Stoughton   COUNT DATE : 6/3/10

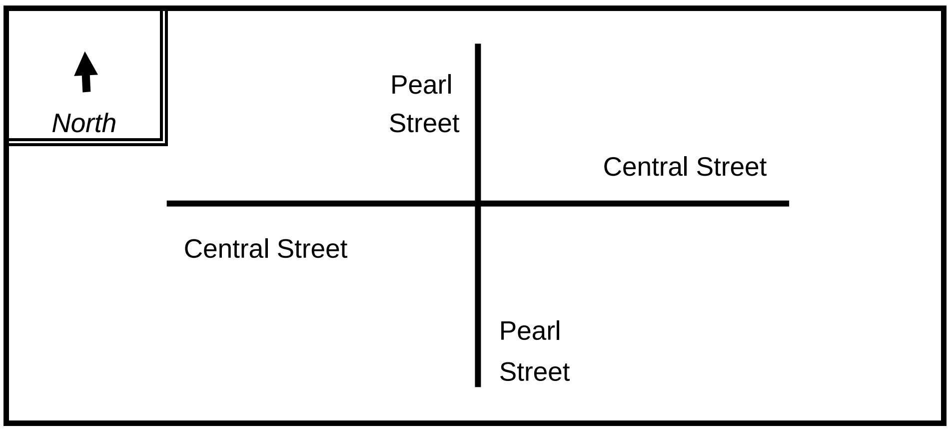
DISTRICT : 5   UNSIGNALIZED :   SIGNALIZED : X

~ INTERSECTION DATA ~

MAJOR STREET : Central Street

MINOR STREET(S) : Pearl Street

INTERSECTION DIAGRAM
(Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	EB	WB	NB	SB		
PEAK HOURLY VOLUMES (AM/PM) :	698	858	402	367		2,325

" K " FACTOR : **0.090**   INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **25,833**

TOTAL # OF CRASHES : 48   # OF YEARS : 3   AVERAGE # OF CRASHES PER YEAR (**A**) : **16.00**

CRASH RATE CALCULATION : **1.70**   RATE = $\frac{(A * 1{,}000{,}000)}{(V * 365)}$

Comments : MassDOT District 5 Average Rate = 0.77

Project Title & Date: Safety and Operations Analyses at Selceted Intersections

Appendix B

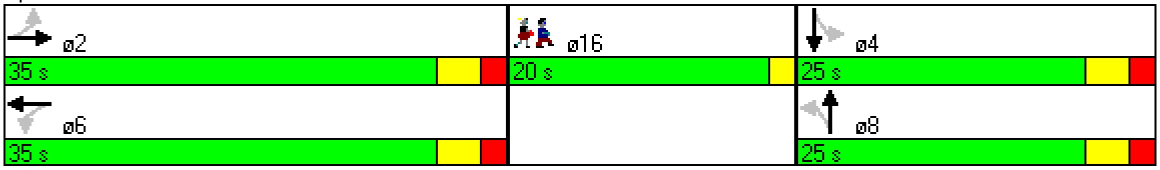
AM/PM Peak Hour Intersection Capacity Analysis
Existing Traffic Conditions
Central Street at Pearl Street, Stoughton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	10	623	65	88	437	333	74	268	60	222	131	14
Confl. Peds. (#/hr)	6		6	6		6	12					12
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	2%	2%	2%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	35.0	35.0		35.0	35.0		25.0	25.0		25.0	25.0	
Total Split (s)	35.0	35.0	0.0	35.0	35.0	0.0	25.0	25.0	0.0	25.0	25.0	0.0
Total Split (%)	43.8%	43.8%	0.0%	43.8%	43.8%	0.0%	31.3%	31.3%	0.0%	31.3%	31.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		Max	Max		Max	Max	
Act Effct Green (s)		30.4		30.4	30.4			20.3			20.3	
Actuated g/C Ratio		0.48		0.48	0.48			0.32			0.32	
v/c Ratio		1.26		0.45	1.11			0.86			1.48	
Control Delay		151.2		23.5	87.8			41.5			259.4	
Queue Delay		0.0		0.0	0.0			0.0			0.0	
Total Delay		151.2		23.5	87.8			41.5			259.4	
LOS		F		C	F			D			F	
Approach Delay		151.2			81.2			41.5			259.4	
Approach LOS		F			F			D			F	

Intersection Summary

Cycle Length: 80
Actuated Cycle Length: 64
Natural Cycle: 140
Control Type: Semi Act-Uncoord
Maximum v/c Ratio: 1.48
Intersection Signal Delay: 123.5 Intersection LOS: F
Intersection Capacity Utilization 126.0% ICU Level of Service H
Analysis Period (min) 15

Splits and Phases: 3: Int



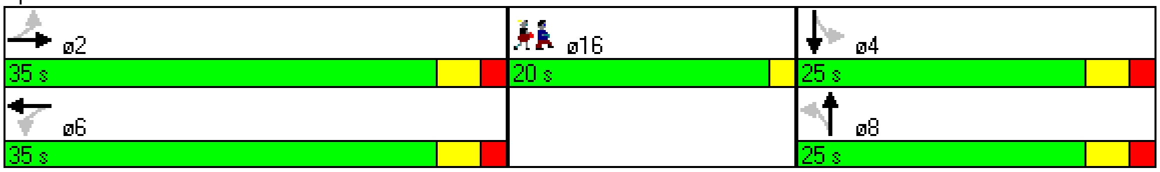
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	20.0
Total Split (s)	20.0
Total Split (%)	25%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	13	472	55	45	545	251	60	203	54	306	246	23
Confl. Peds. (#/hr)	2		1	1		2	6					6
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	35.0	35.0		35.0	35.0		25.0	25.0		25.0	25.0	
Total Split (s)	35.0	35.0	0.0	35.0	35.0	0.0	25.0	25.0	0.0	25.0	25.0	0.0
Total Split (%)	43.8%	43.8%	0.0%	43.8%	43.8%	0.0%	31.3%	31.3%	0.0%	31.3%	31.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		Max	Max		Max	Max	
Act Effct Green (s)		30.4		30.4	30.4			20.3			20.3	
Actuated g/C Ratio		0.48		0.48	0.48			0.32			0.32	
v/c Ratio		1.03		0.16	1.08			0.67			1.80	
Control Delay		68.9		14.1	74.8			29.0			393.5	
Queue Delay		0.0		0.0	0.0			0.0			0.0	
Total Delay		68.9		14.1	74.8			29.0			393.5	
LOS		E		B	E			C			F	
Approach Delay		68.9			71.6			29.0			393.5	
Approach LOS		E			E			C			F	

Intersection Summary	
Cycle Length: 80	
Actuated Cycle Length: 64	
Natural Cycle: 150	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 1.80	
Intersection Signal Delay: 146.5	Intersection LOS: F
Intersection Capacity Utilization 115.4%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	20.0
Total Split (s)	20.0
Total Split (%)	25%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	
Intersection Summary	

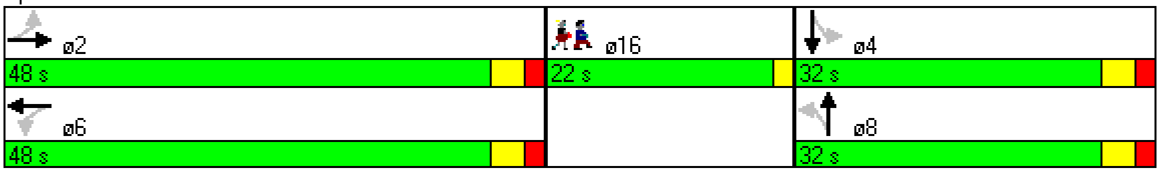
Appendix C

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 1
Upgrade Signal System and Maintain Existing Intersection Layout
Central Street at Pearl Street, Stoughton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	10	623	65	88	437	333	74	268	60	222	131	14
Confl. Peds. (#/hr)	6		6	6		6	12					12
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	2%	2%	2%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	48.0	48.0	0.0	48.0	48.0	0.0	32.0	32.0	0.0	32.0	32.0	0.0
Total Split (%)	47.1%	47.1%	0.0%	47.1%	47.1%	0.0%	31.4%	31.4%	0.0%	31.4%	31.4%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)		43.3		43.3	43.3			27.2			27.2	
Actuated g/C Ratio		0.52		0.52	0.52			0.32			0.32	
v/c Ratio		1.02		0.40	1.03			0.84			1.51	
Control Delay		62.2		21.3	62.8			44.4			274.4	
Queue Delay		0.0		0.0	0.0			0.0			0.0	
Total Delay		62.2		21.3	62.8			44.4			274.4	
LOS		E		C	E			D			F	
Approach Delay		62.2			58.5			44.4			274.4	
Approach LOS		E			E			D			F	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 140	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.51	
Intersection Signal Delay: 91.3	Intersection LOS: F
Intersection Capacity Utilization 126.0%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



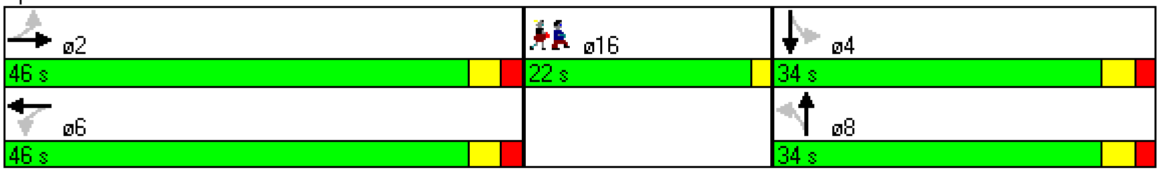
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	13	472	55	45	545	251	60	203	54	306	246	23
Confl. Peds. (#/hr)	2		1	1		2	6					6
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	46.0	46.0	0.0	46.0	46.0	0.0	34.0	34.0	0.0	34.0	34.0	0.0
Total Split (%)	45.1%	45.1%	0.0%	45.1%	45.1%	0.0%	33.3%	33.3%	0.0%	33.3%	33.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)		41.3		41.3	41.3			29.2			29.2	
Actuated g/C Ratio		0.49		0.49	0.49			0.35			0.35	
v/c Ratio		0.96		0.16	1.04			0.62			1.66	
Control Delay		51.9		16.0	67.2			29.8			334.9	
Queue Delay		0.0		0.0	0.0			0.0			0.0	
Total Delay		51.9		16.0	67.2			29.8			334.9	
LOS		D		B	E			C			F	
Approach Delay		51.9			64.5			29.8			334.9	
Approach LOS		D			E			C			F	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.66	
Intersection Signal Delay: 125.1	Intersection LOS: F
Intersection Capacity Utilization 115.4%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

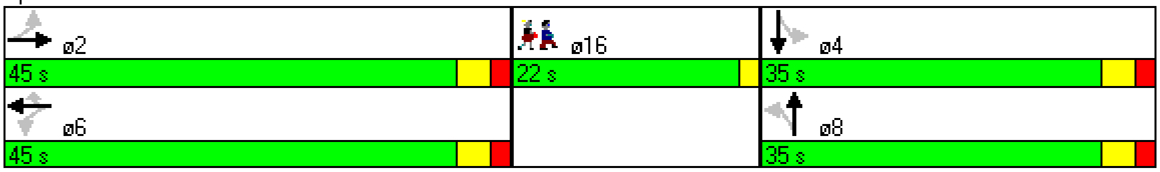
Appendix D

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 2
Upgrade Signal System and
Change WB to a LT/TH Shared Lane and a RT Exclusive Lane
Central Street at Pearl Street, Stoughton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	10	623	65	88	437	333	74	268	60	222	131	14
Confl. Peds. (#/hr)	6		6	6		6	12					12
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	2%	2%	2%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm		Perm	Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6		6	8			4		
Detector Phase	2	2		6	6	6	8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0	21.0	15.0	15.0		15.0	15.0	
Total Split (s)	45.0	45.0	0.0	45.0	45.0	45.0	35.0	35.0	0.0	35.0	35.0	0.0
Total Split (%)	44.1%	44.1%	0.0%	44.1%	44.1%	44.1%	34.3%	34.3%	0.0%	34.3%	34.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0	3.0	3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0	2.0	2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max	Max	None	None		None	None	
Act Effct Green (s)		40.3			40.3	40.3		30.2			30.2	
Actuated g/C Ratio		0.48			0.48	0.48		0.36			0.36	
v/c Ratio		0.98			1.00	0.43		0.76			1.29	
Control Delay		51.5			63.4	3.8		35.4			179.3	
Queue Delay		0.0			0.0	0.0		0.0			0.0	
Total Delay		51.5			63.4	3.8		35.4			179.3	
LOS		D			E	A		D			F	
Approach Delay		51.5			40.3			35.4			179.3	
Approach LOS		D			D			D			F	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.29	
Intersection Signal Delay: 64.8	Intersection LOS: E
Intersection Capacity Utilization 135.7%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



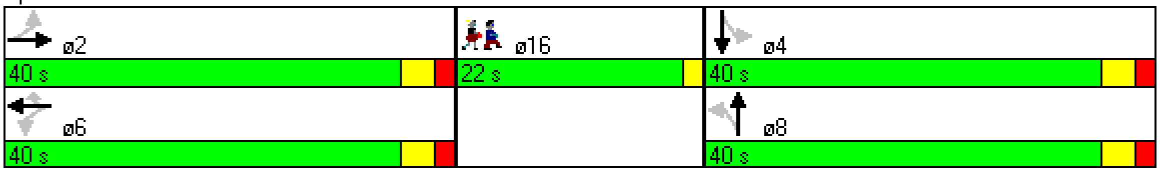
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	13	472	55	45	545	251	60	203	54	306	246	23
Confl. Peds. (#/hr)	2		1	1		2	6					6
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm		Perm	Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6		6	8			4		
Detector Phase	2	2		6	6	6	8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0	21.0	15.0	15.0		15.0	15.0	
Total Split (s)	40.0	40.0	0.0	40.0	40.0	40.0	40.0	40.0	0.0	40.0	40.0	0.0
Total Split (%)	39.2%	39.2%	0.0%	39.2%	39.2%	39.2%	39.2%	39.2%	0.0%	39.2%	39.2%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0	3.0	3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0	2.0	2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max	Max	None	None		None	None	
Act Effct Green (s)		35.3			35.3	35.3		35.3			35.3	
Actuated g/C Ratio		0.42			0.42	0.42		0.42			0.42	
v/c Ratio		0.91			0.95	0.35		0.52			1.31	
Control Delay		45.5			51.1	4.2		22.6			177.6	
Queue Delay		0.0			0.0	0.0		0.0			0.0	
Total Delay		45.5			51.1	4.2		22.6			177.6	
LOS		D			D	A		C			F	
Approach Delay		45.5			37.2			22.6			177.6	
Approach LOS		D			D			C			F	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.31	
Intersection Signal Delay: 72.7	Intersection LOS: E
Intersection Capacity Utilization 123.1%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

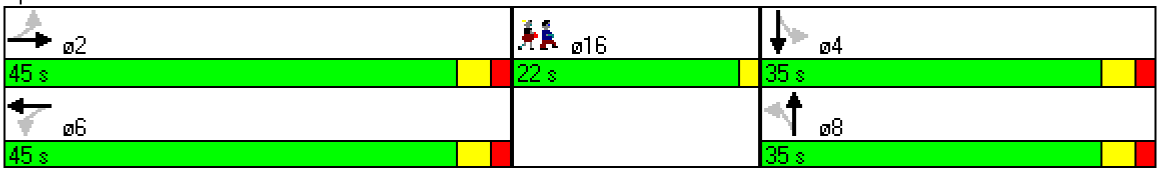
Appendix E

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 3
Upgrade Signal System and
Change WB to a LT/TH Shared Lane and a TH/RT Shared Lane
Central Street at Pearl Street, Stoughton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	10	623	65	88	437	333	74	268	60	222	131	14
Confl. Peds. (#/hr)	6		6	6		6	12					12
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	2%	2%	2%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	45.0	45.0	0.0	45.0	45.0	0.0	35.0	35.0	0.0	35.0	35.0	0.0
Total Split (%)	44.1%	44.1%	0.0%	44.1%	44.1%	0.0%	34.3%	34.3%	0.0%	34.3%	34.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)		40.3			40.3			30.2			30.2	
Actuated g/C Ratio		0.48			0.48			0.36			0.36	
v/c Ratio		0.98			0.85			0.76			1.29	
Control Delay		53.3			26.0			35.3			179.3	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		53.3			26.0			35.3			179.3	
LOS		D			C			D			F	
Approach Delay		53.3			26.0			35.3			179.3	
Approach LOS		D			C			D			F	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 140	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.29	
Intersection Signal Delay: 60.0	Intersection LOS: E
Intersection Capacity Utilization 133.1%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



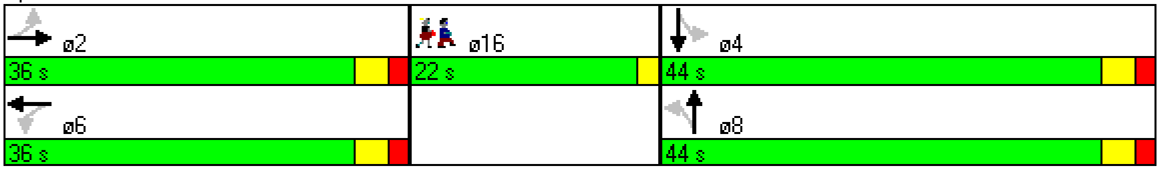
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	13	472	55	45	545	251	60	203	54	306	246	23
Confl. Peds. (#/hr)	2		1	1		2	6					6
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	36.0	36.0	0.0	36.0	36.0	0.0	44.0	44.0	0.0	44.0	44.0	0.0
Total Split (%)	35.3%	35.3%	0.0%	35.3%	35.3%	0.0%	43.1%	43.1%	0.0%	43.1%	43.1%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)		31.2			31.2			39.3			39.3	
Actuated g/C Ratio		0.37			0.37			0.47			0.47	
v/c Ratio		0.95			0.87			0.47			1.14	
Control Delay		54.3			35.0			18.9			108.1	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		54.3			35.0			18.9			108.1	
LOS		D			D			B			F	
Approach Delay		54.3			35.0			18.9			108.1	
Approach LOS		D			D			B			F	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.14	
Intersection Signal Delay: 55.8	Intersection LOS: E
Intersection Capacity Utilization 113.2%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

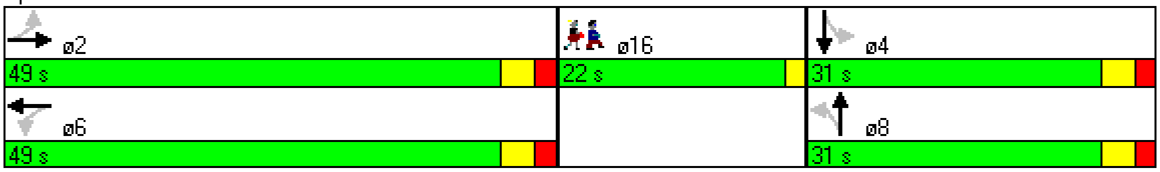
Appendix F

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 4
Upgrade Signal System and Add a SB-LT Exclusive Lane
Central Street at Pearl Street, Stoughton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	10	623	65	88	437	333	74	268	60	222	131	14
Confl. Peds. (#/hr)	6		6	6		6	12					12
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	2%	2%	2%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	49.0	49.0	0.0	49.0	49.0	0.0	31.0	31.0	0.0	31.0	31.0	0.0
Total Split (%)	48.0%	48.0%	0.0%	48.0%	48.0%	0.0%	30.4%	30.4%	0.0%	30.4%	30.4%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)		44.4		44.4	44.4			26.2		26.2	26.2	
Actuated g/C Ratio		0.53		0.53	0.53			0.31		0.31	0.31	
v/c Ratio		0.96		0.38	1.01			0.85		1.38	0.33	
Control Delay		45.5		19.9	55.9			45.3		233.4	25.6	
Queue Delay		0.0		0.0	0.0			0.0		0.0	0.0	
Total Delay		45.5		19.9	55.9			45.3		233.4	25.6	
LOS		D		B	E			D		F	C	
Approach Delay		45.5			52.2			45.3			151.3	
Approach LOS		D			D			D			F	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 140	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.38	
Intersection Signal Delay: 64.7	Intersection LOS: E
Intersection Capacity Utilization 117.3%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



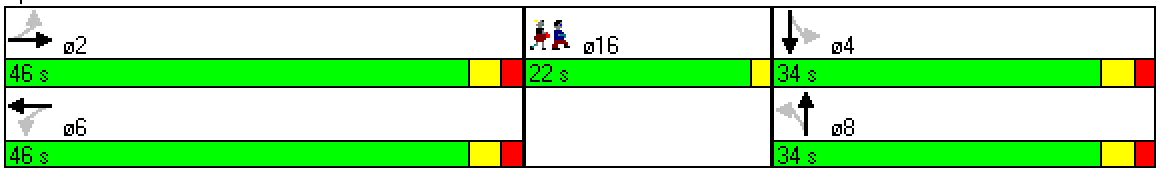
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	13	472	55	45	545	251	60	203	54	306	246	23
Confl. Peds. (#/hr)	2		1	1		2	6					6
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	46.0	46.0	0.0	46.0	46.0	0.0	34.0	34.0	0.0	34.0	34.0	0.0
Total Split (%)	45.1%	45.1%	0.0%	45.1%	45.1%	0.0%	33.3%	33.3%	0.0%	33.3%	33.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)		41.3		41.3	41.3			29.2		29.2	29.2	
Actuated g/C Ratio		0.49		0.49	0.49			0.35		0.35	0.35	
v/c Ratio		0.96		0.16	1.04			0.61		1.27	0.52	
Control Delay		51.9		16.0	67.2			29.4		176.6	27.3	
Queue Delay		0.0		0.0	0.0			0.0		0.0	0.0	
Total Delay		51.9		16.0	67.2			29.4		176.6	27.3	
LOS		D		B	E			C		F	C	
Approach Delay		51.9			64.5			29.4			106.8	
Approach LOS		D			E			C			F	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.27	
Intersection Signal Delay: 67.3	Intersection LOS: E
Intersection Capacity Utilization 99.5%	ICU Level of Service F
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

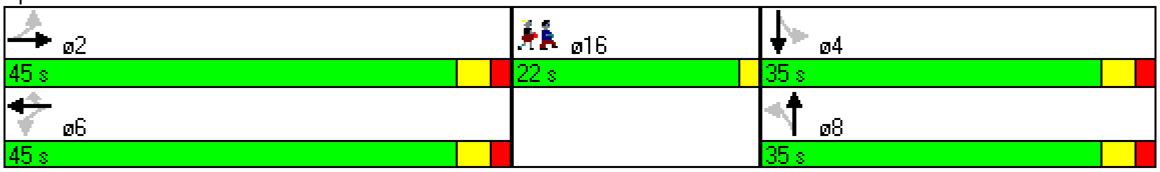
Appendix G

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 5
Upgrade Signal System,
Add a SB-LT Exclusive Lane, and
Change WB to a LT/TH Shared Lane and a RT Exclusive Lane
Central Street at Pearl Street, Stoughton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	10	623	65	88	437	333	74	268	60	222	131	14
Confl. Peds. (#/hr)	6		6	6		6	12					12
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	2%	2%	2%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm		Perm	Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6		6	8			4		
Detector Phase	2	2		6	6	6	8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0	21.0	15.0	15.0		15.0	15.0	
Total Split (s)	45.0	45.0	0.0	45.0	45.0	45.0	35.0	35.0	0.0	35.0	35.0	0.0
Total Split (%)	44.1%	44.1%	0.0%	44.1%	44.1%	44.1%	34.3%	34.3%	0.0%	34.3%	34.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0	3.0	3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0	2.0	2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max	Max	None	None		None	None	
Act Effct Green (s)		40.3			40.3	40.3		30.2		30.2	30.2	
Actuated g/C Ratio		0.48			0.48	0.48		0.36		0.36	0.36	
v/c Ratio		0.98			1.00	0.43		0.73		1.09	0.29	
Control Delay		51.5			63.4	3.8		33.4		117.3	22.0	
Queue Delay		0.0			0.0	0.0		0.0		0.0	0.0	
Total Delay		51.5			63.4	3.8		33.4		117.3	22.0	
LOS		D			E	A		C		F	C	
Approach Delay		51.5			40.3			33.4			79.6	
Approach LOS		D			D			C			E	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 140	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.09	
Intersection Signal Delay: 48.7	Intersection LOS: D
Intersection Capacity Utilization 127.1%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



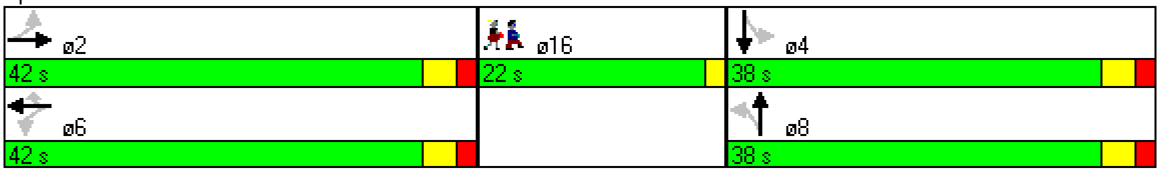
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	13	472	55	45	545	251	60	203	54	306	246	23
Confl. Peds. (#/hr)	2		1	1		2	6					6
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm		Perm	Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6		6	8			4		
Detector Phase	2	2		6	6	6	8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0	4.0	4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0	21.0	15.0	15.0		15.0	15.0	
Total Split (s)	42.0	42.0	0.0	42.0	42.0	42.0	38.0	38.0	0.0	38.0	38.0	0.0
Total Split (%)	41.2%	41.2%	0.0%	41.2%	41.2%	41.2%	37.3%	37.3%	0.0%	37.3%	37.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0	3.0	3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0	2.0	2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max	Max	None	None		None	None	
Act Effct Green (s)		37.3			37.3	37.3		33.3		33.3	33.3	
Actuated g/C Ratio		0.44			0.44	0.44		0.40		0.40	0.40	
v/c Ratio		0.80			0.89	0.34		0.53		1.06	0.46	
Control Delay		32.3			40.1	4.0		23.8		95.7	23.0	
Queue Delay		0.0			0.0	0.0		0.0		0.0	0.0	
Total Delay		32.3			40.1	4.0		23.8		95.7	23.0	
LOS		C			D	A		C		F	C	
Approach Delay		32.3			29.4			23.8			61.7	
Approach LOS		C			C			C			E	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 140	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.06	
Intersection Signal Delay: 37.5	Intersection LOS: D
Intersection Capacity Utilization 107.2%	ICU Level of Service G
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

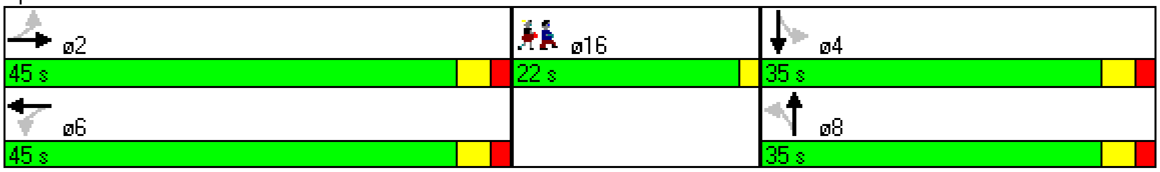
Appendix H

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 6
Upgrade Signal System,
Add a SB-LT Exclusive Lane, and
Change WB to a LT/TH Shared Lane and a TH/RT Shared Lane
Central Street at Pearl Street, Stoughton

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	10	623	65	88	437	333	74	268	60	222	131	14
Confl. Peds. (#/hr)	6		6	6		6	12					12
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	2%	2%	2%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	45.0	45.0	0.0	45.0	45.0	0.0	35.0	35.0	0.0	35.0	35.0	0.0
Total Split (%)	44.1%	44.1%	0.0%	44.1%	44.1%	0.0%	34.3%	34.3%	0.0%	34.3%	34.3%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)		40.3			40.3			30.2		30.2	30.2	
Actuated g/C Ratio		0.48			0.48			0.36		0.36	0.36	
v/c Ratio		0.98			0.85			0.73		1.09	0.29	
Control Delay		53.3			26.0			33.3		117.3	22.0	
Queue Delay		0.0			0.0			0.0		0.0	0.0	
Total Delay		53.3			26.0			33.3		117.3	22.0	
LOS		D			C			C		F	C	
Approach Delay		53.3			26.0			33.3			79.6	
Approach LOS		D			C			C			E	

Intersection Summary	
Cycle Length: 102	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.09	
Intersection Signal Delay: 43.9	Intersection LOS: D
Intersection Capacity Utilization 124.5%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

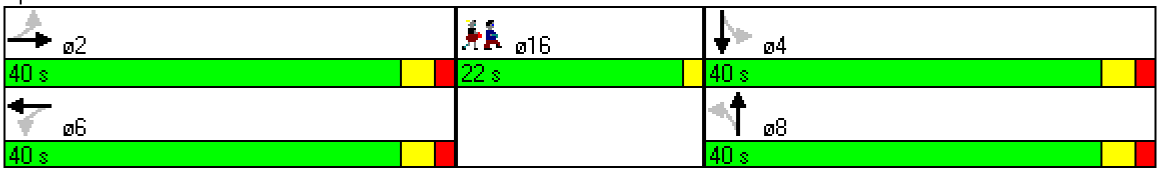
Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	13	472	55	45	545	251	60	203	54	306	246	23
Confl. Peds. (#/hr)	2		1	1		2	6					6
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		15.0	15.0		15.0	15.0	
Total Split (s)	40.0	40.0	0.0	40.0	40.0	0.0	40.0	40.0	0.0	40.0	40.0	0.0
Total Split (%)	39.2%	39.2%	0.0%	39.2%	39.2%	0.0%	39.2%	39.2%	0.0%	39.2%	39.2%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		None	None		None	None	
Act Effct Green (s)		35.3			35.3			35.3		35.3	35.3	
Actuated g/C Ratio		0.42			0.42			0.42		0.42	0.42	
v/c Ratio		0.84			0.78			0.49		0.97	0.43	
Control Delay		36.4			26.5			21.8		71.1	21.1	
Queue Delay		0.0			0.0			0.0		0.0	0.0	
Total Delay		36.4			26.5			21.8		71.1	21.1	
LOS		D			C			C		E	C	
Approach Delay		36.4			26.5			21.8			47.7	
Approach LOS		D			C			C			D	

Intersection Summary

Cycle Length: 102
Actuated Cycle Length: 84
Natural Cycle: 150
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.97
Intersection Signal Delay: 33.6 Intersection LOS: C
Intersection Capacity Utilization 97.3% ICU Level of Service F
Analysis Period (min) 15

Splits and Phases: 3: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	22.0
Total Split (s)	22.0
Total Split (%)	22%
Yellow Time (s)	2.0
All-Red Time (s)	0.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix I

Letter from Stoughton
January 18, 2011

TOWN OF STOUGHTON
10 PEARL STREET
STOUGHTON, MA 02072
ENGINEERING DEPARTMENT

DATE: January 18, 2011

TO: Chen-Yuan Wang
Staff Planner

FROM: Ben Fehan
Town Engineer

SUBJECT: Intersection of Central and Pearl Streets
Stoughton, MA

CC: Francis T. Crimmins, Jr., Town Manager; John Batchelder, Superintendent of Public Works

We have completed our review of the Safety and Operations Analysis of the Intersection of Central and Pearl Streets in Stoughton. We thank you for the opportunity to comment as this intersection is a major one in the town and serves as the gateway for traffic flowing north into Canton.

<u>GENERAL</u>

The Report contains the following:

- Accident data with some analysis
- Aerial photographs
- A description of the traffic signal operation
- Peak period-level of service analysis

The Report is targeted at documenting the safety issues which exist at the intersection. It is not intended to document all the issues which would have to be addressed in the redesign of the intersection such as:

- Roadway widths
- Parking needs of abutters
- Traffic Signal coordination
- Intersection redesign
- Pedestrian access

REPORT FINDINGS/IMPROVEMENTS NEEDED

We concur with the following report findings:

- The existing traffic signals are antiquated and not clearly visible.
- Modern post mounted traffic signals should be installed w/std. pedestrian signals.
- The existing traffic island should be removed.
- Land acquisition should be investigated to facilitate proper lane design.

RELATED DESIGN ISSUES

In addition to the report findings, we have identified other criteria which should be included in the design scope. They include:

- Consideration of private parking needs.
- Scheduling of a Public Hearing to receive citizen input.
- Drainage improvements.
- Traffic light coordination with nearby intersections.
- Pavement marking coordination.

Once again we thank you for the time and effort that you and your staff have placed in this report. We assume that you will be issuing a final version soon with the conclusion that traffic improvements are needed and we look forward to receiving that report. We also trust that you will provide MADOT District 5 office with copies of the final document. We would appreciate receiving three copies of the final report.

Appendix J

MassDOT Project Implementation Process

The following description of the implementation process is based on Chapter 2 of the *MassDOT Highway Division's Project Development and Design Guide (2005)*. The text below borrows heavily from that document.

1 NEEDS IDENTIFICATION

For each of the locations at which an improvement is to be implemented, MassDOT Highway Division leads an effort to define the problem, establishes project goals and objectives, and defines the scope of the planning needed for implementation. To that end, it has to complete a Project Need Form (PNF), which states in general terms the deficiencies or needs related to the transportation facility or location. The PNF documents the problems and explains why corrective action is needed. For this study, the information defining the need for the project will be drawn primarily, perhaps exclusively, from the present report. Also, at this point in the process, MassDOT Highway Division meets with potential participants, such as the Boston Region Metropolitan Planning Organization (MPO) and community members, to allow for an informal review of the project.

The PNF is reviewed by the MassDOT Highway Division district office whose jurisdiction includes the location of the proposed project. MassDOT Highway Division also sends the PNF to the MPO, for informational purposes. The outcome of this step determines whether the project requires further planning, whether it is already well supported by prior planning studies, and, therefore, whether it is ready to move forward into the design phase, or whether it should be dismissed from further consideration.

2 PLANNING

This phase will likely not be required for the implementation of the improvements proposed in this planning study, as this planning report should constitute the outcome of this step. However, in general, the purpose of this implementation step is for the project proponent to identify issues, impacts, and approvals that may need to be obtained, so that the subsequent design and permitting processes are understood.

The level of planning needed will vary widely, based on the complexity of the project. Typical tasks include: define the existing context, confirm project need, establish goals and objectives, initiate public outreach, define the project, collect data, develop and analyze alternatives, make recommendations, and provide documentation. Likely outcomes include consensus on the project definition to enable it to move forward into environmental documentation (if needed) and design, or a recommendation to delay the project or dismiss it from further consideration.

3 PROJECT INITIATION

At this point in the process, the proponent, MassDOT Highway Division, fills out, for each improvement, a Project Initiation Form (PIF), which is reviewed by its Project Review Committee (PRC) and the MPO. The PRC is composed of the Chief

Engineer, each District Highway Director, and representatives of the Project Management, Environmental, Planning, Right-of-Way, Traffic, and Bridge departments, and the Capital Expenditure Program Office (CEPO). The PIF documents the project type and description, summarizes the project planning process, identifies likely funding and project management responsibility, and defines a plan for interagency and public participation. First the PRC reviews and evaluates the proposed project based on the Executive Office of Transportation and Public Works's statewide priorities and criteria. If the result is positive, MassDOT Highway Division moves the project forward to the design phase, and to programming review by the MPO. The PRC may provide a Project Management Plan to define roles and responsibilities for subsequent steps. The MPO review includes project evaluation based on the MPO's regional priorities and criteria. The MPO may assign project evaluation criteria score, a Transportation Improvement Program (TIP) year, a tentative project category, and a tentative funding category.

4 ENVIRONMENTAL, DESIGN, AND RIGHT-OF-WAY PROCESS

This step has four distinct but closely integrated elements: public outreach, environmental documentation and permitting (if required), design, and right-of-way acquisition (if required). The outcome of this step is a fully designed and permitted project ready for construction. However, a project does not have to be fully designed in order for the MPO to program it in the TIP.

5 PROGRAMMING

Programming, which typically begins during the design phase, can actually occur at any time during the process, from planning to design. In this step, which is distinct from project initiation, where the MPO receives preliminary information on the proposed project, the proponent requests that the MPO place the project in the region's TIP. The MPO considers the project in terms of regional needs, evaluation criteria, and compliance with the regional Transportation Plan and decides whether to place it in the draft TIP for public review and then in the final TIP.

6 PROCUREMENT

Following project design and programming, MassDOT Highway Division publishes a request for proposals. It then reviews the bids and awards the contract to the qualified bidder with the lowest bid.

7 CONSTRUCTION

After a construction contract is awarded, MassDOT Highway Division and the contractor develop a public participation plan and a management plan for the construction process.

8 PROJECT ASSESSMENT

The purpose of this step is to receive constituents’ comments on the project development process and the project’s design elements. MassDOT Highway Division can apply what is learned in this process to future projects.

MEMORANDUM

To: **Donald N. Onusseit** **February 17, 2011**
Wilmington Public Works Superintendent

From: **Chen-Yuan Wang and Efi Pagitsas**

Re: **Safety and Operations Analyses at Selected Boston Region MPO Intersections: Lowell Street (Route 129) at Woburn Street in Wilmington**

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersection of Lowell Street (Route 129) at Woburn Street in Wilmington. It contains the following sections:

- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Analyses of Improvement Alternatives
- Improvement Recommendations and Discussion

The memorandum also includes a collection of technical appendices that contain methods and data applied in the study and detailed reports of the intersection capacity analysis.

INTERSECTION LAYOUT AND TRAFFIC CONTROL

This signalized intersection is located in the southeastern section of Wilmington and about half a mile west of Interstate 93 (I-93) Exit 38. Lowell Street, a two-lane roadway running in the east-west direction, is the major street of the intersection. It is a part of State Route 129, a principal arterial in eastern Massachusetts that runs through several communities north of Boston from Marblehead in the east to Chelmsford in the west.[1] Woburn Street, the minor street of the intersection, is a two-lane urban minor arterial. It runs from the Wilmington/Woburn border, through this intersection, to the northern section of the town. It connects Route 38 (via Eames Street) in the south and I-93 (via Concord Street), Route 62, and Route 125 (via Andover Street) in the north.

Figure 1 shows the intersection layout and the area nearby. Both approaches of Lowell Street remain a single lane shared by all movements, with a slightly flared area near the intersection in the eastbound direction. Both approaches of Woburn Street also remain a single lane shared by all movements, with a slightly flared area near the intersection in the northbound direction.

[1] Along the way, Route 129 connects Route 1, Interstate 95 (I-95)/Route 128, Route 28, I-93, Route 38, Route 62, and Route 3.

CTPS

FIGURE 1
Lowell Street (Route 129) at Woburn Street, Wilmington

Safety and Operations Improvements at Selected Intersections

There are crosswalks, apparently newly installed and with appropriate curb ramps, across the westbound and the northbound approaches. Sidewalks exist on all corners of the intersection except the northwest corner. They continue on both sides of Lowell Street in the shopping area east of the intersection, but discontinue further east and west of the intersection. On the other hand, Woburn Street has a sidewalk continuously on its west side.

The traffic signal is pre-timed and operates in two traffic phases: (1) eastbound/westbound (EB/WB) all movements (left turns permitted), and (2) northbound/southbound (NB/SB) all movements (left turns permitted). Stopwatch measurements at the intersection indicate that the traffic signal cycle is fixed at about 72 seconds (41 seconds for the EB/WB phase and 31 seconds for the NB/SB phase, including a 6-second clearance time for each phase). The signal control also includes an on-call exclusive pedestrian phase that lasts about 24 seconds. Pedestrian signal heads with push buttons are located at both ends of the two existing crosswalks. Although there is a push button on the northwest corner, there are no pedestrian signal indications for crossing either street from the corner. Right turns on red are allowed on all approaches.

All the signal heads are post-mounted and positioned about 10 to 12 feet high. They are located on the four corners of the intersection and provide each approach with at least two signal indications. Recently the town added a third signal indication to the southbound approach to improve the drivers' view from the curving section of Woburn Street north of the intersection. In the same project (2008), the town upgraded the signal indications from 8-inch incandescent to 12-inch LED (light-emitting diode), and redirected and/or relocated several signal heads (see Appendix A). However, the upgrade was an interim improvement under a limited budget. The signal system is still not actuated by approaching traffic. The post-mounted signals are visible from the Woburn Street approaches, but they are not obvious from the wider and faster Lowell Street approaches because of their low height.

The land uses in the vicinity of the intersection are single-family residences mixed with commercial developments and office parks. At the intersection, the southwest corner is an open area own by the Town, and the northwest corner is a large parking lot for school buses. East of the intersection, both sides of Lowell Street are shopping plazas that consist of a supermarket and several retail shops and offices. Further east on Lowell Street there are mainly single-family houses just before Lowell Street reaches I-93. West of the intersection, a major corporation's office park is located on the south side and several commercial developments are on the north side of Lowell Street. Further west on Lowell Street are open parklands and scattered single-family houses just before its intersection with Route 38.

North of the intersection, both sides of Woburn Street are mainly residential areas. South of the intersection, there are single-family houses on both sides of Woburn Street for about half a mile. Further south, Woburn Street reaches a major industrial and office park area that spans the Wilmington/Woburn border between I-93 and Route 38.

Lowell Street (Route 129) in the vicinity of the intersection has a speed limit of 40 miles per hour (MPH). It is reduced to 25 MPH in both directions about 300 feet (EB) and 500 feet (WB) ahead of the intersection. Woburn Street in the vicinity of the intersection has a speed limit of 30 MPH. It is reduced to 20 MPH in both directions about 300 feet (NB) and 400 feet (SB) ahead of the intersection. There is a speed limit sign of 45 MPH in the WB direction just past the intersection, which appears to be abrupt and inconsistent with other sections of Route 129 in the area.

ISSUES AND CONCERNS

A review of the recent crash data from 2006 to 2008 indicates that the intersection has a high number of crashes and a crash rate much higher than other signalized intersections in the area (see the next section for further analysis).

The intersection is congested during peak periods on almost all approaches, depending on the peak direction. As a principal arterial in the region, Lowell Street has heavy traffic in both directions during peak periods. Traffic frequently backs up in the westbound direction in the AM peak hour and in the eastbound direction in the PM peak hour. On Woburn Street, traffic is heavy on the SB approach in the AM peak hour and on the NB approach in the PM peak hour.

Given the incapability of adapting to traffic demand, the pre-timed signals appear to operate effectively during the peak periods. However, they may not operate effectively in the off-peak periods, as the signals would idle in green lights when the designated street is already clear.[2] Sometimes drivers waiting at the intersection may be confused by the late signal responses and behave aggressively. A fully actuated traffic signal system would operate effectively in all time periods.

The issues and concerns for this intersection can be summarized as follows:

- High number of crashes and high crash rate at the intersection
- Outdated traffic signal system, not actuated by traffic demand
- No crosswalk connecting the sidewalks on the west side of Woburn Street across the intersection
- Traffic congestion during peak hours, especially on Lowell Street

CRASH DATA ANALYSIS

Based on the 2006–2008 MassDOT Registry of Motor Vehicles Division crash data, Table 1 shows that on average nearly 20 crashes occurred at the intersection each year. About one-third (36%) of the total crashes resulted in personal injuries. The crash types consist of over 60% angle collisions, over 20% rear-end collisions, nearly 15% of single-vehicle collisions, and about 5% other types (one single vehicle crash and one unknown). About 20% of the total crashes occurred during weekday peak periods. About 15% of the total crashes occurred in wet or icy conditions. Over 15% of the total crashes occurred in dark conditions.

Crash rate[3] is another effective tool for examining the relative safety of a particular location. Based on the above data and the recently collected traffic volume data, the crash rate for this intersection is calculated as 2.12 (see Appendix B for the calculation sheet). The rate is much

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[2] Field observations during off-peak periods on a Saturday and a Monday indicate quite a few such occasions.

[3] Crash rates normalize crash frequency (crashes per year) by vehicle exposure (traffic volumes or miles traveled). Crash rates are expressed as "crashes per million entering vehicles" for intersection locations and as "crashes per million miles traveled" for roadway segments.

higher than the average rate for the signalized locations in MassDOT Highway Division's District 4, which is estimated to be 0.78.[4]

TABLE 1
Summary of Crash Data (2006–2008)

Statistics Period		2006	2007	2008	2006–08	Average
Total number of crashes		22	16	21	59	20
Severity	**Property damage only**	8	9	13	30	10
	Personal injury	10	5	6	21	7
	Fatality	0	0	0	0	0
	Not reported	4	2	2	8	3
Collision Type	**Angle**	14	15	8	37	12
	Rear-end	3	1	9	13	4
	Sideswipe	4	1	3	8	3
	Head-on	0	0	0	0	0
	Single vehicle	1	0	0	1	0
	Not reported	0	0	1	1	0
Crashes involving pedestrian(s)		0	0	0	0	0
Crashes involving cyclist(s)		0	0	0	0	0
Occurred during weekday peak periods*		5	3	4	12	4
Wet or icy pavement conditions		4	1	3	8	3
Dark/lighted conditions		5	3	2	10	3

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

INTERSECTION CAPACITY ANALYSIS

Staff collected turning-movement counts at the intersection on May 19, 2010. The data were recorded in 15-minute intervals for the peak traffic periods in the morning, from 7:00 to 9:00, and in the evening, from 4:00 to 6:00. The intersection carried about 2,050 vehicles in the morning peak hour, from 7:00 to 8:00, and about 2,300 vehicles in the evening peak hour, from 5:00 to 6:00 (see Table 2). About 3 pedestrians and 1 pedestrian were observed during the AM peak hour and the PM peak hour, respectively. No bicyclists were observed in either the AM or the PM peak hour.[5]

Based on the turning-movement counts and the signal timings measured at the site, the intersection capacity was analyzed using an intersection capacity analysis program, Synchro.[6] The program indicated that the intersection operates at an overall level of service (LOS) E with an average delay of over one minute per vehicle in both the AM and PM peak hours (see Table

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[4] The average crash rates estimated by the MassDOT Highway Division are based upon a database that contains intersection crash rates submitted to the Highway Division as part of a review process for an environmental impact report or functional design report. The most recent average crash rates, which are updated on a nearly yearly basis, are based on all entries in the database, not just those entries made within the past year.

[5] It was raining lightly in the AM peak hour and heavily in the PM peak hour.

[6] Synchro is developed and distributed by Trafficware, Ltd. It can perform capacity analysis and traffic simulation (when combined with SimTraffic) for an individual intersection or a series of intersections.

3). The level-of-service criteria are based on the Highway Capacity Manual 2000.[7] Detailed analysis settings and results for both the AM and PM peak hour are included in Appendix C.

TABLE 2
AM and PM Peak-Hour Traffic Volumes and Pedestrian Crossings

Street name		**Lowell Street**						**Woburn Street**						**Total**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	Turning volume	24	606	140	123	378	33	39	59	52	134	392	72	2050
	Approach volume	770			532			150			598			
	Pedestrian crossings	0			0			1			2			3
PM peak hour	Turning volume	85	665	82	52	470	124	101	342	138	75	92	65	2291
	Approach volume	832			646			581			232			
	Pedestrian crossings	0			0			0			1			1

TABLE 3
Intersection Capacity Analysis, Existing Conditions

Street name		**Lowell Street**						**Woburn Street**						**Overall**
Direction		**Eastbound**			**Westbound**			**Northbound**			**Southbound**			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	LOS	**D**			**F**			**C**			**F**			**E**
	Delay (sec/veh)	41			117			21			91			74
PM peak hour	LOS	**F**			**C**			**F**			**C**			**E**
	Delay (sec/veh)	103			34			83			33			71

As the analysis shows, traffic on the WB approach endures extensive delays in the AM peak hour, as the WB left turns were frequently deterred by the heavy EB through traffic and block the entire approach. In the PM peak, the same situation occurs in the opposite direction and traffic on the EB approach endures extensive delays. On Woburn Street, traffic on the SB approach endures noticeable delays in the AM peak hour and traffic on the NB approach endures noticeable delays in the PM peak hour.

ANALYSES OF IMPROVEMENT ALTERNATIVES

To improve traffic operations at this intersection, we examined a number of traffic signal and geometric design strategies. The analyses were performed progressively, from simple to more involved modifications in the improvement alternatives. As mentioned earlier, the intersection capacity was evaluated using the Synchro optimization and simulation software.

A basic assumption for all the alternatives is a fully actuated traffic signal system with pedestrian signal heads and push buttons in place of the existing outdated system. With the actuated signal

[7] Transportation Research Board, *Highway Capacity Manual 2000*, National Research Council, Washington D.C., 2000.

system, the traffic signal cycle length was extended from the existing 72 seconds to 80 seconds in order to reduce the time lost to signal changing during peak hours. An on-call exclusive pedestrian phase of 24 seconds was also assumed for all the alternatives. The alternatives tested for this intersection include:

1) Operate the upgraded signal system under the existing intersection layout and phasing sequence (two-phase EB/WB and NB/SB operation with left turns permitted)
2) Add an exclusive RT (right-turn) lane on the EB approach, and operate the upgraded signal system under the existing phasing sequence
3) Add an exclusive LT (left-turn) lane on both EB/WB approaches, and put in a protected/permissive LT phase prior to the existing EB/WB phase
4) Add an exclusive RT (right-turn) lane on the EB approach and an exclusive LT (left-turn) lane on both EB/WB approaches, and incorporate a protected/permissive EB/WB LT phase
5) Add an exclusive LT (left-turn) lane on both NB/SB approaches, and put in a protected/permissive LT phase prior to the existing NB/SB phase

Table 4 summarizes the intersection capacity analyses for the six alternatives. Detailed analysis settings and results for both the AM and PM peak hours for the alternatives are included in Appendices D to H separately. As Table 4 shows, traffic operations at the intersection would be improved noticeably by simply upgrading the signal system (Alternative 1), especially the operations on Lowell Street.

Alternative 2 was developed in an attempt to utilize the open space in the southwest quadrant to address the relatively high EB right-turn volume in the peak hours. However, Synchro tests show that it would not improve, but rather deteriorate, traffic operations on all other approaches, except the EB approach itself. Ironically, adding the EB-RT lane would facilitate traffic flow on the EB approach, which it in turn would seriously deter the WB left turns and consequently impede traffic on the entire WB approach.

Adding an LT lane on both the EB and WB approaches (Alternative 3) would improve the intersection traffic operations significantly in the PM peak hour, but only marginally in the AM peak hour. The EB approach in the AM peak hour would inversely deteriorate because the high EB through and right-turn traffic would still share a lane, with limited green time (less than the simple two-phase operation in Alternative 1) in each traffic cycle.

With the available space in the southwest quadrant, Alternative 4 (adding an EB-LT lane on top of Alternative 3) was a logical next option to pursue. Synchro tests show that it would significantly improve traffic operations at the intersection in both the AM and PM peak hours. All the approaches would operate at a desirable LOS C or LOS D in the peak hours, except the SB approach in the AM peak hour (acceptable LOS E).

Alternative 5 (adding a LT lane on the NB and SB approaches) was developed to test if it can shift some NB/SB phase time to the EB/WB phase and maintain the existing EB/WB layout. The expansion appears to be feasible by using the open space/parking lot in the southwest/northwest quadrant and realigning Woburn Street slightly to the west. Synchro tests show that it would achieve similar but slightly less significant improvement than Alternative 4. Especially in the PM peak hour, it would not improve the congested EB and NB approaches to a desirable LOS C or

LOS D as Alternative 4 would. In terms of safety benefits, Alternative 4 would be more beneficial than Alternative 5, as the LT pockets are placed on the higher volume and higher speed Lowell Street.

TABLE 4
Intersection Capacity Analyses of Improvement Alternatives

Street name		**Lowell Street**		**Woburn Street**		**Overall**
Approach		**Eastbound**	**Westbound**	**Northbound**	**Southbound**	
AM peak hour	Existing	D/41	F/117	C/21	F/91	E/74
	Alternative 1	C/29	D/50	C/23	F/110	E/58
	Alternative 2	B/15	F/91	C/27	F/170	F/81
	Alternative 3	E/70	C/32	C/22	F/95	E/64
	Alternative 4	D/37	C/35	B/19	E/60	D/42
	Alternative 5	C/26	D/40	C/24	E/78	D/45
PM peak hour	Existing	F/103	C/34	F/83	C/33	E/71
	Alternative 1	E/63	C/27	F/81	C/33	D/54
	Alternative 2	C/25	E/66	F/158	E/57	E/73
	Alternative 3	D/48	C/33	E/64	C/30	D/46
	Alternative 4	C/34	C/35	D/55	C/28	D/39
	Alternative 5	E/56	C/26	E/78	C/29	D/50

Note Performance measures: Level of Service (A to F)/Average Delay (seconds per vehicle)
Alternative 1: Operate the upgraded signal system under the existing intersection layout and phasing sequence
Alternative 2: Add an EB-RT, and operate the upgraded signal system under the existing phasing sequence
Alternative 3: Add a LT lane on EB/WB approaches, and add a protected/permissive EB/WB LT phase in each traffic cycle
Alternative 4: Add an EB-RT lane and add a LT lane on EB/WB approaches, and add a protected/permissive EB/WB LT phase in each traffic cycle
Alternative 5: Add a LT lane on NB/SB approaches, and add a protected/permissive NB/SB LT phase in the traffic cycle

The above analyses indicate that simply upgrading to a fully actuated signal system with no major geometry modifications (Alternative 1) would noticeably improve traffic operations at the intersection. Alternative 4 would be most beneficial among the alternatives with intersection layout modifications. At this preliminary planning stage, it appears that Alternative 4 is potential by using the open space in the southwest quadrant and rearranging and realigning Lowell Street layout within its right-of-way or with a slight expansion.[8]

In addition, a future-year scenario of 10% growth over a 20-year planning horizon was tested for the two alternatives.[9] Synchro tests show that under the 2030 projected traffic conditions Alternative 1 would deteriorate to LOS F with an average delay of about one and half minutes in both the AM and PM peak hours. With the expanded intersection capacity, Alternative 4 would operate at acceptable LOS E with an average delay of slightly less than a minute in both the AM and PM peak hours under the projected traffic conditions. Meanwhile, not shown in the capacity

[8] The State Road Inventory File indicates that Lowell Street in the intersection vicinity has a surface width of 26 feet with a right-of-way (ROW) width of 60 feet. Adding an 11-foot wide LT lane appears to be potential within the ROW. If it requires some land takings, it would be minimal and would not affect private homes.

[9] The growth assumption is based on a review of the traffic projections at the intersection from the Boston Region MPO transportation-planning model.

analyses, Alternative 4 would be more beneficial than Alternative 1 in terms of traffic safety as it reduces traffic congestion and provides waiting space for left turns on Lowell Street.

IMPROVEMENT RECOMMENDATIONS AND DISCUSSION

The intersection has a high number of crashes and a crash rate much higher than other signalized intersections in the area. The above safety and operations analyses identified a number of deficiencies related to the existing signal system and the intersection layout. Meanwhile, the intersection is congested during the AM and PM peak hours. To improve traffic operations, the study examined a number of traffic signal and geometric design strategies.

The improvement alternatives were developed and analyzed progressively from simple to more involved modifications of the intersection layout. The alternatives tested for this intersection include:

1) Operate the upgraded signal system under the existing intersection layout and phasing sequence
2) Add an exclusive RT lane on the EB approach, and operate the upgraded signal system under the existing phasing sequence
3) Add an exclusive LT lane on both EB/WB approaches, and put in a protected/permissive LT phase prior to the existing EB/WB phase
4) Add an exclusive EB-RT lane and an exclusive LT lane on both EB/WB approaches, and incorporate a protected/permissive EB/WB LT phase
5) Add an exclusive LT lane on both NB/SB approaches, and put in a protected/permissive LT phase prior to the existing NB/SB phase

The analyses found that simply upgrading to a fully actuated signal system (Alternative 1) would noticeably improve traffic operations at the intersection. Adding an EB-RT lane and adding a LT lane on both the EB and WB approaches (Alternative 4) would be most beneficial in terms of traffic operations and safety among all the alternatives. At this preliminary planning stage, it appears that the expansion is feasible by using the open space in the southwest quadrant and rearranging and realigning the Lowell Street layout within its right-of-way or with a slight expansion.

The study also examined the two alternatives under projected traffic conditions in 2030 and found that in Alternative 1 the level of service would deteriorate to LOS F, with extensive delays on almost all the approaches in peak hours. In Alternative 4, traffic would operate at acceptable LOS E, with acceptable delays (as an urban intersection) under the projected traffic conditions.

The choice of Alternative 1 or Alternative 4 depends on the feasibility of the intersection expansion, which should be further examined in the functional design stage. At this preliminary planning stage, it appears that Alternative 4 could potentially be implemented, by using the open space (owned by the town) in the southwest quadrant and rearranging and realigning the Lowell Street layout within its right-of-way or with a slight expansion.

The most essential improvement for this intersection is to upgrade the outdated signal system. The new signal system should include the following major features:

- Install a fully actuated traffic signal system with necessary equipment update

- Replace the existing post-mounted signals with overhead signal indications supported by mast arms, which can be clearly viewed on all approaches from a distance
- Install crosswalks and curb cuts/ramps on the eastbound and the southbound approaches
- Install a staging area for pedestrians at the northwest corner of the intersection[10]
- Include pre-emption function for emergency vehicles to pass through the intersection
- Install accessible (audible) countdown pedestrian signals

If Alternative 4 is found feasible in the functional design stage, the following features should be considered:

- Install sufficient storage space, at least 150 feet, for EB/WB left turns
- Channelize EB-RT lane to reduce traffic conflicts and shorten pedestrian crossing distance
- Provide sufficient shoulders on both streets for bikes

The entire section of Route 129 from Route 38 to Woburn Street (not including this intersection) was recently rehabilitated. The intersection of Route 129 at Route 38 and a few other locations in the section were reconstructed and upgraded with new overhead signals. As a major intersection on Route 129 in the area, this intersection should also be reconstructed and upgraded with a fully actuated signal system and overhead signal indications. Currently the intersection and its adjacent streets are under the jurisdiction of the Town of Wilmington. This study provides a basis for the Town to proceed with functional designs for this intersection. The Town should also work closely with MassDOT Highway District 4 for the implementation of the proposed improvements (see Appendix I for the MassDOT project implantation process).

In the immediate term, three minor improvements can be considered for the intersection. First, the speed limit sign of 45 MPH in the WB direction just past the intersection should be changed to 40 MPH and moved somewhat further away from the intersection. Second, the 25 MPH speed limit sign on the eastbound approach is too close to the intersection and should be moved about 200 feet further west.

Third, a traffic speed study for all the approaches at the intersection should be performed to examine the potential of reducing the signal clearance (yellow plus all-red time) interval from 6 seconds to 5 seconds. Synchro tests show that the clearance interval reduction would noticeably improve the intersection capacity even under the existing pretimed operation. However, it is essential to make certain that the 5-second clearance interval is sufficient for vehicles to stop or pass through the intersection safely from all approaches.

This study performed calculations with the assumption of a prevailing traffic speed 10 MPH higher than the posted speed limit on both streets and found that a 5-second clearance interval should be sufficient for this intersection under the assumed approaching speeds (see Appendix I for further discussion and detailed calculations). Most importantly, before adopting the change the Town should perform a traffic speed study (or hire a certified consultant) to validate that the prevailing speed (85th percentile speed) is not higher than 35 MPH on Lowell Street and is not higher than 30 MPH on Woburn Street.

---

[10] The installation of the crosswalks and the staging area would provide pedestrians a direct connection between the sidewalks on Woburn Street across the intersection and increase pedestrian safety.

Appendix A

Intersection Signal Improvements Project (Proposed May 2008)
Lowell Street at Woburn Street, Wilmington

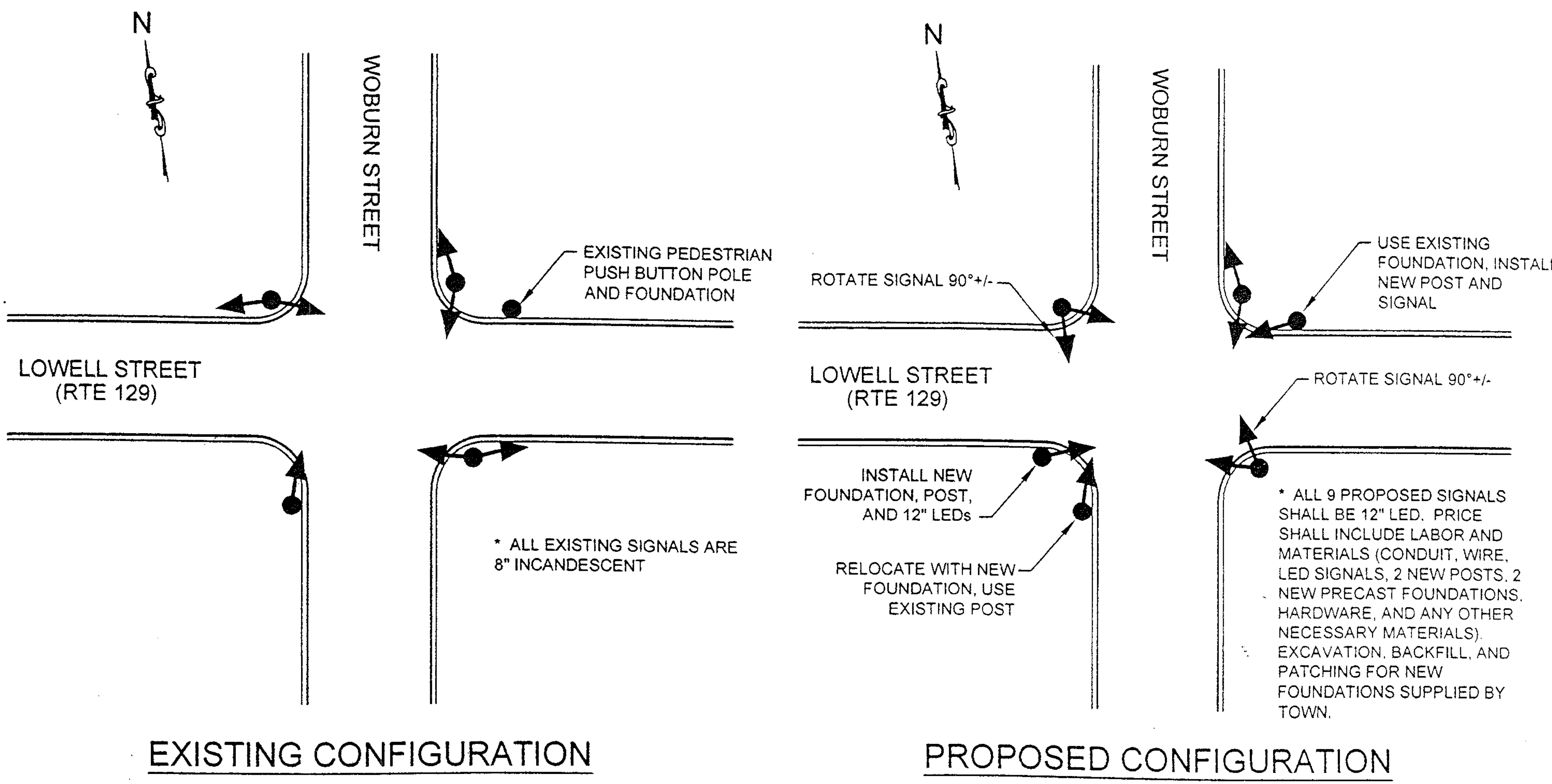


FIGURE 1 - INTERSECTION CONFIGURATION

Appendix B

Intersection Crash Rate Calculation
Lowell Street at Woburn Street, Wilmington

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Wilmington | COUNT DATE : 5/19/10

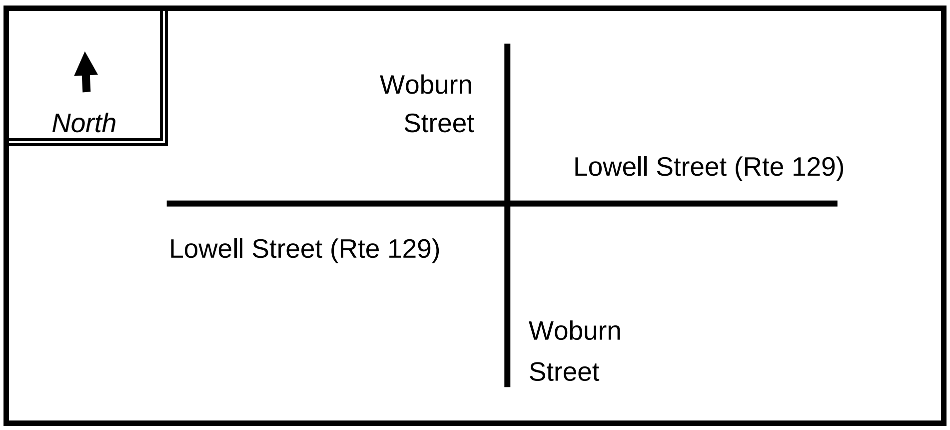
DISTRICT : 4 | UNSIGNALIZED : | SIGNALIZED : X

~ INTERSECTION DATA ~

MAJOR STREET : Lowell Street (Route 129)

MINOR STREET(S) : Woburn Street

INTERSECTION DIAGRAM
(Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	**1**	**2**	**3**	**4**	**5**	**Total Peak Hourly Approach Volume**
DIRECTION :	EB	WB	NB	SB		
PEAK HOURLY VOLUMES (AM/PM) :	832	646	581	232		**2,291**

" K " FACTOR : **0.090**

INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **25,456**

TOTAL # OF CRASHES : 59

OF YEARS : 3

AVERAGE # OF CRASHES PER YEAR (**A**) : **19.67**

CRASH RATE CALCULATION : **2.12**

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

Comments : MassDOT District 4 Average Rate = 0.78

Project Title & Date: Safety and Operations Analyses at Selceted Intersections

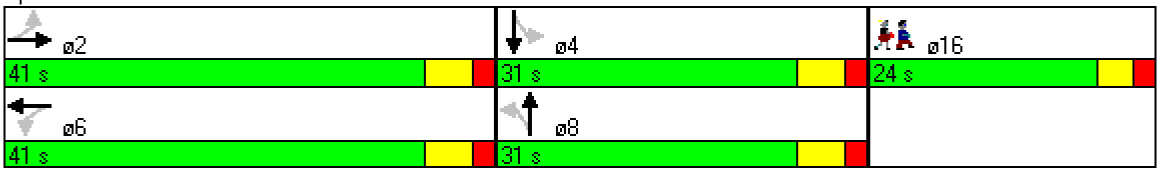
Appendix C

AM/PM Peak Hour Intersection Capacity Analysis
Existing Traffic Conditions
Lowell Street at Woburn Street, Wilmington

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	24	641	147	130	405	33	41	63	55	142	415	76
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	5%	5%	5%	9%	9%	9%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	20.0	20.0		20.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	41.0	41.0	0.0	41.0	41.0	0.0	31.0	31.0	0.0	31.0	31.0	0.0
Total Split (%)	42.7%	42.7%	0.0%	42.7%	42.7%	0.0%	32.3%	32.3%	0.0%	32.3%	32.3%	0.0%
Yellow Time (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	6.0	6.0	4.0	6.0	6.0	4.0	6.0	6.0	4.0	6.0	6.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		Max	Max		Max	Max	
Act Effct Green (s)		35.3			35.3			25.2			25.2	
Actuated g/C Ratio		0.46			0.46			0.33			0.33	
v/c Ratio		0.99			1.32			0.40			1.16	
Control Delay		50.8			181.2			21.3			115.5	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		50.8			181.2			21.3			115.5	
LOS		D			F			C			F	
Approach Delay		50.8			181.2			21.3			115.5	
Approach LOS		D			F			C			F	

Intersection Summary	
Cycle Length: 96	
Actuated Cycle Length: 76	
Natural Cycle: 150	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 1.32	
Intersection Signal Delay: 101.6	Intersection LOS: F
Intersection Capacity Utilization 130.5%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 1: Int



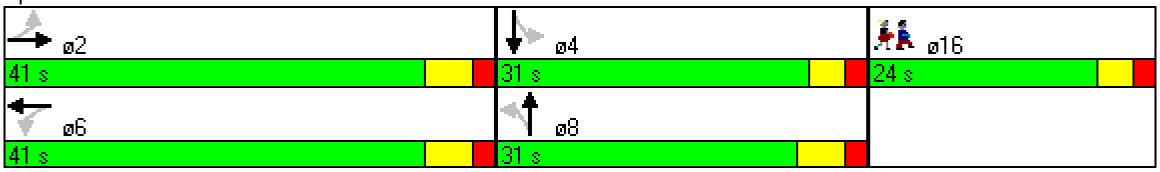
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	25%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	89	691	85	54	488	129	105	356	144	79	96	68
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	20.0	20.0		20.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	41.0	41.0	0.0	41.0	41.0	0.0	31.0	31.0	0.0	31.0	31.0	0.0
Total Split (%)	42.7%	42.7%	0.0%	42.7%	42.7%	0.0%	32.3%	32.3%	0.0%	32.3%	32.3%	0.0%
Yellow Time (s)	4.0	4.0		4.0	4.0		4.0	4.0		3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	6.0	6.0	4.0	6.0	6.0	4.0	6.0	6.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Max	Max		Max	Max		Max	Max		Max	Max	
Act Effct Green (s)		35.3			35.3			25.2			26.3	
Actuated g/C Ratio		0.46			0.46			0.33			0.35	
v/c Ratio		1.21			0.92			1.12			0.66	
Control Delay		129.7			39.2			101.7			31.1	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		129.7			39.2			101.7			31.1	
LOS		F			D			F			C	
Approach Delay		129.7			39.2			101.7			31.1	
Approach LOS		F			D			F			C	

Intersection Summary	
Cycle Length: 96	
Actuated Cycle Length: 76	
Natural Cycle: 150	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 1.21	
Intersection Signal Delay: 87.1	Intersection LOS: F
Intersection Capacity Utilization 112.8%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 1: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	25%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

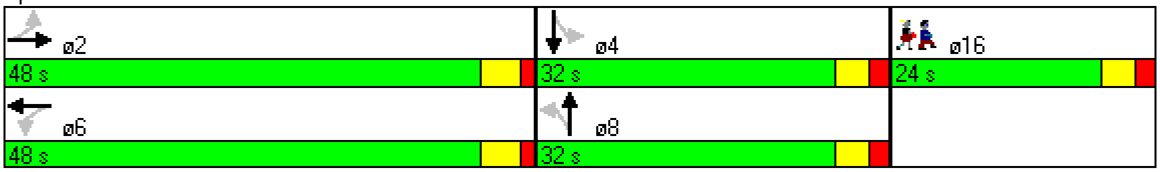
Appendix D

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 1
Upgrade Signal System with Existing Layout and Phasing Sequence
Lowell Street at Woburn Street, Wilmington

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	24	606	140	123	378	31	39	59	52	134	392	72
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	5%	5%	5%	9%	9%	9%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	20.0	20.0		20.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	48.0	48.0	0.0	48.0	48.0	0.0	32.0	32.0	0.0	32.0	32.0	0.0
Total Split (%)	46.2%	46.2%	0.0%	46.2%	46.2%	0.0%	30.8%	30.8%	0.0%	30.8%	30.8%	0.0%
Yellow Time (s)	3.5	3.5		3.5	3.5		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Min	Min		Min	Min		None	None		None	None	
Act Effct Green (s)		43.3			43.3			27.2			27.2	
Actuated g/C Ratio		0.52			0.52			0.32			0.32	
v/c Ratio		0.84			0.95			0.38			1.14	
Control Delay		28.8			49.7			23.1			110.1	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		28.8			49.7			23.1			110.1	
LOS		C			D			C			F	
Approach Delay		28.8			49.7			23.1			110.1	
Approach LOS		C			D			C			F	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.14	
Intersection Signal Delay: 57.6	Intersection LOS: E
Intersection Capacity Utilization 121.9%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 1: Int



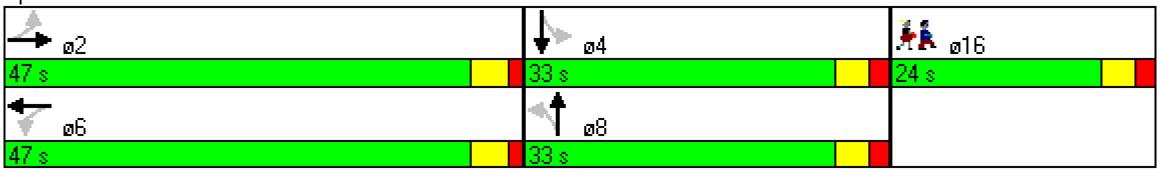
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	85	665	82	52	470	129	101	342	138	75	92	65
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	20.0	20.0		20.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	47.0	47.0	0.0	47.0	47.0	0.0	33.0	33.0	0.0	33.0	33.0	0.0
Total Split (%)	45.2%	45.2%	0.0%	45.2%	45.2%	0.0%	31.7%	31.7%	0.0%	31.7%	31.7%	0.0%
Yellow Time (s)	3.5	3.5		3.5	3.5		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Min	Min		Min	Min		None	None		None	None	
Act Effct Green (s)		42.3			42.3			28.2			28.2	
Actuated g/C Ratio		0.50			0.50			0.34			0.34	
v/c Ratio		1.03			0.79			1.05			0.65	
Control Delay		62.7			27.1			80.9			33.3	
Queue Delay		0.0			0.0			0.0			0.0	
Total Delay		62.7			27.1			80.9			33.3	
LOS		E			C			F			C	
Approach Delay		62.7			27.1			80.9			33.3	
Approach LOS		E			C			F			C	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.05	
Intersection Signal Delay: 54.2	Intersection LOS: D
Intersection Capacity Utilization 107.2%	ICU Level of Service G
Analysis Period (min) 15	

Splits and Phases: 1: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

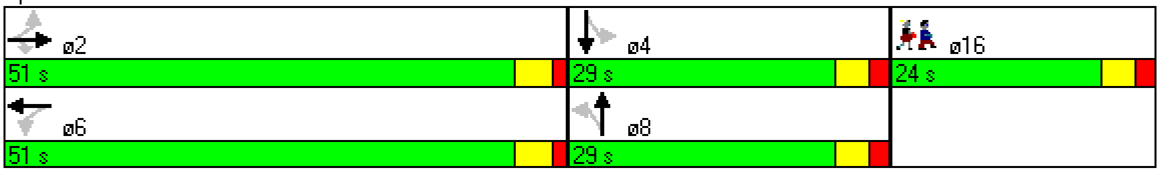
Appendix E

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 2
Add an EB-RT Lane and Operate Traffic Signals with Existing Phasing Sequence
Lowell Street at Woburn Street, Wilmington

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	24	606	140	123	378	31	39	59	52	134	392	72
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	5%	5%	5%	9%	9%	9%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm		Perm	Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2		2	6			8			4		
Detector Phase	2	2	2	6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0	4.0	4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	20.0	20.0	20.0	20.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	51.0	51.0	51.0	51.0	51.0	0.0	29.0	29.0	0.0	29.0	29.0	0.0
Total Split (%)	49.0%	49.0%	49.0%	49.0%	49.0%	0.0%	27.9%	27.9%	0.0%	27.9%	27.9%	0.0%
Yellow Time (s)	3.5	3.5	3.5	3.5	3.5		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5	1.5	1.5	1.5		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Min	Min	Min	Min	Min		None	None		None	None	
Act Effct Green (s)		46.4	46.4		46.4			24.2			24.2	
Actuated g/C Ratio		0.55	0.55		0.55			0.29			0.29	
v/c Ratio		0.64	0.16		1.10			0.45			1.28	
Control Delay		18.0	2.8		90.9			27.1			170.2	
Queue Delay		0.0	0.0		0.0			0.0			0.0	
Total Delay		18.0	2.8		90.9			27.1			170.2	
LOS		B	A		F			C			F	
Approach Delay		15.2			90.9			27.1			170.2	
Approach LOS		B			F			C			F	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.28	
Intersection Signal Delay: 81.0	Intersection LOS: F
Intersection Capacity Utilization 113.4%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 1: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

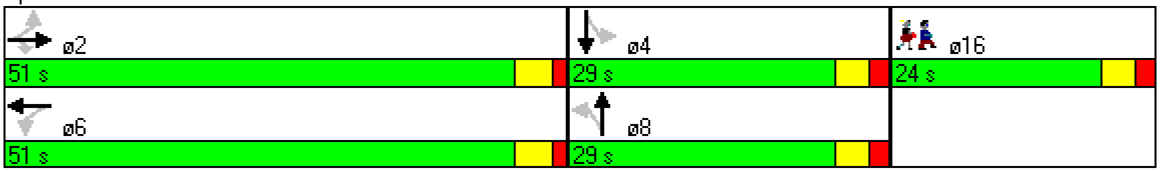
Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	85	665	82	52	470	129	101	342	138	75	92	65
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm		Perm	Perm			Perm			Perm		
Protected Phases		2			6			8			4	
Permitted Phases	2		2	6			8			4		
Detector Phase	2	2	2	6	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0	4.0	4.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	20.0	20.0	20.0	20.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	51.0	51.0	51.0	51.0	51.0	0.0	29.0	29.0	0.0	29.0	29.0	0.0
Total Split (%)	49.0%	49.0%	49.0%	49.0%	49.0%	0.0%	27.9%	27.9%	0.0%	27.9%	27.9%	0.0%
Yellow Time (s)	3.5	3.5	3.5	3.5	3.5		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5	1.5	1.5	1.5		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	Min	Min	Min	Min	Min		None	None		None	None	
Act Effct Green (s)		46.4	46.4		46.4			24.2			24.2	
Actuated g/C Ratio		0.55	0.55		0.55			0.29			0.29	
v/c Ratio		0.83	0.09		1.04			1.25			0.86	
Control Delay		26.8	4.2		66.4			158.0			56.8	
Queue Delay		0.0	0.0		0.0			0.0			0.0	
Total Delay		26.8	4.2		66.4			158.0			56.8	
LOS		C	A		E			F			E	
Approach Delay		24.6			66.4			158.0			56.8	
Approach LOS		C			E			F			E	

Intersection Summary

Cycle Length: 104
Actuated Cycle Length: 84
Natural Cycle: 150
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 1.25
Intersection Signal Delay: 73.4 Intersection LOS: E
Intersection Capacity Utilization 121.3% ICU Level of Service H
Analysis Period (min) 15

Splits and Phases: 1: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

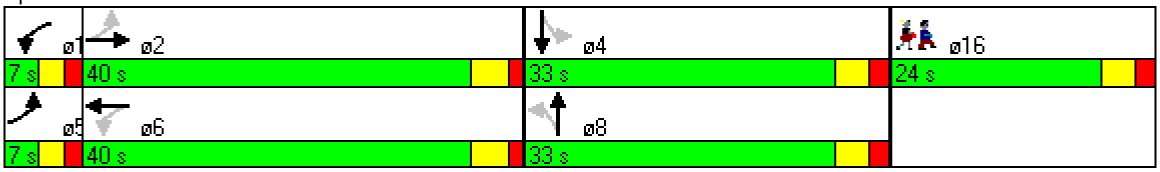
Appendix F

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 3
Add a LT Lane on EB/WB Approaches,
and Add a Protected/Permissive EB/WB LT Phase in Each Traffic Cycle
Lowell Street at Woburn Street, Wilmington

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	24	606	140	123	378	31	39	59	52	134	392	72
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	5%	5%	5%	9%	9%	9%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt			pm+pt			Perm			Perm		
Protected Phases	5	2		1	6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	5	2		1	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	2.0	4.0		2.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	7.0	20.0		7.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	7.0	40.0	0.0	7.0	40.0	0.0	33.0	33.0	0.0	33.0	33.0	0.0
Total Split (%)	6.7%	38.5%	0.0%	6.7%	38.5%	0.0%	31.7%	31.7%	0.0%	31.7%	31.7%	0.0%
Yellow Time (s)	2.5	3.5		2.5	3.5		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag	Lead	Lag		Lead	Lag							
Lead-Lag Optimize?	Yes	Yes		Yes	Yes							
Recall Mode	None	Min		None	Min		None	None		None	None	
Act Effct Green (s)	39.3	35.3		41.8	39.7			28.2			28.2	
Actuated g/C Ratio	0.47	0.42		0.50	0.47			0.34			0.34	
v/c Ratio	0.07	1.05		0.88	0.51			0.36			1.10	
Control Delay	12.9	71.8		69.7	20.4			22.2			95.3	
Queue Delay	0.0	0.0		0.0	0.0			0.0			0.0	
Total Delay	12.9	71.8		69.7	20.4			22.2			95.3	
LOS	B	E		E	C			C			F	
Approach Delay		70.0			31.8			22.2			95.3	
Approach LOS		E			C			C			F	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.10	
Intersection Signal Delay: 64.0	Intersection LOS: E
Intersection Capacity Utilization 98.0%	ICU Level of Service F
Analysis Period (min) 15	

Splits and Phases: 1: Int



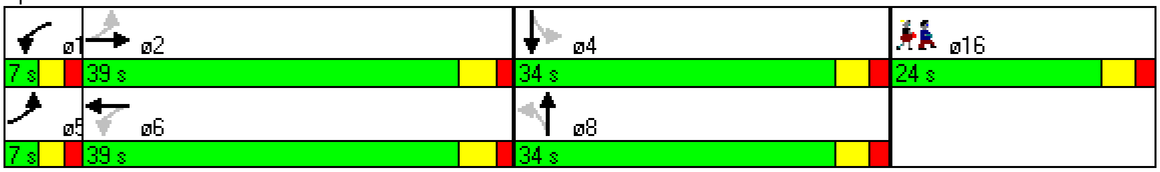
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	85	665	82	52	470	129	101	342	138	75	92	65
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt			pm+pt			Perm			Perm		
Protected Phases	5	2		1	6			8			4	
Permitted Phases	2			6			8			4		
Detector Phase	5	2		1	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	2.0	4.0		2.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	7.0	20.0		7.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	7.0	39.0	0.0	7.0	39.0	0.0	34.0	34.0	0.0	34.0	34.0	0.0
Total Split (%)	6.7%	37.5%	0.0%	6.7%	37.5%	0.0%	32.7%	32.7%	0.0%	32.7%	32.7%	0.0%
Yellow Time (s)	2.5	3.5		2.5	3.5		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	4.0	4.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag	Lead	Lag		Lead	Lag							
Lead-Lag Optimize?	Yes	Yes		Yes	Yes							
Recall Mode	None	Min		None	Min		None	None		None	None	
Act Effct Green (s)	38.6	35.8		37.7	34.4			29.3			29.3	
Actuated g/C Ratio	0.47	0.43		0.46	0.42			0.35			0.35	
v/c Ratio	0.49	0.97		0.35	0.83			0.99			0.60	
Control Delay	25.6	50.9		20.0	34.0			63.6			30.0	
Queue Delay	0.0	0.0		0.0	0.0			0.0			0.0	
Total Delay	25.6	50.9		20.0	34.0			63.6			30.0	
LOS	C	D		B	C			E			C	
Approach Delay		48.3			32.9			63.6			30.0	
Approach LOS		D			C			E			C	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 82.6	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.99	
Intersection Signal Delay: 45.9	Intersection LOS: D
Intersection Capacity Utilization 91.1%	ICU Level of Service F
Analysis Period (min) 15	

Splits and Phases: 1: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

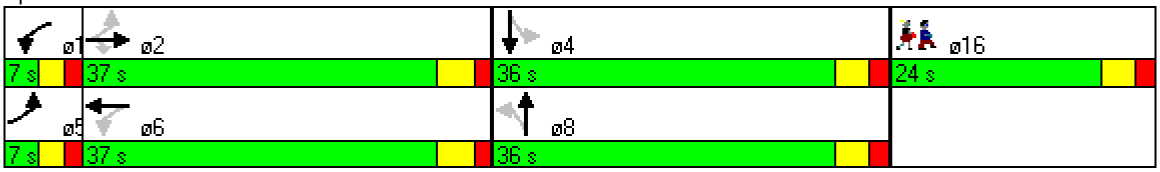
Appendix G

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 4
Add An EB-RT Lane and a LT Lane on EB/WB Approaches, and Add a Protected/Permissive EB/WB LT Phase in Each Traffic Cycle
Lowell Street at Woburn Street, Wilmington

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	24	606	140	123	378	31	39	59	52	134	392	72
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	5%	5%	5%	9%	9%	9%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt		Perm	pm+pt			Perm			Perm		
Protected Phases	5	2		1	6			8			4	
Permitted Phases	2		2	6			8			4		
Detector Phase	5	2	2	1	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	2.0	4.0	4.0	2.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	7.0	20.0	20.0	7.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	7.0	37.0	37.0	7.0	37.0	0.0	36.0	36.0	0.0	36.0	36.0	0.0
Total Split (%)	6.7%	35.6%	35.6%	6.7%	35.6%	0.0%	34.6%	34.6%	0.0%	34.6%	34.6%	0.0%
Yellow Time (s)	2.5	3.5	3.5	2.5	3.5		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5	1.5	1.5	1.5		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	5.0	4.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag	Lead	Lag	Lag	Lead	Lag							
Lead-Lag Optimize?	Yes	Yes	Yes	Yes	Yes							
Recall Mode	None	Min	Min	None	Min		None	None		None	None	
Act Effct Green (s)	36.3	32.3	32.3	38.8	36.7			31.2			31.2	
Actuated g/C Ratio	0.43	0.38	0.38	0.46	0.44			0.37			0.37	
v/c Ratio	0.08	0.91	0.22	0.88	0.55			0.32			0.98	
Control Delay	14.6	44.8	6.4	71.6	23.4			19.3			60.6	
Queue Delay	0.0	0.0	0.0	0.0	0.0			0.0			0.0	
Total Delay	14.6	44.8	6.4	71.6	23.4			19.3			60.6	
LOS	B	D	A	E	C			B			E	
Approach Delay		36.9			34.5			19.3			60.6	
Approach LOS		D			C			B			E	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 84	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.98	
Intersection Signal Delay: 41.9	Intersection LOS: D
Intersection Capacity Utilization 89.5%	ICU Level of Service E
Analysis Period (min) 15	

Splits and Phases: 1: Int



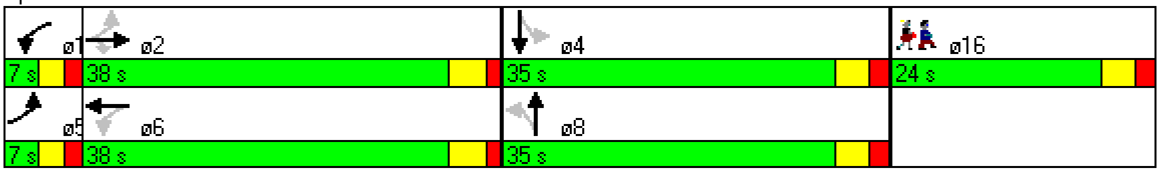
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	85	665	82	52	470	129	101	342	138	75	92	65
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	pm+pt		Perm	pm+pt			Perm			Perm		
Protected Phases	5	2		1	6			8			4	
Permitted Phases	2		2	6			8			4		
Detector Phase	5	2	2	1	6		8	8		4	4	
Switch Phase												
Minimum Initial (s)	2.0	4.0	4.0	2.0	4.0		4.0	4.0		4.0	4.0	
Minimum Split (s)	7.0	20.0	20.0	7.0	20.0		20.0	20.0		20.0	20.0	
Total Split (s)	7.0	38.0	38.0	7.0	38.0	0.0	35.0	35.0	0.0	35.0	35.0	0.0
Total Split (%)	6.7%	36.5%	36.5%	6.7%	36.5%	0.0%	33.7%	33.7%	0.0%	33.7%	33.7%	0.0%
Yellow Time (s)	2.5	3.5	3.5	2.5	3.5		3.0	3.0		3.0	3.0	
All-Red Time (s)	1.5	1.5	1.5	1.5	1.5		2.0	2.0		2.0	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	4.0	5.0	5.0	4.0	5.0	4.0	5.0	5.0	4.0	5.0	5.0	4.0
Lead/Lag	Lead	Lag	Lag	Lead	Lag							
Lead-Lag Optimize?	Yes	Yes	Yes	Yes	Yes							
Recall Mode	None	Min	Min	None	Min		None	None		None	None	
Act Effct Green (s)	37.6	34.8	34.8	36.7	33.4			30.3			30.3	
Actuated g/C Ratio	0.46	0.42	0.42	0.44	0.40			0.37			0.37	
v/c Ratio	0.54	0.87	0.12	0.35	0.85			0.96			0.57	
Control Delay	29.5	38.1	7.7	20.6	36.7			54.5			27.8	
Queue Delay	0.0	0.0	0.0	0.0	0.0			0.0			0.0	
Total Delay	29.5	38.1	7.7	20.6	36.7			54.5			27.8	
LOS	C	D	A	C	D			D			C	
Approach Delay		34.2			35.4			54.5			27.8	
Approach LOS		C			D			D			C	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 82.6	
Natural Cycle: 140	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 0.96	
Intersection Signal Delay: 39.1	Intersection LOS: D
Intersection Capacity Utilization 86.1%	ICU Level of Service E
Analysis Period (min) 15	

Splits and Phases: 1: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

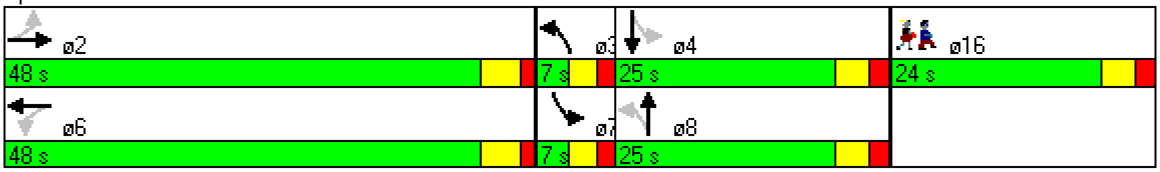
Appendix H

AM/PM Peak Hour Intersection Capacity Analysis
Alternative 5
Add a LT Lane on NB/SB Approaches,
and Add a Protected/Permissive NB/SB LT Phase in Each Traffic Cycle
Lowell Street at Woburn Street, Wilmington

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	24	606	140	123	378	31	39	59	52	134	392	72
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	5%	5%	5%	9%	9%	9%	2%	2%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			pm+pt			pm+pt		
Protected Phases		2			6		3	8		7	4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		3	8		7	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		3.0	4.0		3.0	4.0	
Minimum Split (s)	20.0	20.0		20.0	20.0		7.0	20.0		7.0	20.0	
Total Split (s)	48.0	48.0	0.0	48.0	48.0	0.0	7.0	25.0	0.0	7.0	25.0	0.0
Total Split (%)	46.2%	46.2%	0.0%	46.2%	46.2%	0.0%	6.7%	24.0%	0.0%	6.7%	24.0%	0.0%
Yellow Time (s)	3.5	3.5		3.5	3.5		2.5	3.0		2.5	3.0	
All-Red Time (s)	1.5	1.5		1.5	1.5		1.5	2.0		1.5	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	4.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag							Lead	Lag		Lead	Lag	
Lead-Lag Optimize?							Yes	Yes		Yes	Yes	
Recall Mode	Min	Min		Min	Min		None	None		None	None	
Act Effct Green (s)		43.6			43.6		18.1	15.5		23.0	20.3	
Actuated g/C Ratio		0.54			0.54		0.22	0.19		0.28	0.25	
v/c Ratio		0.81			0.90		0.29	0.35		0.42	1.06	
Control Delay		25.9			39.7		27.5	23.0		29.0	92.2	
Queue Delay		0.0			0.0		0.0	0.0		0.0	0.0	
Total Delay		25.9			39.7		27.5	23.0		29.0	92.2	
LOS		C			D		C	C		C	F	
Approach Delay		25.9			39.7			24.2			78.1	
Approach LOS		C			D			C			E	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 81.2	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.06	
Intersection Signal Delay: 44.6	Intersection LOS: D
Intersection Capacity Utilization 114.5%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 1: Int



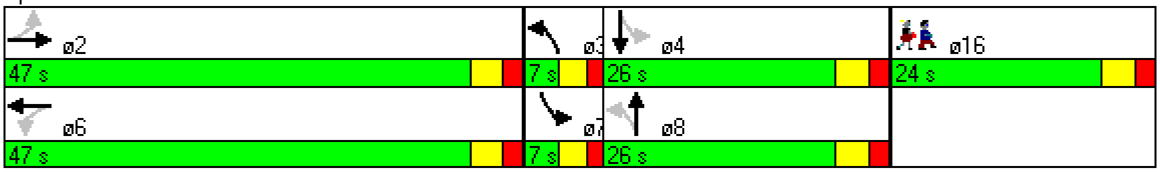
Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	85	665	82	52	470	129	101	342	138	75	92	65
Confl. Peds. (#/hr)	1		1	1		1			1	1		
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	2%	2%	2%	1%	1%	1%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm			Perm			pm+pt			pm+pt		
Protected Phases		2			6		3	8		7	4	
Permitted Phases	2			6			8			4		
Detector Phase	2	2		6	6		3	8		7	4	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		3.0	4.0		3.0	4.0	
Minimum Split (s)	20.0	20.0		20.0	20.0		7.0	20.0		7.0	20.0	
Total Split (s)	47.0	47.0	0.0	47.0	47.0	0.0	7.0	26.0	0.0	7.0	26.0	0.0
Total Split (%)	45.2%	45.2%	0.0%	45.2%	45.2%	0.0%	6.7%	25.0%	0.0%	6.7%	25.0%	0.0%
Yellow Time (s)	3.0	3.0		3.0	3.0		2.5	3.0		2.5	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		1.5	2.0		1.5	2.0	
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	4.0	5.0	5.0	4.0	4.0	5.0	4.0	4.0	5.0	4.0
Lead/Lag							Lead	Lag		Lead	Lag	
Lead-Lag Optimize?							Yes	Yes		Yes	Yes	
Recall Mode	Min	Min		Min	Min		None	None		None	None	
Act Effct Green (s)		42.5			42.5		24.6	21.2		24.6	21.2	
Actuated g/C Ratio		0.51			0.51		0.30	0.26		0.30	0.26	
v/c Ratio		1.01			0.78		0.30	1.06		0.52	0.35	
Control Delay		56.0			25.8		25.0	89.1		37.1	24.7	
Queue Delay		0.0			0.0		0.0	0.0		0.0	0.0	
Total Delay		56.0			25.8		25.0	89.1		37.1	24.7	
LOS		E			C		C	F		D	C	
Approach Delay		56.0			25.8			78.0			28.7	
Approach LOS		E			C			E			C	

Intersection Summary	
Cycle Length: 104	
Actuated Cycle Length: 82.6	
Natural Cycle: 150	
Control Type: Actuated-Uncoordinated	
Maximum v/c Ratio: 1.06	
Intersection Signal Delay: 50.3	Intersection LOS: D
Intersection Capacity Utilization 105.0%	ICU Level of Service G
Analysis Period (min) 15	

Splits and Phases: 1: Int



Lane Group	ø16
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	16
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	1.0
Minimum Split (s)	24.0
Total Split (s)	24.0
Total Split (%)	23%
Yellow Time (s)	3.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Recall Mode	None
Act Effct Green (s)	
Actuated g/C Ratio	
v/c Ratio	
Control Delay	
Queue Delay	
Total Delay	
LOS	
Approach Delay	
Approach LOS	

Intersection Summary

Appendix I

MassDOT Project Implementation Process

The following description of the implementation process is based on Chapter 2 of the *MassDOT Highway Division's Project Development and Design Guide (2005)*. The text below borrows heavily from that document.

1 NEEDS IDENTIFICATION

For each of the locations at which an improvement is to be implemented, MassDOT Highway Division leads an effort to define the problem, establishes project goals and objectives, and defines the scope of the planning needed for implementation. To that end, it has to complete a Project Need Form (PNF), which states in general terms the deficiencies or needs related to the transportation facility or location. The PNF documents the problems and explains why corrective action is needed. For this study, the information defining the need for the project will be drawn primarily, perhaps exclusively, from the present report. Also, at this point in the process, MassDOT Highway Division meets with potential participants, such as the Boston Region Metropolitan Planning Organization (MPO) and community members, to allow for an informal review of the project.

The PNF is reviewed by the MassDOT Highway Division district office whose jurisdiction includes the location of the proposed project. MassDOT Highway Division also sends the PNF to the MPO, for informational purposes. The outcome of this step determines whether the project requires further planning, whether it is already well supported by prior planning studies, and, therefore, whether it is ready to move forward into the design phase, or whether it should be dismissed from further consideration.

2 PLANNING

This phase will likely not be required for the implementation of the improvements proposed in this planning study, as this planning report should constitute the outcome of this step. However, in general, the purpose of this implementation step is for the project proponent to identify issues, impacts, and approvals that may need to be obtained, so that the subsequent design and permitting processes are understood.

The level of planning needed will vary widely, based on the complexity of the project. Typical tasks include: define the existing context, confirm project need, establish goals and objectives, initiate public outreach, define the project, collect data, develop and analyze alternatives, make recommendations, and provide documentation. Likely outcomes include consensus on the project definition to enable it to move forward into environmental documentation (if needed) and design, or a recommendation to delay the project or dismiss it from further consideration.

3 PROJECT INITIATION

At this point in the process, the proponent, MassDOT Highway Division, fills out, for each improvement, a Project Initiation Form (PIF), which is reviewed by its Project Review Committee (PRC) and the MPO. The PRC is composed of the Chief

Engineer, each District Highway Director, and representatives of the Project Management, Environmental, Planning, Right-of-Way, Traffic, and Bridge departments, and the Capital Expenditure Program Office (CEPO). The PIF documents the project type and description, summarizes the project planning process, identifies likely funding and project management responsibility, and defines a plan for interagency and public participation. First the PRC reviews and evaluates the proposed project based on the Executive Office of Transportation and Public Works's statewide priorities and criteria. If the result is positive, MassDOT Highway Division moves the project forward to the design phase, and to programming review by the MPO. The PRC may provide a Project Management Plan to define roles and responsibilities for subsequent steps. The MPO review includes project evaluation based on the MPO's regional priorities and criteria. The MPO may assign project evaluation criteria score, a Transportation Improvement Program (TIP) year, a tentative project category, and a tentative funding category.

4 ENVIRONMENTAL, DESIGN, AND RIGHT-OF-WAY PROCESS

This step has four distinct but closely integrated elements: public outreach, environmental documentation and permitting (if required), design, and right-of-way acquisition (if required). The outcome of this step is a fully designed and permitted project ready for construction. However, a project does not have to be fully designed in order for the MPO to program it in the TIP.

5 PROGRAMMING

Programming, which typically begins during the design phase, can actually occur at any time during the process, from planning to design. In this step, which is distinct from project initiation, where the MPO receives preliminary information on the proposed project, the proponent requests that the MPO place the project in the region's TIP. The MPO considers the project in terms of regional needs, evaluation criteria, and compliance with the regional Transportation Plan and decides whether to place it in the draft TIP for public review and then in the final TIP.

6 PROCUREMENT

Following project design and programming, MassDOT Highway Division publishes a request for proposals. It then reviews the bids and awards the contract to the qualified bidder with the lowest bid.

7 CONSTRUCTION

After a construction contract is awarded, MassDOT Highway Division and the contractor develop a public participation plan and a management plan for the construction process.

8 PROJECT ASSESSMENT

The purpose of this step is to receive constituents' comments on the project development process and the project's design elements. MassDOT Highway Division can apply what is learned in this process to future projects.

Appendix J

Review of Traffic Signal Clearance Interval
Lowell Street at Woburn Street, Wilmington

The clearance interval is the time following a green signal indication during which a yellow signal indication is displayed to warn motorists of the impending change in right of way assignment (so called the yellow change interval) and followed by an all-red interval for vehicles to clear the intersection. Yellow change intervals inconsistent with normal operating speeds create a dilemma zone in which drivers can neither stop safely nor reach the intersection before the signal turns red. Lengthening the yellow interval, within appropriate guidelines, has been shown to significantly reduce the number of inadvertent red-light violations. On the other hand, too long of a yellow interval decreases capacity of the intersection and increases delay to motorists. This in turn can cause driver frustration and may result in motorists intentionally violating the red-light and entering the intersection later.

All the existing signal phases at this intersection include a clearance (yellow change + all-red) interval of 6 seconds. Based on the commonly used ITE (Institute of Traffic Engineers) formula, the yellow clearance interval consists of reaction time, deceleration time, and time to clear the intersection.[1] The calculation for both streets of the intersection shows that a total of 5 seconds clearance time is applicable for safe operations.

The components and assumptions for the clearance time desirable for the Lowell Street approaches are:

- Reaction time = 1 second
- Deceleration time = 2.6 seconds, assuming average vehicle speed = 35 MPH (posted speed limit: 25 MPH) and average deceleration = 10 feet/sec.^{2}
- All-red time= 1.4 seconds, assuming distance to clear the intersection = 60 feet = 40 feet (Woburn Street width) + 20 feet (a vehicle length to clear the intersection)

Stopwatch measurements at the intersection estimate the existing 6-second clearance interval consists of 4-second yellow time and 2-second all-red time. The calculation indicates that a 5-second clearance interval consisting of 3.5 seconds of yellow time (reaction time plus deceleration time) and 1.5 seconds of all-red time is applicable for the Lowell Street approaches if the prevailing speed (85th percentile speed) approaching the intersection is 35 MPH or lower.

The components and assumptions for the clearance time desirable for the Woburn Street approaches are:

- Reaction time = 1 second
- Deceleration time = 2.2 seconds, assuming average vehicle speed = 30 MPH (posted speed limit: 20 MPH) and average deceleration = 10 feet/sec.^{2}
- All-red time= 1.8 seconds, assuming distance to clear the intersection = 80 feet = 60 feet (Lowell Street width) + 20 feet (a vehicle length to clear the intersection)

The calculation indicates that a 5-second clearance interval consisting of 3 seconds of yellow time (reaction time plus deceleration time) and 2 seconds of all-red time is applicable for the Woburn Street approaches if the prevailing speed approaching the intersection is 30 MPH or lower.

---

[1] *Traffic Signal Clearance Interval*, Philip J. Tarnoff, ITE Journal, April 2004

The above calculation indicate that a 5-second clearance interval should be sufficient and effective if the prevailing speed is 35 MPH or lower on Lowell Street and 30 MPH or lower on Woburn Street. It is essential to validate the prevailing speed assumptions through a traffic speed study at the intersection before adopting the changes.