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DRAFT MEMORANDUM

DATE **February 22, 2012**

TO **Town of Framingham**

FROM **Steven P. Andrews and Seth Asante, MPO Staff**

RE **FFY 2011 Safety and Operations Analyses at Selected Boston Region MPO Intersections: Union Avenue at Mt. Wayte Avenue**

INTRODUCTION

This memorandum summarizes safety and operations analyses and proposes improvement strategies for the intersection of Union Avenue at Mt. Wayte Avenue in Framingham. It contains the following sections:

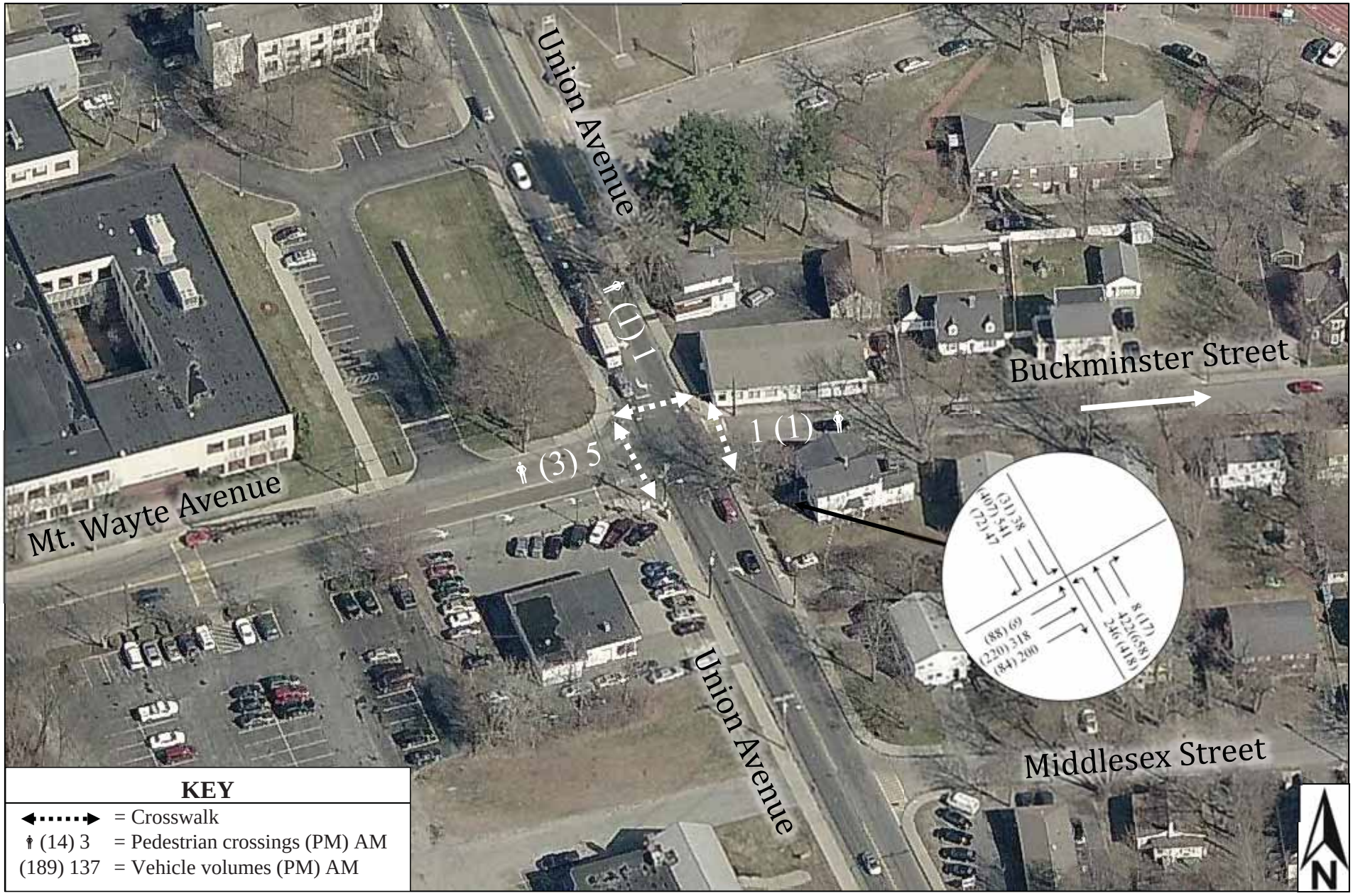
- Intersection Layout and Traffic Control
- Issues and Concerns
- Crash Data Analysis
- Intersection Capacity Analysis
- Analysis of Improvement Alternatives
- Improvement Recommendations and Discussion

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 analyses.

INTERSECTION LAYOUT AND TRAFFIC CONTROL

This signalized intersection is located about one mile north of downtown Framingham. Union Avenue is a two-lane arterial that connects Concord Street in downtown Framingham to Route 9 (as Main Street). Mt. Wayte is a two-lane local road looping around Farm Pond. Mt. Wayte turns into Buckminster Street, which is a one-way local road. All the streets at the intersection are under the Town's jurisdiction.

Figure 1 shows the intersection layout and the area nearby. The intersection has a fairly common layout. Approaching the intersection, the Union Avenue northbound and southbound approaches flare out to two lanes: one left-turn lane and one shared through and right-turn lane. The Mt. Wayte Avenue eastbound approach is two lanes wide. One lane turns into a shared through and left-turn lane, and the other lane turns into a right-turn lane. With the exception of Buckminster Street, there is no on-street parking near the intersection.



BOSTON REGION MPO

FIGURE 1
Union Avenue at Mt. Wayte Avenue, Framingham

Safety and Operations Improvements at Selected Intersections

Crosswalks are installed across three of the approaches. There is no crosswalk across the northbound Union Avenue approach. The crosswalk's painted lines are somewhat faded. The crosswalk slopes down to the level of the road surface, but there are no curb ramps with tactile strips. There are no pedestrian signal heads at the intersection. Currently, pedestrians must cross concurrently with traffic. Most of the approaches have a sidewalk, and the sidewalks are in good condition, though the sidewalk on the south side of Mt. Wayte Avenue is not in as good of a condition as the other sidewalks. This sidewalk is used as a driveway for an auto repair shop on the southwest corner of the intersection. The traffic signal cabinet takes up some space on the sidewalk, causing the sidewalk on that corner to be narrower than elsewhere.

The traffic signal is semi-actuated and operates in three traffic phases: northbound all movements (left turns protected), northbound/southbound all movements (left turns permitted), and eastbound all movements. There is no exclusive pedestrian phase, a phase where vehicles at all of the approaches are stopped and pedestrians are permitted to cross. The eastbound phase is actuated. The traffic signal permits obtained by the town indicate that the northbound protected left-turn and through phase is 6 seconds long, including 3 seconds of yellow time. The northbound/southbound phase is 45 seconds long, including a 5-second clearance interval. The eastbound phase is actuated, with a minimum phase of 9 seconds that includes a 5-second clearance interval, and a maximum phase of 30 seconds that includes a 5-second clearance interval. Right turns on red are permitted for all of the approaches.

All of the signal heads are post-mounted and positioned about 8 to 9 feet high. The signal heads appear to be approximately 8 to 10 inches in diameter. Signals are located at each of the four corners of the intersection. Each approach receives two signal indications from the far-side signals, but because the signal heads are low to the ground large vehicles could obscure the view of the signals for following vehicles

The land use in the vicinity of the intersection is mainly residential. A light industrial building is located on the northwest corner of the intersection, and an auto repair shop is located on the southwest corner of the intersection. A small shopping center is located about a quarter mile west of the intersection. Beyond the shopping center, just over a mile away from the intersection, is Barbieri Elementary School, where approximately 450 students are enrolled. An athletic facility is located just north of the intersection. Marian High School, a private school with about 275 students, is located approximately a half mile south of the intersection. MetroWest Medical Center is located just south of the high school, about six-tenths of a mile south of the intersection. To the east of the intersection are Fuller Middle School, where about 500 students are enrolled, and the Framingham MassBay Community College Campus, where approximately 1,800 students are enrolled.

The school start and release times are as follows:

- Barbieri Elementary School, 9:05 AM and 3:05 PM
- Fuller Middle School, 8:15 AM and 2:25 PM
- Marian High School: 7:15AM and 1:45 PM

ISSUES AND CONCERNS

A review of the recent crash data from 2006 to 2008 indicates that a high number of crashes occurred at the intersection. The crash rate at this intersection is much higher than at other signalized intersection in the area. Over half of the crashes were classified as angle crashes. About 70% of the crashes in 2006 were angle crashes, but the percentage of angle crashes dropped to only 30% in 2008. Most of the crashes only caused property damage.

The northbound Union Avenue approach is very congested during the peak hours. Recent turning movement counts (see Table 2 in the Intersection Capacity Analysis section) show significant northbound and eastbound left-turn volumes. Left turns account for almost 40% of the vehicles using the northbound approach. During the morning peak hour, 34% of the vehicles travelling eastbound on Mt. Wayte Avenue make right turns. In the afternoon, about a fifth of the vehicles make left turns from Mt. Wayte Avenue. The large volume of left turns from the northbound approach causes significant delays on Union Avenue.

The MetroWest Medical Center is located just south of the intersection. This traffic signal does not feature signal preemption. Preemption would help ambulances get to the medical center more quickly.

The traffic signal cabinet is located on the southwest corner of the intersection. Because the door to the cabinet opens towards the street, any technicians working inside the cabinet are somewhat exposed to vehicles. Moving or rotating the cabinet would be more convenient for technicians and vehicles.

There is no pedestrian equipment at the intersection. Currently, pedestrians cross with traffic. While few pedestrians use the intersection, pedestrian signal heads would help them cross safely. The crosswalks are faded and need to be restriped. While most of the sidewalks and crosswalks are lined up with each other, providing a path for people who use wheelchairs, the crosswalk across the southbound approach of Union Avenue does not line up with the sidewalk on the north side of Buckminster Street. A person in a wheelchair would have to maneuver their way to the curb ramp on the north side of Buckminster Street.

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

- High number of crashes and high crash rate
- Traffic congestion during peak hours, including lots of school buses during the AM peak hour
- Outdated traffic signal equipment
- No pedestrian signals
- Severely faded crosswalk markings on all approaches
- No ADA-compliant curb ramps
- Traffic signal cabinet door opens toward the street

CRASH DATA ANALYSIS

Based on the 2006–08 MassDOT Registry of Motor Vehicles Division crash data, Table 1 shows that, on average, about 11 crashes occurred at the intersection each year. Almost 30% of the crashes resulted in personal injuries, and about 60% of the total crashes involved property damage only. None of the crashes resulted in a fatality. The crash types, not including data that were not reported, consisted of about 58% angle collisions, 3% sideswipe collisions, 23% rear-end collisions, 6% single-vehicle collisions, and 10% head-on collisions. No crashes involved pedestrians or bicyclists. 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. Only 10% of the crashes occurred in dark conditions (dawn, dusk, and nighttime.)

Given the high percentage of angle collisions, the left-turning vehicles may not be given enough time. The current phase sequence gives a brief three seconds of protected green time and three seconds of yellow time to northbound left-turning vehicles. No other approaches receive protected turns. Minimal left-turn time coupled with a short left-turn bay could cause left-turning vehicles to block Union Avenue. Left-turning vehicles blocking Union Avenue could explain the long queues observed on Union Avenue, and the long queues could explain why there are so many rear-end collisions.

Crash rates are an effective metric for examining the safety of a particular location relative to a regional or subregional average.[1] Based on the 2006–08 crash data and the recently collected traffic volume data, the crash rate for this intersection is 1.40 crashes per million entering vehicles (see Appendix A for the calculation). This crash rate is higher than the average rate for the signalized locations in MassDOT Highway Division District 3, which is estimated to be 0.90 crashes per million entering vehicles.[2]

[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 are based on a database that contains intersection crash rates submitted to MassDOT as part of the review process for an Environmental Impact Report or Functional Design Report. 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. The average crash rate for District 3 was calculated on July 7, 2011.

TABLE 1
Summary of MassDOT Crash Data (2006–08)

Statistics period		2006	2007	2008	3-Year	Annual
Total number of crashes		14	10	10	34	11
Severity	Property Damage Only	8	5	8	21	7
	Personal Injury	2	5	2	9	3
	Fatality	0	0	0	0	0
	Not Reported	4	0	0	4	1
Collision type	Angle	10	5	3	18	6
	Rear-end	2	2	3	7	2
	Sideswipe	0	1	0	1	0
	Head-on	1	1	1	3	1
	Single Vehicle	1	0	1	2	1
	Not Reported/Unknown	0	1	2	3	1
Involved pedestrian(s)		0	0	0	0	0
Involved cyclist(s)		0	0	0	0	0
Occurred during weekday peak periods*		8	6	2	16	5
Wet or icy pavement conditions		5	6	1	12	3
Dark/lighted conditions		1	1	1	3	1

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

INTERSECTION CAPACITY ANALYSIS

MPO staff collected turning-movement counts at the intersection on April 25 and April 26, 2011. The data were recorded in 15-minute intervals for the peak traffic periods in the morning, from 7:00 to 9:00 AM, and in the evening, from 4:00 to 6:00 PM. The intersection carried about 1,889 vehicles in the morning peak hour, from 8:00 to 9:00 AM, and about 1,995 vehicles in the evening peak hour, from 4:45 to 5:45 PM (see Table 2). Staff observed very few pedestrians and bicyclists at the intersection. Schools in the area begin within the morning observation period, but they all have released their students before the afternoon observation period.

Based on the turning-movement counts and the signal timings measured at the site, the intersection capacity was analyzed by using an intersection capacity analysis program, Synchro.[3] The intersection was modeled as a semi-actuated, signalized intersection. As Table 3 shows, the through and right-turn lanes on Union Avenue were found to operate at level of service (LOS) B with less than 20 seconds of delay per vehicle during the AM and PM peak hours. Table 5 shows the queues for the dedicated lanes. The northbound left-turn lanes experience significant delay (approximately 110 seconds per vehicle). Left-turning vehicles can produce long queues that can block the through and right-turn lanes.

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

TABLE 2
AM and PM Peak-Hour Traffic Volumes and Pedestrian Crossings, April 25–26, 2011

Street name		Union Avenue						Mt. Wayte Avenue			Total
Direction		Northbound			Southbound			Eastbound			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	Turning volume	246	422	8	38	541	47	69	318	200	
	Mvmt. percentage	36%	62%	1%	6%	86%	8%	12%	54%	34%	1889
	Approach volume	676			626			587			
	Ped. crossings	0			1			5			6
PM peak hour	Turning volume	418	658	17	31	407	72	88	220	84	
	Mvmt. percentage	38%	60%	2%	6%	80%	14%	22%	56%	21%	1995
	Approach volume	1093			510			392			
	Ped. crossings	0			1			3			4

TABLE 3
Intersection Capacity Analysis, Existing Conditions

Street name		Union Avenue						Mt. Wayte Avenue			Overall
Direction		Northbound			Southbound			Eastbound			
Turning movement		LT	TH	RT	LT	TH	RT	LT	TH	RT	
AM peak hour	LOS	F	B		B	B		D	C		C
	Delay (sec/veh)	109.2	13.1		11.2	19.8		41.0	20.9		34.8
PM peak hour	LOS	F	B		B	B		C	C		C
	Delay (sec/veh)	106.2	13.9		10.5	14.3		33.5	21.0		36.5

Vehicles traveling on Mt. Wayte Avenue in general experience more delay. During the morning and afternoon peak hours, Mt. Wayte Avenue operates at LOS C. Eastbound vehicles are delayed about 30 seconds. The criteria for the level of service ratings are based on the *Highway Capacity Manual 2000*.[4] Detailed analysis results for both the AM and PM peak hour are included in Appendix B.

ANALYSIS OF IMPROVEMENT ALTERNATIVES

To improve traffic operations at this intersection, staff examined a number of traffic and pedestrian signal strategies. The improvement alternatives progress from simple to more involved modifications. Because of the limited right-of-way available, staff did not examine any lane-addition modifications; all modifications were designed to fit within the current right-of-way. As mentioned earlier, the intersection capacity was evaluated using the Synchro optimization and simulation software.

[4] Transportation Research Board, National Research Council, *Highway Capacity Manual (HCM) 2000*, Washington, D. C., 2000.

All of the alternatives would require a fully actuated traffic signal—that is, a traffic signal system where each approach has sensors for motor vehicles on all four approaches, so that the presence of a vehicle may affect the green time each approach receives. The traffic signal system would also incorporate modern pedestrian signal heads and push buttons instead the current, outdated equipment. The minimum exclusive pedestrian phase is 25 seconds.[5] In Alternatives 3 and 4, the left-turn bay would be lengthened. The current left-turn bay has approximately 60 feet of storage with a 60-foot taper. Signal timings for the morning and afternoon peak periods would not necessarily be the same. The alternatives tested for this intersection include:

Alternative 1	Installing a fully actuated intersection; adding an actuated, exclusive pedestrian phase; optimizing signal timings.
Alternative 2	Installing a fully actuated intersection; adding concurrent pedestrian phases; optimizing signal timings.
Alternative 3	Same phases and timings as Alternative 1; lengthening the northbound left-turn bay.
Alternative 4	Same phases and timings as Alternative 2; lengthening the northbound left-turn bay.

Currently there are no pedestrian signals. Alternative 1 adds an exclusive pedestrian phase. Given the low pedestrian volumes, this phase is not expected to be frequently triggered. The number of pedestrian calls per hour was set to the number of pedestrians who used the intersection (seven in the morning and five in the afternoon). In order to minimize delay, much more time is given to the protected northbound Union Avenue phase. Alternative 2 provides pedestrians concurrent phases. Minimizing delay gives much more time to the northbound phase, as it does in Alternative 1. Alternatives 3 and 4 make the same changes as Alternatives 1 and 2, respectively, but also would also include lengthening the northbound left-turn bay.

During data collection for the turning-movement counts, staff recorded the length of the queue for each approach at the end of each 15-minute period. In the afternoon, queues frequently extended more than 150 feet. The analysis of existing conditions shows that during the afternoon peak hour the 95th percentile queue extends more than 250 feet. Because the Middlesex Street intersection with Union Avenue is about 150 feet south of the intersection of Union Avenue at Mt. Wayte Avenue, this distance was chosen as the maximum length of the dedicated left-turn lane. The proposed left-turn lane would be 150 feet long, with an 80-foot taper; the 80-foot taper represents the approximate width of Middlesex Street at Union Avenue. South of the intersection, Union Avenue's pavement width is just over 30 feet wide. Extending the left-turn bay would fit within that width.

Table 4 summarizes the intersection capacity analyses for both the AM and PM peak hours for each of the alternatives (detailed analysis settings and results for the alternatives are included in Appendices C to F). Table 3 shows measures of effectiveness based on each lane group. Table 4 shows the measures of effectiveness based on each approach. Table 5 examines the dedicated

[5] The minimum crossing time is based on a walking speed of 3.5 feet per second (the longest crossing takes 18 seconds to complete) in addition to a "walk" indication time of 4 seconds and a steady upraised hand time of 3 seconds. A person who left at the beginning of the "walk" indication could cross if they walk faster than 2.8 feet per second.

lane queues. According to data obtained by the field staff during the collection of turning-movement counts, the longest morning northbound left-turn queue was approximately 100 feet long; the average was 30 feet long. The longest afternoon queue was approximately 250 feet long; the average queue length was 165 feet long. During both the morning and afternoon peak hours, the southbound left-turn lane had a maximum queue length of about 50 feet, and usually there was no queue. During the morning peak hour, the longest queue was about 175 feet; the average queue length was about 100 feet. The eastbound right-turn lane did not have long queues in the afternoon; at worst, the queue was about 75 feet long. Only eight queue length samples were taken by field staff. This represents the queue length for approximately 10% of the cycles.

TABLE 4
Intersection Capacity Analyses of Improvement Alternatives

Street name		Union Avenue				Mt. Wayte Avenue		Overall	
Direction		Northbound		Southbound		Eastbound			
Measurement		LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay
AM peak hour	**Existing**	**D**	**48.3**	**B**	**19.2**	**C**	**34.2**	**C**	**34.8**
	Alternative 1	D	35.8	C	34.6	E	60.6	D	43.0
	Alternative 2	C	26.3	C	28.6	D	35.6	C	29.8
	Alternative 3	D	35.8	C	34.6	E	60.6	D	43.0
	Alternative 4	C	26.3	C	28.6	D	35.6	C	29.8
PM peak hour	**Existing**	**D**	**49.7**	**B**	**14.0**	**C**	**30.9**	**D**	**36.5**
	Alternative 1	C	26.9	D	38.3	D	53.3	D	35.4
	Alternative 2	C	20.5	C	23.4	D	35.6	C	24.4
	Alternative 3	C	26.9	D	38.3	D	53.3	D	35.4
	Alternative 4	C	20.5	C	23.4	D	35.6	C	24.4

Alternatives:

Alternative 1 Installing a fully actuated intersection; adding an exclusive pedestrian signal; optimizing signal timings
Alternative 2: Installing a fully actuated intersection; adding concurrent pedestrian phases; optimizing signal timings
Alternative 3: Same phases and timings as Alternative 1; lengthening the NB left-turn lane
Alternative 4: Same phases and timings as Alternative 2; lengthening the NB left-turn lane

Note: Delay is measured in seconds per vehicle. Rows highlighted in grey represent alternatives with concurrent pedestrian phases.

The southbound and eastbound dedicated lanes appear to be sufficiently long to accommodate the corresponding traffic demands. The eastbound right-turn queue increases in Alternatives 1 and 3. To limit vehicle-pedestrian interactions, right turns on red are not permitted in Alternatives 1 and 3.

TABLE 5
Dedicated Lane Queues (in Feet) Resulting from Improvement Alternatives, Using Synchro

Street name		Union Avenue				Mt. Wayte Avenue	
Direction		Northbound (Left-turn Lane)		Southbound (Left-turn Lane)		Eastbound (Right-turn Lane)	
Measurement		Q_{50}	Q_{95}	Q_{50}	Q_{95}	Q_{50}	Q_{95}
AM peak hour	**Existing**	**86***	**177***	**14**	**27**	**0**	**46**
	Alternative 1	96	308*	17	46	109	243*
	Alternative 2	82	194*	16	30	0	52
	Alternative 3	96	308*	17	46	109	243*
	Alternative 4	82	194*	16	30	0	52
PM peak hour	**Existing**	**126***	**346***	**10**	**24**	**0**	**31**
	Alternative 1	160	503*	16	44	44	111
	Alternative 2	97	271*	11	25	0	32
	Alternative 3	160	503*	16	44	44	111
	Alternative 4	97	271*	11	25	0	32

Note: Q_{50} is the queue expected for a typical cycle. Q_{95} is the queue that will only be exceeded in about 5% of the time.

* Starred values indicate that the queue is based on a movement where the volume exceeds the capacity. The queue reported here is the maximum queue after two cycles.

The current left-turn bay is not sufficiently long to accommodate left-turning vehicles. Without increasing the left-turn bay's length to 150 feet as suggested in Alternatives 3 and 4, the queues on Union Avenue northbound could become long. Because Middlesex Street crosses Union Avenue about 150 feet south of the intersection, staff limited the left-turn bay length to Middlesex Street intersection in order to limit interference with vehicles turning left onto Union Avenue from Middlesex Street.

TABLE 6
Dedicated Lane Queues (in Feet) Resulting from Improvement Alternatives, Using SimTraffic*

Movement		NB Left-Turn Lane			NB Through and RT Lane		Intersection Queueing Penalty (veh)
Measurement		Average	95th %tile	% of Time NB T/R Blocked	Average	95th %tile	
AM peak hour	**Existing**	**110**	**146**	**58%**	**437**	**897**	**316**
	Alternative 1	112	142	56%	453	875	320
	Alternative 2	97	144	36%	247	522	210
	Alternative 3	140	242	15%	217	466	110
	Alternative 4	126	224	9%	149	318	60
PM peak hour	**Existing**	**117**	**131**	**57%**	**768**	**921**	**501**
	Alternative 1	118	128	53%	744	945	464
	Alternative 2	118	128	48%	659	1006	422
	Alternative 3	197	279	29%	455	876	272
	Alternative 4	159	248	17%	275	641	154

* SimTraffic calculates queue lengths differently from Synchro; therefore, the results are not directly comparable. SimTraffic queues lengths are about 20% shorter than Synchro queues because SimTraffic uses an average vehicle length of about 20 feet instead of the 25 feet used in Synchro. The SimTraffic simulation does not account for the peak-hour factor and does account for blockages. The average queue length as calculated by SimTraffic is the average of the maximum queue length for each simulated two-minute period. The 95th percentile is the average queue length plus 1.65 standard deviations. It is based purely on statistical calculations.

IMPROVEMENT RECOMMENDATIONS AND DISCUSSION

This intersection has a high number of crashes and a crash rate much higher than other signalized intersections in the MassDOT Highway District 3 area. The above safety and operations analyses found a number of deficiencies related to the existing signal system. First, there are no pedestrian signals at the intersection. Second, there is significant congestion during the morning and afternoon peak hours.

Four alternatives were tested. Exclusive and concurrent pedestrian phases were examined, along with a longer northbound left-turn lane.

Alternative 1 is beneficial to pedestrians and traffic operations in the afternoon, but not in the morning. Alternative 2 is beneficial to pedestrians and traffic in the morning and afternoon, but there is still a substantial queue on the northbound approach. Alternatives 3 and 4 substantially reduce the northbound queue.

At this preliminary planning stage, we recommend Alternative 3 for this intersection. Overall Alternative 3 would significantly decrease delay and congestion while providing pedestrians with an exclusive phase. However, the signal plan under Alternative 3 causes additional delay to drivers on Mt. Wayte Avenue. One possible way to mitigate some of this delay would be to overlap a protected right-turn phase over the leading Union Avenue phase. There could be some

conflicts when large vehicles need to make a right or left turn. A more in-depth analysis would need to be conducted to ensure that there is enough space for both sets of turning vehicles.

In Alternatives 3 and 4, the northbound left-turn lane is lengthened to 150 feet. This would place the entrance to the left-turn lane at Middlesex Street. The northbound Union Avenue approach at Middlesex Street could be reconfigured from one lane to two lanes. The additional lane would need to be several hundred feet long to accommodate the left-turn queue (just over 500 feet south of the northbound stop line, according to Synchro). This additional lane would serve as storage for vehicles turning left from northbound Union Avenue to Mt. Wayte Avenue. The roadway's current width of 32 feet would accommodate three 10-foot-wide lanes for most of Union Avenue south of its intersection with Mount Wayte Avenue. In order to prevent Union Avenue northbound vehicles from blocking left-turning vehicles from Middlesex Street, the intersection of Union Avenue at Middlesex Street could be boxed off, as shown in the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD), Section 3B.17. (A boxed intersection is delineated by solid white lines painted along the outline of the area that vehicles must not block.) The MUTCD provides several options for how an intersection can be boxed off: a simple box, as described in Option A in MUTCD, would be a good starting point. If Option A does not work well enough in practice, other options could be explored. The MUTCD requires that a box be accompanied by a "Do Not Block Intersection" (R10-7) sign.

Upgrading the outdated signal system is critically important. The current conditions for pedestrians are less than ideal and should be improved. Combined with an extended dedicated left-turn lane on the northbound approach of Union Avenue, an updated signal system would solve many of the problems at this intersection by both improving vehicle flow and accommodating pedestrians.

Recommendations:

- Implement Alternative 3: replace the current equipment with a fully actuated traffic signal, add an actuated exclusive pedestrian phase, and lengthen the northbound left-turn bay.
- Install functional, ADA-compliant pedestrian signals, including a countdown timer.
- Install ADA-compliant curb ramps.
- Install overhead signal heads that are clearly visible from all approaches.
- Add preemption for emergency vehicles.
- Extend the northbound Union Avenue left-turn bay from 60 feet of storage to 150 feet of storage.
- Prohibit right turns on red at all approaches.
- Repaint and maintain the crosswalks.
- Install a box and an R10-7 ("Do Not Block Intersection") sign at Union Avenue at Middlesex Street. The sign should be directed at northbound Union Avenue traffic.
- Add a crosswalk across the Union Avenue northbound approach.
- Turn the traffic signal cabinet to face the sidewalk at the southwest corner of the intersection.

The total cost of the signal installation (including its support system) can be roughly estimated to be about $1,000,000. Both streets and the intersection are under the jurisdiction of the Town of Framingham. The town can seek funding support from the state by working closely with MassDOT Highway District 3 through the project implementation process (see Appendix G).

Eventually construction will take place near the intersection. Any major upgrades to the intersection would likely occur at that time. In the interim, it would be prudent to increase the length of the left-turn bay and lengthen the protected left-turn signal time for the northbound Union Avenue approach. Increasing the cycle length to 90 seconds, and giving 17 seconds to the protected northbound left-turn phase, 45 seconds to the northbound/southbound phase, and 28 seconds to the actuated eastbound phase, would reduce the congestion caused by left-turning vehicles and reduce vehicle delay.

Because there are currently no pedestrian signals at the intersection, additional signage might increase pedestrian safety. The 2009 MUTCD lists sign R10-15 as an acceptable sign to "remind drivers who are making turns to yield to pedestrians." Figure 2, taken from the MUTCD, shows this sign. In its current state, R10-15 seems to suggest that right-turning vehicles should be aware

FIGURE 2
MUTCD Sign R10-15: Turning Vehicles Must Yield to Pedestrians

of pedestrians. In order to remind vehicles turning left and right to yield to pedestrians, we suggest removing the right-turn arrow. The text "Turning vehicles," on a fluorescent yellow-green background, would fill the top portion of the sign. One sign would be mounted at each corner of the intersection. Drivers at each approach would see two signal heads: one on the near side of the intersection on the left, and another on the far side of the intersection on the right. Placing the sign underneath the signal housing on the far-side signal post would likely be the most visible location for the sign.

Additional comments and recommendations were received from Joe Frawley, Traffic Engineer MassDOT District 3. His comments are included in Appendix H.

SPA/SA/spa

APPENDIX A

Existing Conditions

Intersection Crash Rate Calculation:
Union Avenue at Mt. Wayte Avenue, Framingham

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Framingham COUNT DATE : 4/26/2011

DISTRICT : 3 UNSIGNALIZED : SIGNALIZED : X

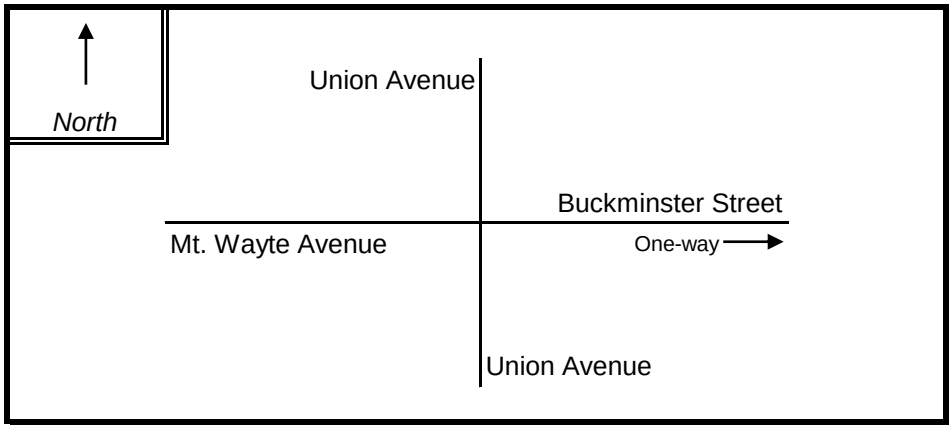
~ INTERSECTION DATA ~

MAJOR STREET : Union Avenue

MINOR STREET(S) : Mt. Wayte Avenue

Buckminster Street (one-way away from intersection)

INTERSECTION DIAGRAM (Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	EB	NB	SB			
PEAK HOURLY VOLUMES (AM/**PM**) :	392	1,093	510			**1,995**

" K " FACTOR : **0.090** INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **22,167**

TOTAL # OF CRASHES : 34 # OF YEARS : 3 AVERAGE # OF CRASHES PER YEAR (**A**) : **11.33**

CRASH RATE CALCULATION : **1.401** RATE = $\frac{(A * 1{,}000{,}000)}{(V * 365)}$

Comments : MassDOT District 3 Average Rate = 0.90 (July 7, 2011)

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

APPENDIX B

Existing Conditions

AM/PM Peak-Hour Intersection Capacity Analysis:
Union Avenue at Mt. Wayte Avenue, Framingham

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Configurations						
Volume (vph)	318	200	246	422	38	541
Turn Type		Prot	pm+pt		Perm	
Protected Phases	4	4	5	2		6
Permitted Phases			2		6	
Detector Phase	4	4	5	2	6	6
Switch Phase						
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0
Total Split (s)	30.0	30.0	6.0	51.0	45.0	45.0
Total Split (%)	37.0%	37.0%	7.4%	63.0%	55.6%	55.6%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0
Lead/Lag			Lead		Lag	Lag
Lead-Lag Optimize?			Yes		Yes	Yes
Recall Mode	None	None	Max	Max	Max	Max

Intersection Summary
Cycle Length: 81
Actuated Cycle Length: 79.5
Natural Cycle: 75
Control Type: Semi Act-Uncoord
Description: Union Avenue at Mt. Wayte Avenue, Framingham

Splits and Phases: 3: Mt. Wayte Ave & Union Ave

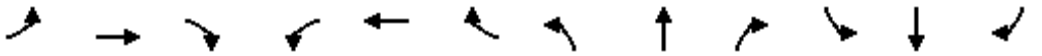
Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	442	225	304	527	52	634
v/c Ratio	0.86	0.38	1.08	0.57	0.13	0.71
Control Delay	45.3	5.2	94.9	14.0	12.3	20.8
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	45.3	5.2	94.9	14.0	12.3	20.8
Queue Length 50th (ft)	206	0	~86	158	14	236
Queue Length 95th (ft)	#362	46	#177	215	27	365
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			60		60	
Base Capacity (vph)	546	620	282	922	390	899
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.81	0.36	1.08	0.57	0.13	0.71

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	69	318	200	0	0	0	246	422	8	38	541	47
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	1.00		1.00	0.99	
Flt Protected		0.99	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1733	1478				1604	1591		1693	1777	
Flt Permitted		0.99	1.00				0.23	1.00		0.43	1.00	
Satd. Flow (perm)		1733	1478				393	1591		775	1777	
Peak-hour factor, PHF	0.72	0.92	0.89	0.25	0.25	0.25	0.81	0.82	0.67	0.73	0.93	0.90
Adj. Flow (vph)	96	346	225	0	0	0	304	515	12	52	582	52
RTOR Reduction (vph)	0	0	159	0	0	0	0	1	0	0	4	0
Lane Group Flow (vph)	0	442	66	0	0	0	304	526	0	52	630	0
Confl. Peds. (#/hr)	1						5		1	1		5
Heavy Vehicles (%)	4%	5%	2%	0%	0%	0%	5%	11%	13%	3%	4%	21%
Turn Type	Perm		Prot				pm+pt			Perm		
Protected Phases		4	4				5	2			6	
Permitted Phases	4						2			6		
Actuated Green, G (s)		23.5	23.5				46.1	46.1		40.1	40.1	
Effective Green, g (s)		23.5	23.5				46.1	46.1		40.1	40.1	
Actuated g/C Ratio		0.30	0.30				0.58	0.58		0.50	0.50	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				0.3	3.7		3.7	3.7	
Lane Grp Cap (vph)		512	436				273	921		390	895	
v/s Ratio Prot			0.04				c0.04	0.33			0.35	
v/s Ratio Perm		0.25					c0.60			0.07		
v/c Ratio		0.86	0.15				1.11	0.57		0.13	0.70	
Uniform Delay, d1		26.5	20.7				20.7	10.5		10.5	15.2	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		14.5	0.2				88.5	2.6		0.7	4.6	
Delay (s)		41.0	20.9				109.2	13.1		11.2	19.8	
Level of Service		D	C				F	B		B	B	
Approach Delay (s)		34.2			0.0			48.3			19.2	
Approach LOS		C			A			D			B	

Intersection Summary			
HCM Average Control Delay	34.8	HCM Level of Service	C
HCM Volume to Capacity ratio	0.99		
Actuated Cycle Length (s)	79.6	Sum of lost time (s)	8.0
Intersection Capacity Utilization	77.2%	ICU Level of Service	D
Analysis Period (min)	15		

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	7:57	7:57	7:57	7:57	7:57	7:57
End Time	8:30	8:30	8:30	8:30	8:30	8:30
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	966	984	979	931	884	947
Vehs Exited	962	957	938	924	869	930
Starting Vehs	29	28	17	31	32	27
Ending Vehs	33	55	58	38	47	46
Denied Entry Before	0	2	1	2	5	2
Denied Entry After	0	0	9	2	1	2
Travel Distance (mi)	266	264	262	256	240	258
Travel Time (hr)	22.6	22.2	24.7	16.0	15.2	20.1
Total Delay (hr)	13.2	12.8	15.3	6.9	6.6	11.0
Total Stops	1149	1244	1258	742	721	1023
Fuel Used (gal)	129.8	128.3	133.0	109.5	102.2	120.6

Interval #0 Information Seeding

Start Time	7:57
End Time	8:00
Total Time (min)	3

Volumes adjusted by Growth Factors.

No data recorded this interval.

Interval #1 Information Recording

Start Time	8:00
End Time	8:30
Total Time (min)	30

Volumes adjusted by Growth Factors.

Run Number	1	2	3	4	5	Avg
Vehs Entered	966	984	979	931	884	947
Vehs Exited	962	957	938	924	869	930
Starting Vehs	29	28	17	31	32	27
Ending Vehs	33	55	58	38	47	46
Denied Entry Before	0	2	1	2	5	2
Denied Entry After	0	0	9	2	1	2
Travel Distance (mi)	266	264	262	256	240	258
Travel Time (hr)	22.6	22.2	24.7	16.0	15.2	20.1
Total Delay (hr)	13.2	12.8	15.3	6.9	6.6	11.0
Total Stops	1149	1244	1258	742	721	1023
Fuel Used (gal)	129.8	128.3	133.0	109.5	102.2	120.6

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.4	1.6	0.3	3.0	3.4	0.1	0.2	1.6	0.1	10.5
Delay / Veh (s)	35.6	36.3	9.6	86.3	59.0	45.9	29.8	21.8	17.9	40.3
Total Stops	38	140	61	245	307	7	19	187	19	1023
Travel Dist (mi)	5.5	20.6	13.0	18.6	30.4	0.7	2.4	34.1	3.3	128.5
Travel Time (hr)	0.6	2.3	0.8	3.6	4.4	0.1	0.2	2.8	0.3	15.1
Avg Speed (mph)	9	9	17	6	8	9	11	12	13	9
Fuel Used (gal)	2.6	10.2	4.3	12.3	17.4	0.3	1.1	13.8	1.2	63.3
HC Emissions (g)	0	2	0	1	4	0	0	2	1	11
CO Emissions (g)	98	434	139	287	765	17	38	465	116	2359
NOx Emissions (g)	1	5	1	3	10	0	0	5	2	28
Vehicles Entered	41	156	98	127	208	4	19	269	25	947
Vehicles Exited	40	153	97	122	202	5	19	268	26	932
Hourly Exit Rate	80	306	194	244	404	10	38	536	52	1864
Input Volume	69	318	200	246	422	8	38	541	47	1889
% of Volume	116	96	97	99	96	125	100	99	111	99
Denied Entry Before	0	0	0	1	1	0	0	0	0	2
Denied Entry After	0	0	0	1	1	0	0	0	0	2

Total Network Performance

Total Delay (hr)	11.0
Delay / Veh (s)	42.0
Total Stops	1023
Travel Dist (mi)	257.5
Travel Time (hr)	20.1
Avg Speed (mph)	14
Fuel Used (gal)	120.6
HC Emissions (g)	25
CO Emissions (g)	5776
NOx Emissions (g)	71
Vehicles Entered	947
Vehicles Exited	930
Hourly Exit Rate	1860
Input Volume	3778
% of Volume	49
Denied Entry Before	2
Denied Entry After	2

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	393	138	120	724	92	440
Average Queue (ft)	219	59	110	437	25	248
95th Queue (ft)	377	115	146	897	73	427
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)				9		
Queuing Penalty (veh)				0		
Storage Bay Dist (ft)			60		60	
Storage Blk Time (%)			58	21	1	33
Queuing Penalty (veh)			247	51	5	13

Network Summary

Network wide Queuing Penalty: 316

Intersection: 3: Mt. Wayte Ave & Union Ave

Phase	2	4	5	6
Movement(s) Served	NBTL	EBTL	NBL	SBTL
Maximum Green (s)	46.0	25.0	3.0	40.0
Minimum Green (s)	4.0	4.0	1.0	4.0
Recall	Max	None	Max	Max
Avg. Green (s)	46.4	23.9	3.0	40.4
g/C Ratio	0.58	0.30	0.04	0.50
Cycles Skipped (%)	0	0	0	0
Cycles @ Minimum (%)	0	0	0	0
Cycles Maxed Out (%)	100	82	100	100
Cycles with Peds (%)	0	0	0	0

Controller Summary
Average Cycle Length (s): 80.4
Number of Complete Cycles : 22

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Configurations						
Volume (vph)	220	84	418	658	31	407
Turn Type		Prot	pm+pt		Perm	
Protected Phases	4	4	5	2		6
Permitted Phases			2		6	
Detector Phase	4	4	5	2	6	6
Switch Phase						
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0
Total Split (s)	30.0	30.0	6.0	51.0	45.0	45.0
Total Split (%)	37.0%	37.0%	7.4%	63.0%	55.6%	55.6%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0
Lead/Lag			Lead		Lag	Lag
Lead-Lag Optimize?			Yes		Yes	Yes
Recall Mode	None	None	Max	Max	Max	Max

Intersection Summary
Cycle Length: 81
Actuated Cycle Length: 76.7
Natural Cycle: 70
Control Type: Semi Act-Uncoord
Description: Union Avenue at Mt. Wayte Avenue, Framingham

Splits and Phases: 3: Mt. Wayte Ave & Union Ave

S. Andrews, CTPS

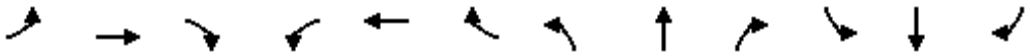
Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	367	95	449	709	43	516
v/c Ratio	0.77	0.20	1.10	0.68	0.15	0.54
Control Delay	37.1	6.1	91.1	15.4	12.6	15.2
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	37.1	6.1	91.1	15.4	12.6	15.2
Queue Length 50th (ft)	160	0	~126	212	10	152
Queue Length 95th (ft)	254	31	#346	377	24	263
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			60		60	
Base Capacity (vph)	585	552	410	1042	288	949
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.63	0.17	1.10	0.68	0.15	0.54

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	88	220	84	0	0	0	418	658	17	31	407	72
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	0.99		1.00	0.97	
Flt Protected		0.98	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1790	1492				1667	1730		1693	1797	
Flt Permitted		0.98	1.00				0.33	1.00		0.31	1.00	
Satd. Flow (perm)		1790	1492				586	1730		550	1797	
Peak-hour factor, PHF	0.63	0.97	0.88	0.25	0.25	0.25	0.93	0.96	0.71	0.72	0.96	0.78
Adj. Flow (vph)	140	227	95	0	0	0	449	685	24	43	424	92
RTOR Reduction (vph)	0	0	70	0	0	0	0	2	0	0	9	0
Lane Group Flow (vph)	0	367	25	0	0	0	449	707	0	43	507	0
Confl. Peds. (#/hr)	1						3		1	1		3
Heavy Vehicles (%)	0%	1%	1%	0%	0%	0%	1%	2%	0%	3%	3%	0%
Turn Type	Perm		Prot				pm+pt			Perm		
Protected Phases		4	4				5	2			6	
Permitted Phases	4						2			6		
Actuated Green, G (s)		20.5	20.5				46.1	46.1		40.1	40.1	
Effective Green, g (s)		20.5	20.5				46.1	46.1		40.1	40.1	
Actuated g/C Ratio		0.27	0.27				0.60	0.60		0.52	0.52	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				0.3	3.7		3.7	3.7	
Lane Grp Cap (vph)		479	399				395	1041		288	941	
v/s Ratio Prot			0.02				c0.04	0.41			0.28	
v/s Ratio Perm		0.21					c0.64			0.08		
v/c Ratio		0.77	0.06				1.14	0.68		0.15	0.54	
Uniform Delay, d1		25.8	20.9				18.2	10.3		9.4	12.1	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		7.6	0.1				88.0	3.6		1.1	2.2	
Delay (s)		33.5	21.0				106.2	13.9		10.5	14.3	
Level of Service		C	C				F	B		B	B	
Approach Delay (s)		30.9			0.0			49.7			14.0	
Approach LOS		C			A			D			B	

Intersection Summary			
HCM Average Control Delay	36.5	HCM Level of Service	D
HCM Volume to Capacity ratio	0.99		
Actuated Cycle Length (s)	76.6	Sum of lost time (s)	8.0
Intersection Capacity Utilization	77.1%	ICU Level of Service	D
Analysis Period (min)	15		

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	4:42	4:42	4:42	4:42	4:42	4:42
End Time	5:15	5:15	5:15	5:15	5:15	5:15
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	930	951	893	974	933	937
Vehs Exited	917	942	879	954	918	922
Starting Vehs	28	35	29	31	31	31
Ending Vehs	41	44	43	51	46	46
Denied Entry Before	4	1	1	4	6	3
Denied Entry After	105	86	124	37	34	78
Travel Distance (mi)	256	261	244	267	255	257
Travel Time (hr)	59.2	37.4	49.6	33.2	31.1	42.1
Total Delay (hr)	50.1	28.2	40.8	23.8	22.0	33.0
Total Stops	1382	1398	1540	1336	1210	1374
Fuel Used (gal)	211.0	161.1	184.1	154.3	144.3	171.0

Interval #0 Information Seeding

Start Time	4:42
End Time	4:45
Total Time (min)	3

Volumes adjusted by Growth Factors.

No data recorded this interval.

Interval #1 Information Recording

Start Time	4:45
End Time	5:15
Total Time (min)	30

Volumes adjusted by Growth Factors.

Run Number	1	2	3	4	5	Avg
Vehs Entered	930	951	893	974	933	937
Vehs Exited	917	942	879	954	918	922
Starting Vehs	28	35	29	31	31	31
Ending Vehs	41	44	43	51	46	46
Denied Entry Before	4	1	1	4	6	3
Denied Entry After	105	86	124	37	34	78
Travel Distance (mi)	256	261	244	267	255	257
Travel Time (hr)	59.2	37.4	49.6	33.2	31.1	42.1
Total Delay (hr)	50.1	28.2	40.8	23.8	22.0	33.0
Total Stops	1382	1398	1540	1336	1210	1374
Fuel Used (gal)	211.0	161.1	184.1	154.3	144.3	171.0

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.3	0.9	0.1	12.1	17.6	0.5	0.1	0.9	0.1	32.6
Delay / Veh (s)	29.6	29.1	5.9	243.9	222.4	194.0	26.9	15.3	9.5	126.2
Total Stops	35	94	33	463	588	20	15	106	20	1374
Travel Dist (mi)	5.5	14.9	6.1	26.5	42.2	1.3	2.1	26.1	4.3	129.0
Travel Time (hr)	0.6	1.4	0.3	13.1	19.0	0.5	0.2	1.8	0.3	37.2
Avg Speed (mph)	10	10	19	5	6	6	11	15	17	8
Fuel Used (gal)	2.5	6.9	1.8	36.1	54.5	1.5	0.9	9.8	1.4	115.6
HC Emissions (g)	0	0	0	1	2	0	0	1	0	5
CO Emissions (g)	54	174	49	291	680	11	28	364	36	1687
NOx Emissions (g)	0	2	0	3	6	0	0	4	0	16
Vehicles Entered	42	112	46	181	291	9	17	205	34	937
Vehicles Exited	42	114	46	177	280	9	17	205	34	924
Hourly Exit Rate	84	228	92	354	560	18	34	410	68	1848
Input Volume	88	220	84	418	658	17	31	407	72	1995
% of Volume	95	104	110	85	85	106	110	101	94	93
Denied Entry Before	0	0	0	2	1	0	0	0	0	3
Denied Entry After	0	0	0	29	48	1	0	0	0	78

Total Network Performance

Total Delay (hr)	33.0
Delay / Veh (s)	127.9
Total Stops	1374
Travel Dist (mi)	256.6
Travel Time (hr)	42.1
Avg Speed (mph)	12
Fuel Used (gal)	171.0
HC Emissions (g)	12
CO Emissions (g)	3893
NOx Emissions (g)	39
Vehicles Entered	937
Vehicles Exited	922
Hourly Exit Rate	1844
Input Volume	3990
% of Volume	46
Denied Entry Before	3
Denied Entry After	78

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	254	63	120	812	50	285
Average Queue (ft)	156	33	117	768	20	148
95th Queue (ft)	246	60	131	921	49	275
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)				25		
Queuing Penalty (veh)				0		
Storage Bay Dist (ft)			60		60	
Storage Blk Time (%)			57	26	0	22
Queuing Penalty (veh)			383	110	1	7

Network Summary

Network wide Queuing Penalty: 501

Intersection: 3: Mt. Wayte Ave & Union Ave

Phase	2	4	5	6
Movement(s) Served	NBTL	EBTL	NBL	SBTL
Maximum Green (s)	46.0	25.0	3.0	40.0
Minimum Green (s)	4.0	4.0	1.0	4.0
Recall	Max	None	Max	Max
Avg. Green (s)	48.6	20.2	3.1	40.3
g/C Ratio	0.62	0.26	0.04	0.51
Cycles Skipped (%)	0	0	0	0
Cycles @ Minimum (%)	0	0	0	0
Cycles Maxed Out (%)	100	35	100	100
Cycles with Peds (%)	0	0	0	0

Controller Summary
Average Cycle Length (s): 78.5
Number of Complete Cycles : 22

APPENDIX C

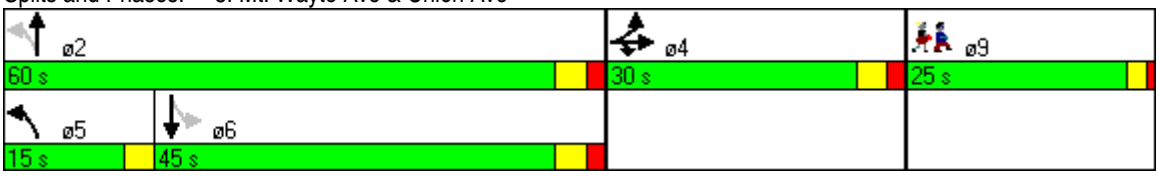
Alternative 1:
Add an Exclusive Pedestrian Phase and Optimize Signal Timing

AM/PM Peak-Hour Intersection Capacity Analysis:
Union Avenue at Mt. Wayte Avenue, Framingham

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT	ø9
Lane Configurations							
Volume (vph)	318	200	246	422	38	541	
Turn Type		Prot	pm+pt		Perm		
Protected Phases	4	4	5	2		6	9
Permitted Phases			2		6		
Detector Phase	4	4	5	2 5	6	6	
Switch Phase							
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0	25.0
Total Split (s)	30.0	30.0	15.0	60.0	45.0	45.0	25.0
Total Split (%)	26.1%	26.1%	13.0%	52.2%	39.1%	39.1%	22%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0	2.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0	
Lead/Lag			Lead		Lag	Lag	
Lead-Lag Optimize?			Yes		Yes	Yes	
Recall Mode	None	None	None	None	None	None	None

Intersection Summary
Cycle Length: 115
Actuated Cycle Length: 95
Natural Cycle: 150
Control Type: Actuated-Uncoordinated
Description: Union Avenue at Mt. Wayte Avenue, Framingham

Splits and Phases: 3: Mt. Wayte Ave & Union Ave



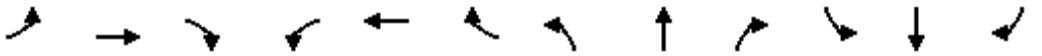
S. Andrews, CTPS

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	442	225	304	527	52	634
v/c Ratio	0.96	0.57	0.95	0.57	0.15	0.84
Control Delay	69.3	38.9	60.2	17.2	21.0	37.6
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	69.3	38.9	60.2	17.2	21.0	37.6
Queue Length 50th (ft)	243	109	96	159	17	301
Queue Length 95th (ft)	#592	#243	#308	367	46	#725
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			60		60	
Base Capacity (vph)	461	393	319	930	355	756
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.96	0.57	0.95	0.57	0.15	0.84

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	69	318	200	0	0	0	246	422	8	38	541	47
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	1.00		1.00	0.99	
Flt Protected		0.99	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1734	1478				1604	1591		1693	1777	
Flt Permitted		0.99	1.00				0.14	1.00		0.47	1.00	
Satd. Flow (perm)		1734	1478				239	1591		835	1777	
Peak-hour factor, PHF	0.72	0.92	0.89	0.25	0.25	0.25	0.81	0.82	0.67	0.73	0.93	0.90
Adj. Flow (vph)	96	346	225	0	0	0	304	515	12	52	582	52
RTOR Reduction (vph)	0	0	0	0	0	0	0	0	0	0	0	0
Lane Group Flow (vph)	0	442	225	0	0	0	304	527	0	52	634	0
Confl. Peds. (#/hr)	1						5		1	1		5
Heavy Vehicles (%)	4%	5%	2%	0%	0%	0%	5%	11%	13%	3%	4%	21%
Turn Type	Split		Prot				pm+pt			Perm		
Protected Phases	4	4	4				5	2			6	
Permitted Phases							2			6		
Actuated Green, G (s)		25.2	25.2				55.5	55.5		40.4	40.4	
Effective Green, g (s)		25.2	25.2				55.5	55.5		40.4	40.4	
Actuated g/C Ratio		0.26	0.26				0.57	0.57		0.42	0.42	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				2.0	4.0		4.0	4.0	
Lane Grp Cap (vph)		449	383				306	908		347	738	
v/s Ratio Prot		c0.25	0.15				c0.12	0.33			0.36	
v/s Ratio Perm							c0.44			0.06		
v/c Ratio		0.98	0.59				0.99	0.58		0.15	0.86	
Uniform Delay, d1		35.9	31.5				23.3	13.4		17.7	25.9	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		38.2	2.7				49.4	1.1		0.3	10.1	
Delay (s)		74.0	34.2				72.6	14.5		18.0	36.0	
Level of Service		E	C				E	B		B	D	
Approach Delay (s)		60.6			0.0			35.8			34.6	
Approach LOS		E			A			D			C	

Intersection Summary			
HCM Average Control Delay	43.0	HCM Level of Service	D
HCM Volume to Capacity ratio	0.96		
Actuated Cycle Length (s)	97.3	Sum of lost time (s)	14.6
Intersection Capacity Utilization	77.2%	ICU Level of Service	D
Analysis Period (min)	15		

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	7:57	7:57	7:57	7:57	7:57	7:57
End Time	8:30	8:30	8:30	8:30	8:30	8:30
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	962	1039	952	939	906	963
Vehs Exited	950	1013	930	942	914	950
Starting Vehs	34	30	30	46	42	34
Ending Vehs	46	56	52	43	34	47
Denied Entry Before	0	1	0	1	1	0
Denied Entry After	0	5	0	18	0	5
Travel Distance (mi)	263	281	258	260	251	263
Travel Time (hr)	27.2	29.1	25.4	25.5	19.5	25.3
Total Delay (hr)	17.9	19.1	16.2	16.2	10.5	16.0
Total Stops	1167	1446	1169	1094	879	1151
Fuel Used (gal)	139.1	150.9	134.6	134.7	117.9	135.4

Interval #0 Information Seeding

Start Time	7:57
End Time	8:00
Total Time (min)	3
Volumes adjusted by Growth Factors.	
No data recorded this interval.	

Interval #1 Information Recording

Start Time	8:00
End Time	8:30
Total Time (min)	30
Volumes adjusted by Growth Factors.	

Run Number	1	2	3	4	5	Avg
Vehs Entered	962	1039	952	939	906	963
Vehs Exited	950	1013	930	942	914	950
Starting Vehs	34	30	30	46	42	34
Ending Vehs	46	56	52	43	34	47
Denied Entry Before	0	1	0	1	1	0
Denied Entry After	0	5	0	18	0	5
Travel Distance (mi)	263	281	258	260	251	263
Travel Time (hr)	27.2	29.1	25.4	25.5	19.5	25.3
Total Delay (hr)	17.9	19.1	16.2	16.2	10.5	16.0
Total Stops	1167	1446	1169	1094	879	1151
Fuel Used (gal)	139.1	150.9	134.6	134.7	117.9	135.4

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.7	3.4	0.9	3.3	3.4	0.1	0.3	3.2	0.2	15.5
Delay / Veh (s)	74.7	77.5	33.4	91.9	59.4	52.2	51.5	40.6	40.6	58.4
Total Stops	48	226	84	236	243	6	25	262	21	1151
Travel Dist (mi)	4.6	21.0	13.3	19.1	31.0	0.7	2.4	35.7	2.6	130.4
Travel Time (hr)	0.9	4.1	1.5	4.0	4.5	0.1	0.3	4.4	0.3	20.2
Avg Speed (mph)	5	5	9	6	8	9	7	8	8	7
Fuel Used (gal)	3.3	15.0	6.4	13.2	17.8	0.4	1.4	18.7	1.3	77.3
HC Emissions (g)	0	2	1	2	4	0	0	2	1	11
CO Emissions (g)	107	405	210	376	763	31	35	468	118	2513
NOx Emissions (g)	1	4	2	4	10	0	0	5	1	29
Vehicles Entered	36	161	101	130	209	5	19	281	21	963
Vehicles Exited	34	156	101	127	208	5	18	282	20	951
Hourly Exit Rate	68	312	202	254	416	10	36	564	40	1902
Input Volume	69	318	200	246	422	8	38	541	47	1889
% of Volume	99	98	101	103	99	125	95	104	85	101
Denied Entry Before	0	0	0	0	0	0	0	0	0	0
Denied Entry After	0	0	0	2	3	0	0	0	0	5

Total Network Performance

Total Delay (hr)	16.0
Delay / Veh (s)	60.2
Total Stops	1151
Travel Dist (mi)	262.6
Travel Time (hr)	25.3
Avg Speed (mph)	11
Fuel Used (gal)	135.4
HC Emissions (g)	24
CO Emissions (g)	5718
NOx Emissions (g)	69
Vehicles Entered	963
Vehicles Exited	950
Hourly Exit Rate	1900
Input Volume	3778
% of Volume	50
Denied Entry Before	0
Denied Entry After	5

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	525	372	120	776	90	674
Average Queue (ft)	343	172	112	453	23	383
95th Queue (ft)	645	467	142	875	68	639
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)	1	0		9		1
Queuing Penalty (veh)	0	0		0		0
Storage Bay Dist (ft)			60		60	
Storage Blk Time (%)			56	24	0	48
Queuing Penalty (veh)			243	58	1	18

Network Summary

Network wide Queuing Penalty: 320

Intersection: 3: Mt. Wayte Ave & Union Ave

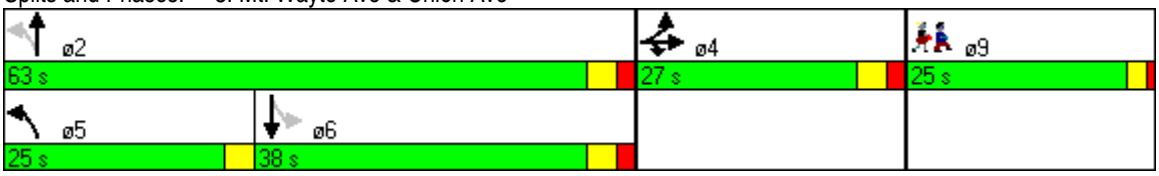
Phase	2	4	5	6	9
Movement(s) Served	NBTL	EBTL	NBL	SBTL	Ped
Maximum Green (s)	55.0	25.0	12.0	40.0	22.0
Minimum Green (s)	4.0	4.0	1.0	4.0	4.0
Recall	None	None	None	None	None
Avg. Green (s)	57.0	25.1	11.9	40.1	27.9
g/C Ratio	0.56	0.26	0.13	0.42	0.05
Cycles Skipped (%)	6	0	0	0	82
Cycles @ Minimum (%)	0	0	0	0	0
Cycles Maxed Out (%)	59	89	95	89	18
Cycles with Peds (%)	0	0	0	0	18

Controller Summary
Average Cycle Length (s): 95.2
Number of Complete Cycles : 18

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT	ø9
Lane Configurations							
Volume (vph)	220	84	418	658	31	407	
Turn Type		Prot	pm+pt		Perm		
Protected Phases	4	4	5	2		6	9
Permitted Phases			2		6		
Detector Phase	4	4	5	2 5	6	6	
Switch Phase							
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0	25.0
Total Split (s)	27.0	27.0	25.0	63.0	38.0	38.0	25.0
Total Split (%)	23.5%	23.5%	21.7%	54.8%	33.0%	33.0%	22%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0	2.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0	
Lead/Lag			Lead		Lag	Lag	
Lead-Lag Optimize?			Yes		Yes	Yes	
Recall Mode	None	None	None	None	None	None	None

Intersection Summary
Cycle Length: 115
Actuated Cycle Length: 95
Natural Cycle: 130
Control Type: Actuated-Uncoordinated
Description: Union Avenue at Mt. Wayte Avenue, Framingham

Splits and Phases: 3: Mt. Wayte Ave & Union Ave

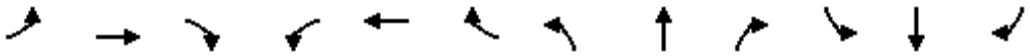


Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	367	95	449	709	43	516
v/c Ratio	0.88	0.27	0.89	0.66	0.17	0.82
Control Delay	59.0	34.6	40.6	17.8	26.7	41.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	59.0	34.6	40.6	17.8	26.7	41.7
Queue Length 50th (ft)	199	44	160	217	16	256
Queue Length 95th (ft)	#490	111	#503	605	44	#610
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			60		60	
Base Capacity (vph)	419	349	507	1067	248	630
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.88	0.27	0.89	0.66	0.17	0.82

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	88	220	84	0	0	0	418	658	17	31	407	72
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	0.99		1.00	0.97	
Flt Protected		0.98	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1791	1492				1668	1730		1693	1797	
Flt Permitted		0.98	1.00				0.16	1.00		0.40	1.00	
Satd. Flow (perm)		1791	1492				289	1730		705	1797	
Peak-hour factor, PHF	0.63	0.97	0.88	0.25	0.25	0.25	0.93	0.96	0.71	0.72	0.96	0.78
Adj. Flow (vph)	140	227	95	0	0	0	449	685	24	43	424	92
RTOR Reduction (vph)	0	0	0	0	0	0	0	0	0	0	0	0
Lane Group Flow (vph)	0	367	95	0	0	0	449	709	0	43	516	0
Confl. Peds. (#/hr)	1						3		1	1		3
Heavy Vehicles (%)	0%	1%	1%	0%	0%	0%	1%	2%	0%	3%	3%	0%
Turn Type	Split		Prot				pm+pt			Perm		
Protected Phases	4	4	4				5	2			6	
Permitted Phases							2			6		
Actuated Green, G (s)		22.2	22.2				58.6	58.6		33.4	33.4	
Effective Green, g (s)		22.2	22.2				58.6	58.6		33.4	33.4	
Actuated g/C Ratio		0.23	0.23				0.60	0.60		0.34	0.34	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				2.0	4.0		4.0	4.0	
Lane Grp Cap (vph)		408	340				488	1041		242	616	
v/s Ratio Prot		c0.20	0.06				c0.21	0.41			0.29	
v/s Ratio Perm							c0.34			0.06		
v/c Ratio		0.90	0.28				0.92	0.68		0.18	0.84	
Uniform Delay, d1		36.5	31.0				23.2	13.1		22.4	29.5	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		22.4	0.6				22.4	2.0		0.5	10.1	
Delay (s)		58.9	31.6				45.6	15.1		22.9	39.6	
Level of Service		E	C				D	B		C	D	
Approach Delay (s)		53.3			0.0			26.9			38.3	
Approach LOS		D			A			C			D	

Intersection Summary					
HCM Average Control Delay	35.4	HCM Level of Service		D	
HCM Volume to Capacity ratio	0.89				
Actuated Cycle Length (s)	97.4	Sum of lost time (s)		14.6	
Intersection Capacity Utilization	77.1%	ICU Level of Service		D	
Analysis Period (min)	15				

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	4:42	4:42	4:42	4:42	4:42	4:42
End Time	5:15	5:15	5:15	5:15	5:15	5:15
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	964	905	967	942	941	943
Vehs Exited	934	891	961	935	944	933
Starting Vehs	29	35	33	52	38	38
Ending Vehs	59	49	39	59	35	48
Denied Entry Before	0	0	0	9	10	4
Denied Entry After	77	148	44	44	23	67
Travel Distance (mi)	260	248	267	260	260	259
Travel Time (hr)	38.6	67.8	34.8	29.8	32.2	40.6
Total Delay (hr)	29.4	59.0	25.4	20.5	23.0	31.4
Total Stops	1371	1315	1334	1225	1159	1280
Fuel Used (gal)	166.1	229.6	157.8	145.0	150.4	169.8

Interval #0 Information Seeding

Start Time	4:42
End Time	4:45
Total Time (min)	3
Volumes adjusted by Growth Factors.	
No data recorded this interval.	

Interval #1 Information Recording

Start Time	4:45
End Time	5:15
Total Time (min)	30
Volumes adjusted by Growth Factors.	

Run Number	1	2	3	4	5	Avg
Vehs Entered	964	905	967	942	941	943
Vehs Exited	934	891	961	935	944	933
Starting Vehs	29	35	33	52	38	38
Ending Vehs	59	49	39	59	35	48
Denied Entry Before	0	0	0	9	10	4
Denied Entry After	77	148	44	44	23	67
Travel Distance (mi)	260	248	267	260	260	259
Travel Time (hr)	38.6	67.8	34.8	29.8	32.2	40.6
Total Delay (hr)	29.4	59.0	25.4	20.5	23.0	31.4
Total Stops	1371	1315	1334	1225	1159	1280
Fuel Used (gal)	166.1	229.6	157.8	145.0	150.4	169.8

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.8	1.9	0.3	9.8	15.3	0.3	0.2	2.1	0.3	31.1
Delay / Veh (s)	61.1	62.6	27.3	194.5	185.0	134.7	42.2	38.0	35.6	119.7
Total Stops	54	134	32	365	459	11	22	174	29	1280
Travel Dist (mi)	6.1	14.5	5.8	26.8	44.3	1.1	2.0	25.3	4.2	130.2
Travel Time (hr)	1.0	2.4	0.6	10.8	16.8	0.3	0.3	3.0	0.5	35.7
Avg Speed (mph)	6	6	10	6	7	7	8	9	9	7
Fuel Used (gal)	4.0	9.5	2.5	30.9	50.1	1.0	1.1	12.8	2.0	113.9
HC Emissions (g)	0	0	0	1	3	0	0	1	0	5
CO Emissions (g)	74	192	67	284	725	8	33	358	36	1777
NOx Emissions (g)	1	2	1	3	7	0	0	4	0	17
Vehicles Entered	46	110	44	183	303	7	16	201	33	943
Vehicles Exited	47	110	44	179	293	8	16	197	33	927
Hourly Exit Rate	94	220	88	358	586	16	32	394	66	1854
Input Volume	88	220	84	418	658	17	31	407	72	1995
% of Volume	107	100	105	86	89	94	103	97	92	93
Denied Entry Before	0	0	0	2	2	0	0	0	0	4
Denied Entry After	0	0	0	24	42	1	0	0	0	67

Total Network Performance

Total Delay (hr)	31.4
Delay / Veh (s)	120.7
Total Stops	1280
Travel Dist (mi)	259.1
Travel Time (hr)	40.6
Avg Speed (mph)	11
Fuel Used (gal)	169.8
HC Emissions (g)	12
CO Emissions (g)	3971
NOx Emissions (g)	40
Vehicles Entered	943
Vehicles Exited	933
Hourly Exit Rate	1866
Input Volume	3990
% of Volume	47
Denied Entry Before	4
Denied Entry After	67

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	406	110	120	804	105	433
Average Queue (ft)	238	54	118	744	29	273
95th Queue (ft)	421	101	123	945	85	463
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)				20		0
Queuing Penalty (veh)				0		0
Storage Bay Dist (ft)			60		60	
Storage Blk Time (%)			53	22	0	49
Queuing Penalty (veh)			357	92	0	15

Network Summary

Network wide Queuing Penalty: 464

Intersection: 3: Mt. Wayte Ave & Union Ave

Phase	2	4	5	6	9
Movement(s) Served	NBTL	EBTL	NBL	SBTL	Ped
Maximum Green (s)	58.0	22.0	22.0	33.0	22.0
Minimum Green (s)	4.0	4.0	1.0	4.0	4.0
Recall	None	None	None	None	None
Avg. Green (s)	62.5	21.9	22.5	35.6	27.9
g/C Ratio	0.62	0.22	0.22	0.36	0.05
Cycles Skipped (%)	0	0	0	0	82
Cycles @ Minimum (%)	0	0	0	0	0
Cycles Maxed Out (%)	76	78	100	89	18
Cycles with Peds (%)	0	0	0	0	18

Controller Summary
Average Cycle Length (s): 100.1
Number of Complete Cycles : 17

APPENDIX D

Alternative 2:
Add Concurrent Pedestrian Phases and Optimize Signal Timing

AM/PM Peak-Hour Intersection Capacity Analysis:
Union Avenue at Mt. Wayte Avenue, Framingham

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Configurations						
Volume (vph)	318	200	246	422	38	541
Turn Type		Prot	pm+pt		Perm	
Protected Phases	4	4	5	2		6
Permitted Phases			2		6	
Detector Phase	4	4	5	2 5	6	6
Switch Phase						
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0
Total Split (s)	29.0	29.0	13.0	61.0	48.0	48.0
Total Split (%)	32.2%	32.2%	14.4%	67.8%	53.3%	53.3%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0
Lead/Lag			Lead		Lag	Lag
Lead-Lag Optimize?			Yes		Yes	Yes
Recall Mode	Ped	Ped	None	Ped	Ped	Ped

Intersection Summary
Cycle Length: 90
Actuated Cycle Length: 80.7
Natural Cycle: 75
Control Type: Actuated-Uncoordinated
Description: Union Avenue at Mt. Wayte Avenue, Framingham

Splits and Phases: 3: Mt. Wayte Ave & Union Ave

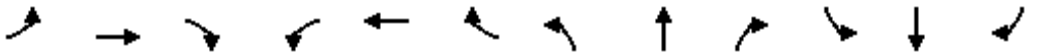
S. Andrews, CTPS

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	442	225	304	527	52	634
v/c Ratio	0.88	0.38	0.93	0.57	0.15	0.85
Control Delay	49.5	6.0	50.9	13.1	15.0	32.2
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	49.5	6.0	50.9	13.1	15.0	32.2
Queue Length 50th (ft)	217	0	82	153	16	277
Queue Length 95th (ft)	#435	52	#194	201	30	416
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			60		60	
Base Capacity (vph)	522	603	328	1119	450	963
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.85	0.37	0.93	0.47	0.12	0.66

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	69	318	200	0	0	0	246	422	8	38	541	47
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	1.00		1.00	0.99	
Flt Protected		0.99	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1733	1478				1604	1591		1692	1776	
Flt Permitted		0.99	1.00				0.16	1.00		0.47	1.00	
Satd. Flow (perm)		1733	1478				263	1591		834	1776	
Peak-hour factor, PHF	0.72	0.92	0.89	0.25	0.25	0.25	0.81	0.82	0.67	0.73	0.93	0.90
Adj. Flow (vph)	96	346	225	0	0	0	304	515	12	52	582	52
RTOR Reduction (vph)	0	0	159	0	0	0	0	1	0	0	4	0
Lane Group Flow (vph)	0	442	66	0	0	0	304	526	0	52	630	0
Confl. Peds. (#/hr)	1						5		1	1		5
Heavy Vehicles (%)	4%	5%	2%	0%	0%	0%	5%	11%	13%	3%	4%	21%
Turn Type	Perm		Prot				pm+pt			Perm		
Protected Phases		4	4				5	2			6	
Permitted Phases	4						2			6		
Actuated Green, G (s)		23.5	23.5				47.0	47.0		33.9	33.9	
Effective Green, g (s)		23.5	23.5				47.0	47.0		33.9	33.9	
Actuated g/C Ratio		0.29	0.29				0.58	0.58		0.42	0.42	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				2.0	4.0		4.0	4.0	
Lane Grp Cap (vph)		506	431				322	929		351	748	
v/s Ratio Prot			0.04				c0.12	0.33			0.35	
v/s Ratio Perm		0.26					c0.43			0.06		
v/c Ratio		0.87	0.15				0.94	0.57		0.15	0.84	
Uniform Delay, d1		27.1	21.1				16.9	10.4		14.4	20.9	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		15.7	0.2				35.1	1.0		0.3	8.9	
Delay (s)		42.8	21.3				52.1	11.4		14.7	29.8	
Level of Service		D	C				D	B		B	C	
Approach Delay (s)		35.6			0.0			26.3			28.6	
Approach LOS		D			A			C			C	

Intersection Summary			
HCM Average Control Delay	29.8	HCM Level of Service	C
HCM Volume to Capacity ratio	0.89		
Actuated Cycle Length (s)	80.5	Sum of lost time (s)	8.0
Intersection Capacity Utilization	77.2%	ICU Level of Service	D
Analysis Period (min)	15		

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	7:57	7:57	7:57	7:57	7:57	7:57
End Time	8:30	8:30	8:30	8:30	8:30	8:30
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	930	985	981	930	859	936
Vehs Exited	934	968	973	923	851	930
Starting Vehs	33	33	26	31	33	31
Ending Vehs	29	50	34	38	41	38
Denied Entry Before	0	2	1	2	1	1
Denied Entry After	2	2	0	0	1	1
Travel Distance (mi)	256	269	268	254	236	256
Travel Time (hr)	17.2	18.5	18.8	15.9	14.6	17.0
Total Delay (hr)	8.1	8.9	9.2	6.8	6.2	7.8
Total Stops	820	911	870	692	671	795
Fuel Used (gal)	113.4	119.3	120.6	108.9	100.4	112.5

Interval #0 Information Seeding

Start Time	7:57
End Time	8:00
Total Time (min)	3
Volumes adjusted by Growth Factors.	
No data recorded this interval.	

Interval #1 Information Recording

Start Time	8:00
End Time	8:30
Total Time (min)	30
Volumes adjusted by Growth Factors.	

Run Number	1	2	3	4	5	Avg
Vehs Entered	930	985	981	930	859	936
Vehs Exited	934	968	973	923	851	930
Starting Vehs	33	33	26	31	33	31
Ending Vehs	29	50	34	38	41	38
Denied Entry Before	0	2	1	2	1	1
Denied Entry After	2	2	0	0	1	1
Travel Distance (mi)	256	269	268	254	236	256
Travel Time (hr)	17.2	18.5	18.8	15.9	14.6	17.0
Total Delay (hr)	8.1	8.9	9.2	6.8	6.2	7.8
Total Stops	820	911	870	692	671	795
Fuel Used (gal)	113.4	119.3	120.6	108.9	100.4	112.5

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.5	1.8	0.3	1.5	1.2	0.0	0.1	1.8	0.1	7.4
Delay / Veh (s)	44.6	43.3	10.5	41.3	21.3	18.2	28.9	25.3	19.0	28.6
Total Stops	40	155	72	156	143	3	19	189	18	795
Travel Dist (mi)	5.1	20.3	13.3	18.9	31.0	0.7	2.3	33.1	3.1	127.6
Travel Time (hr)	0.7	2.6	0.8	2.1	2.3	0.1	0.2	3.0	0.3	12.0
Avg Speed (mph)	8	8	16	10	15	14	11	11	13	11
Fuel Used (gal)	2.7	10.9	4.5	8.6	12.2	0.2	1.1	14.2	1.2	55.6
HC Emissions (g)	0	2	0	1	4	0	0	2	1	10
CO Emissions (g)	89	413	154	239	700	7	33	483	122	2240
NOx Emissions (g)	1	5	1	2	10	0	0	6	2	27
Vehicles Entered	38	155	100	127	209	4	18	261	24	936
Vehicles Exited	38	152	100	126	206	5	18	258	24	927
Hourly Exit Rate	76	304	200	252	412	10	36	516	48	1854
Input Volume	69	318	200	246	422	8	38	541	47	1889
% of Volume	110	96	100	102	98	125	95	95	102	98
Denied Entry Before	0	0	0	0	1	0	0	0	0	1
Denied Entry After	0	0	0	1	0	0	0	0	0	1

Total Network Performance

Total Delay (hr)	7.8
Delay / Veh (s)	30.3
Total Stops	795
Travel Dist (mi)	256.5
Travel Time (hr)	17.0
Avg Speed (mph)	16
Fuel Used (gal)	112.5
HC Emissions (g)	24
CO Emissions (g)	5584
NOx Emissions (g)	68
Vehicles Entered	936
Vehicles Exited	930
Hourly Exit Rate	1860
Input Volume	3778
% of Volume	49
Denied Entry Before	1
Denied Entry After	1

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	458	216	120	558	105	486
Average Queue (ft)	245	74	97	247	24	267
95th Queue (ft)	414	189	144	522	76	458
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)				0		
Queuing Penalty (veh)				0		
Storage Bay Dist (ft)			60		60	
Storage Blk Time (%)			36	16	0	37
Queuing Penalty (veh)			155	40	1	14

Network Summary

Network wide Queuing Penalty: 210

Intersection: 3: Mt. Wayte Ave & Union Ave

Phase	2	4	5	6
Movement(s) Served	NBTL	EBTL	NBL	SBTL
Maximum Green (s)	56.0	24.0	10.0	43.0
Minimum Green (s)	4.0	4.0	1.0	4.0
Recall	Ped	Ped	None	Ped
Avg. Green (s)	53.1	23.3	10.0	39.8
g/C Ratio	0.61	0.27	0.12	0.46
Cycles Skipped (%)	0	0	0	0
Cycles @ Minimum (%)	0	0	0	0
Cycles Maxed Out (%)	50	81	95	55
Cycles with Peds (%)	100	100	0	100

Controller Summary
Average Cycle Length (s): 86.4
Number of Complete Cycles : 20

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Configurations						
Volume (vph)	220	84	418	658	31	407
Turn Type		Prot	pm+pt		Perm	
Protected Phases	4	4	5	2		6
Permitted Phases			2		6	
Detector Phase	4	4	5	2 5	6	6
Switch Phase						
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0
Total Split (s)	21.0	21.0	16.0	49.0	33.0	33.0
Total Split (%)	30.0%	30.0%	22.9%	70.0%	47.1%	47.1%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0
Lead/Lag			Lead		Lag	Lag
Lead-Lag Optimize?			Yes		Yes	Yes
Recall Mode	Ped	Ped	None	Ped	Ped	Ped

Intersection Summary
Cycle Length: 70
Actuated Cycle Length: 65.9
Natural Cycle: 70
Control Type: Actuated-Uncoordinated
Description: Union Avenue at Mt. Wayte Avenue, Framingham

Splits and Phases: 3: Mt. Wayte Ave & Union Ave

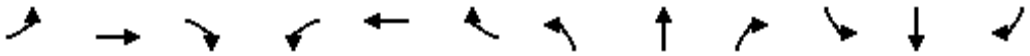
S. Andrews, CTPS

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	367	95	449	709	43	516
v/c Ratio	0.85	0.22	0.91	0.67	0.17	0.77
Control Delay	46.6	7.2	36.3	12.4	15.8	26.8
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	46.6	7.2	36.3	12.4	15.8	26.8
Queue Length 50th (ft)	143	0	97	166	11	174
Queue Length 95th (ft)	#302	32	#271	272	25	282
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			60		60	
Base Capacity (vph)	436	435	496	1160	301	776
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.84	0.22	0.91	0.61	0.14	0.66

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	88	220	84	0	0	0	418	658	17	31	407	72
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	0.99		1.00	0.97	
Flt Protected		0.98	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1790	1492				1668	1730		1693	1797	
Flt Permitted		0.98	1.00				0.21	1.00		0.40	1.00	
Satd. Flow (perm)		1790	1492				377	1730		705	1797	
Peak-hour factor, PHF	0.63	0.97	0.88	0.25	0.25	0.25	0.93	0.96	0.71	0.72	0.96	0.78
Adj. Flow (vph)	140	227	95	0	0	0	449	685	24	43	424	92
RTOR Reduction (vph)	0	0	72	0	0	0	0	2	0	0	12	0
Lane Group Flow (vph)	0	367	23	0	0	0	449	707	0	43	504	0
Confl. Peds. (#/hr)	1						3		1	1		3
Heavy Vehicles (%)	0%	1%	1%	0%	0%	0%	1%	2%	0%	3%	3%	0%
Turn Type	Perm		Prot				pm+pt			Perm		
Protected Phases		4	4				5	2			6	
Permitted Phases	4						2			6		
Actuated Green, G (s)		15.8	15.8				40.1	40.1		24.1	24.1	
Effective Green, g (s)		15.8	15.8				40.1	40.1		24.1	24.1	
Actuated g/C Ratio		0.24	0.24				0.61	0.61		0.37	0.37	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				2.0	4.0		4.0	4.0	
Lane Grp Cap (vph)		429	358				484	1053		258	657	
v/s Ratio Prot			0.02				c0.18	0.41			0.28	
v/s Ratio Perm		0.21					c0.38			0.06		
v/c Ratio		0.86	0.06				0.93	0.67		0.17	0.77	
Uniform Delay, d1		24.0	19.3				12.7	8.5		14.1	18.4	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		15.8	0.1				23.7	1.9		0.4	5.7	
Delay (s)		39.7	19.4				36.4	10.4		14.5	24.1	
Level of Service		D	B				D	B		B	C	
Approach Delay (s)		35.6			0.0			20.5			23.4	
Approach LOS		D			A			C			C	

Intersection Summary			
HCM Average Control Delay	24.4	HCM Level of Service	C
HCM Volume to Capacity ratio	0.87		
Actuated Cycle Length (s)	65.9	Sum of lost time (s)	8.0
Intersection Capacity Utilization	77.1%	ICU Level of Service	D
Analysis Period (min)	15		

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	4:42	4:42	4:42	4:42	4:42	4:42
End Time	5:15	5:15	5:15	5:15	5:15	5:15
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	1005	1028	981	996	969	996
Vehs Exited	998	1016	972	989	943	984
Starting Vehs	31	34	27	28	21	29
Ending Vehs	38	46	36	35	47	39
Denied Entry Before	4	1	1	1	5	2
Denied Entry After	44	29	51	2	6	27
Travel Distance (mi)	277	283	271	277	265	274
Travel Time (hr)	37.4	30.0	35.2	19.7	23.9	29.2
Total Delay (hr)	27.6	20.0	25.6	9.9	14.5	19.5
Total Stops	1529	1514	1460	1025	1377	1380
Fuel Used (gal)	167.6	150.9	159.7	124.0	131.6	146.8

Interval #0 Information Seeding

Start Time	4:42
End Time	4:45
Total Time (min)	3

Volumes adjusted by Growth Factors.

No data recorded this interval.

Interval #1 Information Recording

Start Time	4:45
End Time	5:15
Total Time (min)	30

Volumes adjusted by Growth Factors.

Run Number	1	2	3	4	5	Avg
Vehs Entered	1005	1028	981	996	969	996
Vehs Exited	998	1016	972	989	943	984
Starting Vehs	31	34	27	28	21	29
Ending Vehs	38	46	36	35	47	39
Denied Entry Before	4	1	1	1	5	2
Denied Entry After	44	29	51	2	6	27
Travel Distance (mi)	277	283	271	277	265	274
Travel Time (hr)	37.4	30.0	35.2	19.7	23.9	29.2
Total Delay (hr)	27.6	20.0	25.6	9.9	14.5	19.5
Total Stops	1529	1514	1460	1025	1377	1380
Fuel Used (gal)	167.6	150.9	159.7	124.0	131.6	146.8

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.5	1.4	0.1	6.4	8.6	0.3	0.2	1.4	0.2	19.1
Delay / Veh (s)	47.6	44.9	5.7	114.8	97.2	91.7	33.0	24.4	18.8	69.5
Total Stops	48	132	33	434	508	16	21	159	29	1380
Travel Dist (mi)	5.4	15.3	5.9	29.9	47.5	1.5	2.1	26.0	4.6	138.2
Travel Time (hr)	0.7	2.0	0.3	7.5	10.2	0.3	0.2	2.3	0.4	24.0
Avg Speed (mph)	7	8	19	7	9	9	10	12	12	9
Fuel Used (gal)	3.0	8.6	1.7	23.8	35.2	1.0	1.0	11.0	1.8	87.1
HC Emissions (g)	0	0	0	1	2	0	0	1	0	5
CO Emissions (g)	58	199	46	279	570	8	42	355	43	1600
NOx Emissions (g)	0	2	0	3	6	0	0	4	0	17
Vehicles Entered	41	116	44	202	325	10	17	205	36	996
Vehicles Exited	39	115	45	200	317	10	17	205	37	985
Hourly Exit Rate	78	230	90	400	634	20	34	410	74	1970
Input Volume	88	220	84	418	658	17	31	407	72	1995
% of Volume	89	105	107	96	96	118	110	101	103	99
Denied Entry Before	0	0	0	1	1	0	0	0	0	2
Denied Entry After	0	0	0	14	13	0	0	0	0	27

Total Network Performance

Total Delay (hr)	19.5
Delay / Veh (s)	71.1
Total Stops	1380
Travel Dist (mi)	274.5
Travel Time (hr)	29.2
Avg Speed (mph)	13
Fuel Used (gal)	146.8
HC Emissions (g)	12
CO Emissions (g)	3898
NOx Emissions (g)	40
Vehicles Entered	996
Vehicles Exited	984
Hourly Exit Rate	1968
Input Volume	3990
% of Volume	49
Denied Entry Before	2
Denied Entry After	27

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	328	58	120	814	109	368
Average Queue (ft)	183	32	118	659	26	207
95th Queue (ft)	317	56	128	1006	73	348
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)				12		
Queuing Penalty (veh)				0		
Storage Bay Dist (ft)			60		60	
Storage Blk Time (%)			48	21	0	38
Queuing Penalty (veh)			322	87	1	12

Network Summary

Network wide Queuing Penalty: 422

Intersection: 3: Mt. Wayte Ave & Union Ave

Phase	2	4	5	6
Movement(s) Served	NBTL	EBTL	NBL	SBTL
Maximum Green (s)	44.0	16.0	13.0	28.0
Minimum Green (s)	4.0	4.0	1.0	4.0
Recall	Ped	Ped	None	Ped
Avg. Green (s)	43.4	16.0	13.0	27.4
g/C Ratio	0.62	0.23	0.19	0.39
Cycles Skipped (%)	0	0	0	0
Cycles @ Minimum (%)	0	0	0	0
Cycles Maxed Out (%)	88	88	100	88
Cycles with Peds (%)	100	100	0	100

Controller Summary
Average Cycle Length (s): 69.8
Number of Complete Cycles : 25

APPENDIX E

Alternative 3:
Add an Exclusive Pedestrian Phase, Optimize Signal Timing,
and Lengthen the Northbound Left-Turn Lane

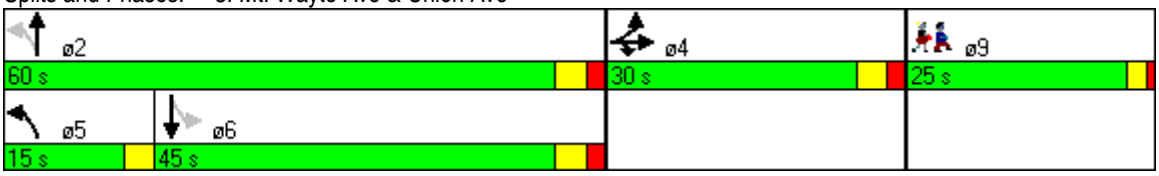
AM/PM Peak-Hour Intersection Capacity Analysis:
Union Avenue at Mt. Wayte Avenue, Framingham

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT	ø9
Lane Configurations							
Volume (vph)	318	200	246	422	38	541	
Turn Type		Prot	pm+pt		Perm		
Protected Phases	4	4	5	2		6	9
Permitted Phases			2		6		
Detector Phase	4	4	5	2 5	6	6	
Switch Phase							
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	4.0	25.0	25.0	25.0	25.0
Total Split (s)	30.0	30.0	15.0	60.0	45.0	45.0	25.0
Total Split (%)	26.1%	26.1%	13.0%	52.2%	39.1%	39.1%	22%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0	2.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0	
Lead/Lag			Lead		Lag	Lag	
Lead-Lag Optimize?			Yes		Yes	Yes	
Recall Mode	None	None	None	None	None	None	None
Act Effct Green (s)	25.2	25.2	57.6	55.5	40.4	40.4	
Actuated g/C Ratio	0.27	0.27	0.61	0.58	0.43	0.43	
v/c Ratio	0.96	0.57	0.95	0.57	0.15	0.84	
Control Delay	69.3	38.9	60.2	17.2	21.0	37.6	
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0	
Total Delay	69.3	38.9	60.2	17.2	21.0	37.6	
LOS	E	D	E	B	C	D	
Approach Delay	59.0			32.9		36.3	
Approach LOS	E			C		D	

Intersection Summary

Cycle Length: 115
Actuated Cycle Length: 95
Natural Cycle: 150
Control Type: Actuated-Uncoordinated
Maximum v/c Ratio: 0.96
Intersection Signal Delay: 42.0 — Intersection LOS: D
Intersection Capacity Utilization 77.2% — ICU Level of Service D
Analysis Period (min) 15
Description: Union Avenue at Mt. Wayte Avenue, Framingham

Splits and Phases: 3: Mt. Wayte Ave & Union Ave

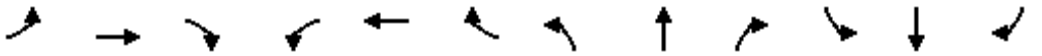


Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	442	225	304	527	52	634
v/c Ratio	0.96	0.57	0.95	0.57	0.15	0.84
Control Delay	69.3	38.9	60.2	17.2	21.0	37.6
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	69.3	38.9	60.2	17.2	21.0	37.6
Queue Length 50th (ft)	243	109	96	159	17	301
Queue Length 95th (ft)	#592	#243	#308	367	46	#725
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			150		60	
Base Capacity (vph)	461	393	319	930	355	756
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.96	0.57	0.95	0.57	0.15	0.84

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	69	318	200	0	0	0	246	422	8	38	541	47
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	1.00		1.00	0.99	
Flt Protected		0.99	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1734	1478				1604	1591		1693	1777	
Flt Permitted		0.99	1.00				0.14	1.00		0.47	1.00	
Satd. Flow (perm)		1734	1478				239	1591		835	1777	
Peak-hour factor, PHF	0.72	0.92	0.89	0.25	0.25	0.25	0.81	0.82	0.67	0.73	0.93	0.90
Adj. Flow (vph)	96	346	225	0	0	0	304	515	12	52	582	52
RTOR Reduction (vph)	0	0	0	0	0	0	0	0	0	0	0	0
Lane Group Flow (vph)	0	442	225	0	0	0	304	527	0	52	634	0
Confl. Peds. (#/hr)	1						5		1	1		5
Heavy Vehicles (%)	4%	5%	2%	0%	0%	0%	5%	11%	13%	3%	4%	21%
Turn Type	Split		Prot				pm+pt			Perm		
Protected Phases	4	4	4				5	2			6	
Permitted Phases							2			6		
Actuated Green, G (s)		25.2	25.2				55.5	55.5		40.4	40.4	
Effective Green, g (s)		25.2	25.2				55.5	55.5		40.4	40.4	
Actuated g/C Ratio		0.26	0.26				0.57	0.57		0.42	0.42	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				2.0	4.0		4.0	4.0	
Lane Grp Cap (vph)		449	383				306	908		347	738	
v/s Ratio Prot		c0.25	0.15				c0.12	0.33			0.36	
v/s Ratio Perm							c0.44			0.06		
v/c Ratio		0.98	0.59				0.99	0.58		0.15	0.86	
Uniform Delay, d1		35.9	31.5				23.3	13.4		17.7	25.9	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		38.2	2.7				49.4	1.1		0.3	10.1	
Delay (s)		74.0	34.2				72.6	14.5		18.0	36.0	
Level of Service		E	C				E	B		B	D	
Approach Delay (s)		60.6			0.0			35.8			34.6	
Approach LOS		E			A			D			C	

Intersection Summary					
HCM Average Control Delay	43.0	HCM Level of Service		D	
HCM Volume to Capacity ratio	0.96				
Actuated Cycle Length (s)	97.3	Sum of lost time (s)		14.6	
Intersection Capacity Utilization	77.2%	ICU Level of Service		D	
Analysis Period (min)	15				

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	7:57	7:57	7:57	7:57	7:57	7:57
End Time	8:30	8:30	8:30	8:30	8:30	8:30
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	951	1016	947	953	918	956
Vehs Exited	947	974	937	934	918	942
Starting Vehs	22	26	25	40	34	30
Ending Vehs	26	68	35	59	34	45
Denied Entry Before	0	1	0	1	1	0
Denied Entry After	0	0	0	6	1	1
Travel Distance (mi)	263	273	259	257	253	261
Travel Time (hr)	21.3	23.4	20.9	20.7	17.5	20.8
Total Delay (hr)	11.9	13.7	11.7	11.6	8.5	11.5
Total Stops	909	983	841	892	746	875
Fuel Used (gal)	126.2	132.3	123.4	122.1	111.9	123.2

Interval #0 Information Seeding

Start Time	7:57
End Time	8:00
Total Time (min)	3

Volumes adjusted by Growth Factors.

No data recorded this interval.

Interval #1 Information Recording

Start Time	8:00
End Time	8:30
Total Time (min)	30

Volumes adjusted by Growth Factors.

Run Number	1	2	3	4	5	Avg
Vehs Entered	951	1016	947	953	918	956
Vehs Exited	947	974	937	934	918	942
Starting Vehs	22	26	25	40	34	30
Ending Vehs	26	68	35	59	34	45
Denied Entry Before	0	1	0	1	1	0
Denied Entry After	0	0	0	6	1	1
Travel Distance (mi)	263	273	259	257	253	261
Travel Time (hr)	21.3	23.4	20.9	20.7	17.5	20.8
Total Delay (hr)	11.9	13.7	11.7	11.6	8.5	11.5
Total Stops	909	983	841	892	746	875
Fuel Used (gal)	126.2	132.3	123.4	122.1	111.9	123.2

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.5	2.6	0.9	1.8	1.3	0.0	0.3	3.4	0.3	11.0
Delay / Veh (s)	62.4	60.7	33.2	52.1	20.3	12.5	48.0	44.3	45.1	41.7
Total Stops	36	178	78	146	120	1	31	263	22	875
Travel Dist (mi)	4.1	20.2	13.0	18.2	33.0	0.6	2.8	35.1	2.8	129.8
Travel Time (hr)	0.7	3.3	1.4	2.4	2.4	0.0	0.4	4.6	0.4	15.7
Avg Speed (mph)	6	6	9	8	15	18	8	8	8	9
Fuel Used (gal)	2.6	12.8	6.2	9.3	12.8	0.2	1.6	18.9	1.5	65.8
HC Emissions (g)	0	2	1	1	4	0	0	2	1	11
CO Emissions (g)	74	425	209	283	737	14	49	489	109	2389
NOx Emissions (g)	1	5	2	3	10	0	1	6	1	28
Vehicles Entered	32	155	99	123	222	4	22	277	22	956
Vehicles Exited	30	149	96	122	222	4	22	276	22	943
Hourly Exit Rate	60	298	192	244	444	8	44	552	44	1886
Input Volume	69	318	200	246	422	8	38	541	47	1889
% of Volume	87	94	96	99	105	100	116	102	94	100
Denied Entry Before	0	0	0	0	0	0	0	0	0	0
Denied Entry After	0	0	0	0	1	0	0	0	0	1

Total Network Performance

Total Delay (hr)	11.5
Delay / Veh (s)	43.5
Total Stops	875
Travel Dist (mi)	260.9
Travel Time (hr)	20.8
Avg Speed (mph)	13
Fuel Used (gal)	123.2
HC Emissions (g)	24
CO Emissions (g)	5545
NOx Emissions (g)	68
Vehicles Entered	956
Vehicles Exited	942
Hourly Exit Rate	1884
Input Volume	3778
% of Volume	50
Denied Entry Before	0
Denied Entry After	1

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	521	337	229	473	92	594
Average Queue (ft)	286	128	140	217	25	394
95th Queue (ft)	519	288	242	466	70	669
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)	0					3
Queuing Penalty (veh)	0					0
Storage Bay Dist (ft)			150		60	
Storage Blk Time (%)			15	9	1	48
Queuing Penalty (veh)			66	21	4	18

Network Summary

Network wide Queuing Penalty: 110

Intersection: 3: Mt. Wayte Ave & Union Ave

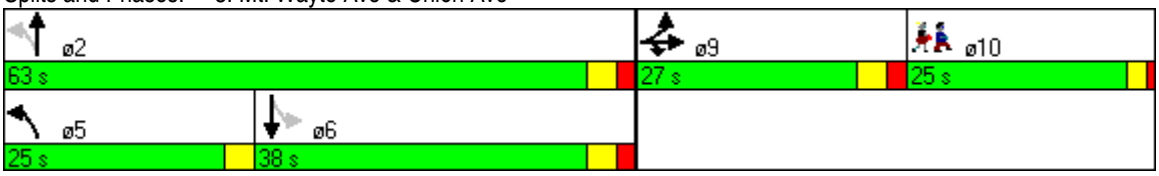
Phase	2	4	5	6	9
Movement(s) Served	NBTL	EBTL	NBL	SBTL	Ped
Maximum Green (s)	55.0	25.0	12.0	40.0	22.0
Minimum Green (s)	4.0	4.0	1.0	4.0	4.0
Recall	None	None	None	None	None
Avg. Green (s)	54.5	25.6	12.3	40.8	26.4
g/C Ratio	0.57	0.27	0.13	0.43	0.06
Cycles Skipped (%)	0	0	0	0	76
Cycles @ Minimum (%)	0	0	0	0	0
Cycles Maxed Out (%)	56	83	94	83	24
Cycles with Peds (%)	0	0	0	0	24

Controller Summary
Average Cycle Length (s): 95.8
Number of Complete Cycles : 18

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT	ø10
Lane Configurations							
Volume (vph)	220	84	418	658	31	407	
Turn Type		Prot	pm+pt		Perm		
Protected Phases	9	9	5	2		6	10
Permitted Phases			2		6		
Detector Phase	9	9	5	2 5	6	6	
Switch Phase							
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0	25.0
Total Split (s)	27.0	27.0	25.0	63.0	38.0	38.0	25.0
Total Split (%)	23.5%	23.5%	21.7%	54.8%	33.0%	33.0%	22%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0	2.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0	
Lead/Lag	Lead	Lead	Lead		Lag	Lag	Lag
Lead-Lag Optimize?	Yes	Yes	Yes		Yes	Yes	Yes
Recall Mode	None	None	None	None	None	None	None

Intersection Summary
Cycle Length: 115
Actuated Cycle Length: 95
Natural Cycle: 130
Control Type: Actuated-Uncoordinated
Description: Union Avenue at Mt. Wayte Avenue, Framingham

Splits and Phases: 3: Mt. Wayte Ave & Union Ave

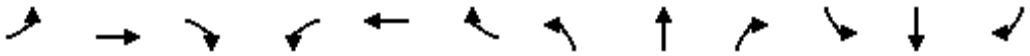


Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	367	95	449	709	43	516
v/c Ratio	0.88	0.27	0.89	0.66	0.17	0.82
Control Delay	59.0	34.6	40.6	17.8	26.7	41.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	59.0	34.6	40.6	17.8	26.7	41.7
Queue Length 50th (ft)	199	44	160	217	16	256
Queue Length 95th (ft)	#490	111	#503	605	44	#610
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			150		60	
Base Capacity (vph)	419	349	507	1067	248	630
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.88	0.27	0.89	0.66	0.17	0.82

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	88	220	84	0	0	0	418	658	17	31	407	72
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	0.99		1.00	0.97	
Flt Protected		0.98	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1791	1492				1668	1730		1693	1797	
Flt Permitted		0.98	1.00				0.16	1.00		0.40	1.00	
Satd. Flow (perm)		1791	1492				289	1730		705	1797	
Peak-hour factor, PHF	0.63	0.97	0.88	0.25	0.25	0.25	0.93	0.96	0.71	0.72	0.96	0.78
Adj. Flow (vph)	140	227	95	0	0	0	449	685	24	43	424	92
RTOR Reduction (vph)	0	0	0	0	0	0	0	0	0	0	0	0
Lane Group Flow (vph)	0	367	95	0	0	0	449	709	0	43	516	0
Confl. Peds. (#/hr)	1						3		1	1		3
Heavy Vehicles (%)	0%	1%	1%	0%	0%	0%	1%	2%	0%	3%	3%	0%
Turn Type	Split		Prot				pm+pt			Perm		
Protected Phases	9	9	9				5	2			6	
Permitted Phases							2			6		
Actuated Green, G (s)		22.2	22.2				58.6	58.6		33.4	33.4	
Effective Green, g (s)		22.2	22.2				58.6	58.6		33.4	33.4	
Actuated g/C Ratio		0.23	0.23				0.60	0.60		0.34	0.34	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				2.0	4.0		4.0	4.0	
Lane Grp Cap (vph)		408	340				488	1041		242	616	
v/s Ratio Prot		c0.20	0.06				c0.21	0.41			0.29	
v/s Ratio Perm							c0.34			0.06		
v/c Ratio		0.90	0.28				0.92	0.68		0.18	0.84	
Uniform Delay, d1		36.5	31.0				23.2	13.1		22.4	29.5	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		22.4	0.6				22.4	2.0		0.5	10.1	
Delay (s)		58.9	31.6				45.6	15.1		22.9	39.6	
Level of Service		E	C				D	B		C	D	
Approach Delay (s)		53.3			0.0			26.9			38.3	
Approach LOS		D			A			C			D	

Intersection Summary					
HCM Average Control Delay	35.4	HCM Level of Service		D	
HCM Volume to Capacity ratio	0.89				
Actuated Cycle Length (s)	97.4	Sum of lost time (s)		14.6	
Intersection Capacity Utilization	77.1%	ICU Level of Service		D	
Analysis Period (min)	15				

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	4:42	4:42	4:42	4:42	4:42	4:42
End Time	5:15	5:15	5:15	5:15	5:15	5:15
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	1029	1027	1018	970	913	991
Vehs Exited	1031	986	1006	971	918	983
Starting Vehs	28	29	32	39	29	31
Ending Vehs	26	70	44	38	24	40
Denied Entry Before	0	0	0	1	9	2
Denied Entry After	3	89	2	7	2	20
Travel Distance (mi)	286	278	281	270	256	274
Travel Time (hr)	29.4	45.3	26.5	20.7	17.6	27.9
Total Delay (hr)	19.3	35.4	16.5	11.1	8.6	18.2
Total Stops	1043	1324	1118	829	729	1008
Fuel Used (gal)	151.4	186.3	141.3	123.8	112.4	143.0

Interval #0 Information Seeding

Start Time	4:42
End Time	4:45
Total Time (min)	3

Volumes adjusted by Growth Factors.

No data recorded this interval.

Interval #1 Information Recording

Start Time	4:45
End Time	5:15
Total Time (min)	30

Volumes adjusted by Growth Factors.

Run Number	1	2	3	4	5	Avg
Vehs Entered	1029	1027	1018	970	913	991
Vehs Exited	1031	986	1006	971	918	983
Starting Vehs	28	29	32	39	29	31
Ending Vehs	26	70	44	38	24	40
Denied Entry Before	0	0	0	1	9	2
Denied Entry After	3	89	2	7	2	20
Travel Distance (mi)	286	278	281	270	256	274
Travel Time (hr)	29.4	45.3	26.5	20.7	17.6	27.9
Total Delay (hr)	19.3	35.4	16.5	11.1	8.6	18.2
Total Stops	1043	1324	1118	829	729	1008
Fuel Used (gal)	151.4	186.3	141.3	123.8	112.4	143.0

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.8	2.0	0.4	5.2	5.8	0.1	0.2	2.6	0.5	17.7
Delay / Veh (s)	63.1	64.8	31.3	91.3	67.8	58.5	51.7	45.5	46.5	64.6
Total Stops	56	132	34	268	243	7	22	206	40	1008
Travel Dist (mi)	6.2	14.5	5.9	30.5	46.2	1.3	1.9	26.2	5.0	137.8
Travel Time (hr)	1.1	2.5	0.6	6.3	7.4	0.2	0.3	3.5	0.7	22.6
Avg Speed (mph)	6	6	9	8	12	12	7	8	7	8
Fuel Used (gal)	4.1	9.5	2.7	21.0	27.4	0.7	1.1	14.3	2.6	83.5
HC Emissions (g)	0	0	0	1	2	0	0	1	0	5
CO Emissions (g)	70	177	92	274	484	8	38	379	39	1561
NOx Emissions (g)	1	1	1	3	6	0	0	4	0	16
Vehicles Entered	47	110	45	207	312	9	15	207	39	991
Vehicles Exited	48	108	45	204	307	9	15	206	39	981
Hourly Exit Rate	96	216	90	408	614	18	30	412	78	1962
Input Volume	88	220	84	418	658	17	31	407	72	1995
% of Volume	109	98	107	98	93	106	97	101	108	98
Denied Entry Before	0	0	0	1	1	0	0	0	0	2
Denied Entry After	0	0	0	8	12	0	0	0	0	20

Total Network Performance

Total Delay (hr)	18.2
Delay / Veh (s)	66.3
Total Stops	1008
Travel Dist (mi)	274.1
Travel Time (hr)	27.9
Avg Speed (mph)	13
Fuel Used (gal)	143.0
HC Emissions (g)	11
CO Emissions (g)	3768
NOx Emissions (g)	40
Vehicles Entered	991
Vehicles Exited	983
Hourly Exit Rate	1966
Input Volume	3990
% of Volume	49
Denied Entry Before	2
Denied Entry After	20

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	404	145	230	693	94	521
Average Queue (ft)	245	59	197	455	25	330
95th Queue (ft)	434	123	279	876	76	520
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)				4		
Queuing Penalty (veh)				0		
Storage Bay Dist (ft)			150		60	
Storage Blk Time (%)			29	13	1	53
Queuing Penalty (veh)			195	55	5	17

Network Summary

Network wide Queuing Penalty: 272

Intersection: 3: Mt. Wayte Ave & Union Ave

Phase	2	5	6	9	10
Movement(s) Served	NBTL	NBL	SBTL	EBTL	Ped
Maximum Green (s)	58.0	22.0	33.0	22.0	22.0
Minimum Green (s)	4.0	1.0	4.0	4.0	4.0
Recall	None	None	None	None	None
Avg. Green (s)	59.3	21.7	32.1	21.2	23.1
g/C Ratio	0.63	0.23	0.34	0.22	0.05
Cycles Skipped (%)	0	0	0	0	78
Cycles @ Minimum (%)	0	0	0	0	0
Cycles Maxed Out (%)	56	89	84	74	22
Cycles with Peds (%)	0	0	0	0	22

Controller Summary
Average Cycle Length (s): 94.4
Number of Complete Cycles : 18

APPENDIX F

Alternative 4:
Add Concurrent Pedestrian Phases, Optimize Signal Timing,
and Lengthen the Northbound Left-Turn Lane

AM/PM Peak-Hour Intersection Capacity Analysis:
Union Avenue at Mt. Wayte Avenue, Framingham

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Configurations						
Volume (vph)	318	200	246	422	38	541
Turn Type		Prot	pm+pt		Perm	
Protected Phases	4	4	5	2		6
Permitted Phases			2		6	
Detector Phase	4	4	5	2 5	6	6
Switch Phase						
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0
Total Split (s)	29.0	29.0	13.0	61.0	48.0	48.0
Total Split (%)	32.2%	32.2%	14.4%	67.8%	53.3%	53.3%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0
Lead/Lag			Lead		Lag	Lag
Lead-Lag Optimize?			Yes		Yes	Yes
Recall Mode	Ped	Ped	None	Ped	Ped	Ped

Intersection Summary
Cycle Length: 90
Actuated Cycle Length: 80.7
Natural Cycle: 75
Control Type: Actuated-Uncoordinated
Description: Union Avenue at Mt. Wayte Avenue, Framingham

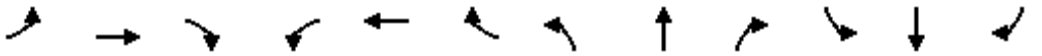
Splits and Phases: 3: Mt. Wayte Ave & Union Ave

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	442	225	304	527	52	634
v/c Ratio	0.88	0.38	0.93	0.57	0.15	0.85
Control Delay	49.5	6.0	50.9	13.1	15.0	32.2
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	49.5	6.0	50.9	13.1	15.0	32.2
Queue Length 50th (ft)	217	0	82	153	16	277
Queue Length 95th (ft)	#435	52	#194	201	30	416
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			150		60	
Base Capacity (vph)	522	603	328	1119	450	963
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.85	0.37	0.93	0.47	0.12	0.66

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	69	318	200	0	0	0	246	422	8	38	541	47
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	1.00		1.00	0.99	
Flt Protected		0.99	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1733	1478				1604	1591		1692	1776	
Flt Permitted		0.99	1.00				0.16	1.00		0.47	1.00	
Satd. Flow (perm)		1733	1478				263	1591		834	1776	
Peak-hour factor, PHF	0.72	0.92	0.89	0.25	0.25	0.25	0.81	0.82	0.67	0.73	0.93	0.90
Adj. Flow (vph)	96	346	225	0	0	0	304	515	12	52	582	52
RTOR Reduction (vph)	0	0	159	0	0	0	0	1	0	0	4	0
Lane Group Flow (vph)	0	442	66	0	0	0	304	526	0	52	630	0
Confl. Peds. (#/hr)	1						5		1	1		5
Heavy Vehicles (%)	4%	5%	2%	0%	0%	0%	5%	11%	13%	3%	4%	21%
Turn Type	Perm		Prot				pm+pt			Perm		
Protected Phases		4	4				5	2			6	
Permitted Phases	4						2			6		
Actuated Green, G (s)		23.5	23.5				47.0	47.0		33.9	33.9	
Effective Green, g (s)		23.5	23.5				47.0	47.0		33.9	33.9	
Actuated g/C Ratio		0.29	0.29				0.58	0.58		0.42	0.42	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				2.0	4.0		4.0	4.0	
Lane Grp Cap (vph)		506	431				322	929		351	748	
v/s Ratio Prot			0.04				c0.12	0.33			0.35	
v/s Ratio Perm		0.26					c0.43			0.06		
v/c Ratio		0.87	0.15				0.94	0.57		0.15	0.84	
Uniform Delay, d1		27.1	21.1				16.9	10.4		14.4	20.9	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		15.7	0.2				35.1	1.0		0.3	8.9	
Delay (s)		42.8	21.3				52.1	11.4		14.7	29.8	
Level of Service		D	C				D	B		B	C	
Approach Delay (s)		35.6			0.0			26.3			28.6	
Approach LOS		D			A			C			C	

Intersection Summary			
HCM Average Control Delay	29.8	HCM Level of Service	C
HCM Volume to Capacity ratio	0.89		
Actuated Cycle Length (s)	80.5	Sum of lost time (s)	8.0
Intersection Capacity Utilization	77.2%	ICU Level of Service	D
Analysis Period (min)	15		

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	7:57	7:57	7:57	7:57	7:57	7:57
End Time	8:30	8:30	8:30	8:30	8:30	8:30
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	925	994	987	946	881	947
Vehs Exited	928	982	976	940	868	939
Starting Vehs	33	33	26	31	34	31
Ending Vehs	30	45	37	37	47	39
Denied Entry Before	0	2	1	2	1	1
Denied Entry After	2	2	0	0	1	1
Travel Distance (mi)	254	271	271	259	240	259
Travel Time (hr)	16.5	17.3	18.2	16.7	14.6	16.6
Total Delay (hr)	7.5	7.6	8.5	7.5	6.0	7.4
Total Stops	723	776	788	734	617	727
Fuel Used (gal)	110.9	116.9	118.7	111.9	100.7	111.8

Interval #0 Information Seeding

Start Time	7:57
End Time	8:00
Total Time (min)	3

Volumes adjusted by Growth Factors.

No data recorded this interval.

Interval #1 Information Recording

Start Time	8:00
End Time	8:30
Total Time (min)	30

Volumes adjusted by Growth Factors.

Run Number	1	2	3	4	5	Avg
Vehs Entered	925	994	987	946	881	947
Vehs Exited	928	982	976	940	868	939
Starting Vehs	33	33	26	31	34	31
Ending Vehs	30	45	37	37	47	39
Denied Entry Before	0	2	1	2	1	1
Denied Entry After	2	2	0	0	1	1
Travel Distance (mi)	254	271	271	259	240	259
Travel Time (hr)	16.5	17.3	18.2	16.7	14.6	16.6
Total Delay (hr)	7.5	7.6	8.5	7.5	6.0	7.4
Total Stops	723	776	788	734	617	727
Fuel Used (gal)	110.9	116.9	118.7	111.9	100.7	111.8

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.5	1.9	0.3	1.3	0.8	0.0	0.1	1.9	0.2	7.0
Delay / Veh (s)	45.9	43.9	10.4	36.8	13.6	12.4	29.5	25.9	21.2	26.7
Total Stops	43	164	70	133	88	2	17	190	20	727
Travel Dist (mi)	5.2	20.7	13.0	19.3	31.5	0.7	2.2	33.1	3.3	128.9
Travel Time (hr)	0.7	2.6	0.8	2.0	1.9	0.0	0.2	3.0	0.3	11.6
Avg Speed (mph)	8	8	16	11	18	16	11	11	12	12
Fuel Used (gal)	2.8	11.2	4.4	8.3	11.1	0.2	1.0	14.3	1.3	54.6
HC Emissions (g)	0	2	0	1	3	0	0	2	1	9
CO Emissions (g)	85	426	148	230	601	11	31	483	117	2133
NOx Emissions (g)	1	5	1	2	8	0	0	6	2	25
Vehicles Entered	39	158	99	130	213	4	17	261	26	947
Vehicles Exited	39	156	99	128	210	5	16	259	26	938
Hourly Exit Rate	78	312	198	256	420	10	32	518	52	1876
Input Volume	69	318	200	246	422	8	38	541	47	1889
% of Volume	113	98	99	104	100	125	84	96	111	99
Denied Entry Before	0	0	0	0	1	0	0	0	0	1
Denied Entry After	0	0	0	1	0	0	0	0	0	1

Total Network Performance

Total Delay (hr)	7.4
Delay / Veh (s)	28.3
Total Stops	727
Travel Dist (mi)	259.2
Travel Time (hr)	16.6
Avg Speed (mph)	16
Fuel Used (gal)	111.8
HC Emissions (g)	23
CO Emissions (g)	5396
NOx Emissions (g)	66
Vehicles Entered	947
Vehicles Exited	939
Hourly Exit Rate	1878
Input Volume	3778
% of Volume	50
Denied Entry Before	1
Denied Entry After	1

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	438	187	225	385	104	490
Average Queue (ft)	256	66	126	149	23	270
95th Queue (ft)	421	139	224	318	75	471
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)						0
Queuing Penalty (veh)						0
Storage Bay Dist (ft)			150		60	
Storage Blk Time (%)			9	3	0	38
Queuing Penalty (veh)			37	8	0	14

Network Summary

Network wide Queuing Penalty: 60

Intersection: 3: Mt. Wayte Ave & Union Ave

Phase	2	4	5	6
Movement(s) Served	NBTL	EBTL	NBL	SBTL
Maximum Green (s)	56.0	24.0	10.0	43.0
Minimum Green (s)	4.0	4.0	1.0	4.0
Recall	Ped	Ped	None	Ped
Avg. Green (s)	50.1	24.0	10.1	37.3
g/C Ratio	0.58	0.28	0.12	0.43
Cycles Skipped (%)	0	0	0	0
Cycles @ Minimum (%)	0	0	0	0
Cycles Maxed Out (%)	48	81	90	52
Cycles with Peds (%)	100	100	0	100

Controller Summary
Average Cycle Length (s): 85.9
Number of Complete Cycles : 20

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Configurations						
Volume (vph)	220	84	418	658	31	407
Turn Type		Prot	pm+pt		Perm	
Protected Phases	4	4	5	2		6
Permitted Phases			2		6	
Detector Phase	4	4	5	2 5	6	6
Switch Phase						
Minimum Initial (s)	4.0	4.0	1.0	4.0	4.0	4.0
Minimum Split (s)	20.0	20.0	6.0	25.0	25.0	25.0
Total Split (s)	21.0	21.0	16.0	49.0	33.0	33.0
Total Split (%)	30.0%	30.0%	22.9%	70.0%	47.1%	47.1%
Yellow Time (s)	3.0	3.0	3.0	3.0	3.0	3.0
All-Red Time (s)	2.0	2.0	0.0	2.0	2.0	2.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0
Total Lost Time (s)	5.0	5.0	3.0	5.0	5.0	5.0
Lead/Lag			Lead		Lag	Lag
Lead-Lag Optimize?			Yes		Yes	Yes
Recall Mode	Ped	Ped	None	Ped	Ped	Ped

Intersection Summary
Cycle Length: 70
Actuated Cycle Length: 65.9
Natural Cycle: 70
Control Type: Actuated-Uncoordinated
Description: Union Avenue at Mt. Wayte Avenue, Framingham

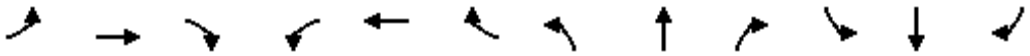
Splits and Phases: 3: Mt. Wayte Ave & Union Ave

Lane Group	EBT	EBR	NBL	NBT	SBL	SBT
Lane Group Flow (vph)	367	95	449	709	43	516
v/c Ratio	0.85	0.22	0.91	0.67	0.17	0.77
Control Delay	46.6	7.2	36.3	12.4	15.8	26.8
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	46.6	7.2	36.3	12.4	15.8	26.8
Queue Length 50th (ft)	143	0	97	166	11	174
Queue Length 95th (ft)	#302	32	#271	272	25	282
Internal Link Dist (ft)	650			739		617
Turn Bay Length (ft)			150		60	
Base Capacity (vph)	436	435	496	1160	301	776
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.84	0.22	0.91	0.61	0.14	0.66

Intersection Summary

Description: Union Avenue at Mt. Wayte Avenue, Framingham

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



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	88	220	84	0	0	0	418	658	17	31	407	72
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	12	11	10	12	12	12	10	10	12	11	12	12
Total Lost time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Lane Util. Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Frpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Flpb, ped/bikes		1.00	1.00				1.00	1.00		1.00	1.00	
Frt		1.00	0.85				1.00	0.99		1.00	0.97	
Flt Protected		0.98	1.00				0.95	1.00		0.95	1.00	
Satd. Flow (prot)		1790	1492				1668	1730		1693	1797	
Flt Permitted		0.98	1.00				0.21	1.00		0.40	1.00	
Satd. Flow (perm)		1790	1492				377	1730		705	1797	
Peak-hour factor, PHF	0.63	0.97	0.88	0.25	0.25	0.25	0.93	0.96	0.71	0.72	0.96	0.78
Adj. Flow (vph)	140	227	95	0	0	0	449	685	24	43	424	92
RTOR Reduction (vph)	0	0	72	0	0	0	0	2	0	0	12	0
Lane Group Flow (vph)	0	367	23	0	0	0	449	707	0	43	504	0
Confl. Peds. (#/hr)	1						3		1	1		3
Heavy Vehicles (%)	0%	1%	1%	0%	0%	0%	1%	2%	0%	3%	3%	0%
Turn Type	Perm		Prot				pm+pt			Perm		
Protected Phases		4	4				5	2			6	
Permitted Phases	4						2			6		
Actuated Green, G (s)		15.8	15.8				40.1	40.1		24.1	24.1	
Effective Green, g (s)		15.8	15.8				40.1	40.1		24.1	24.1	
Actuated g/C Ratio		0.24	0.24				0.61	0.61		0.37	0.37	
Clearance Time (s)		5.0	5.0				3.0	5.0		5.0	5.0	
Vehicle Extension (s)		4.0	4.0				2.0	4.0		4.0	4.0	
Lane Grp Cap (vph)		429	358				484	1053		258	657	
v/s Ratio Prot			0.02				c0.18	0.41			0.28	
v/s Ratio Perm		0.21					c0.38			0.06		
v/c Ratio		0.86	0.06				0.93	0.67		0.17	0.77	
Uniform Delay, d1		24.0	19.3				12.7	8.5		14.1	18.4	
Progression Factor		1.00	1.00				1.00	1.00		1.00	1.00	
Incremental Delay, d2		15.8	0.1				23.7	1.9		0.4	5.7	
Delay (s)		39.7	19.4				36.4	10.4		14.5	24.1	
Level of Service		D	B				D	B		B	C	
Approach Delay (s)		35.6			0.0			20.5			23.4	
Approach LOS		D			A			C			C	

Intersection Summary			
HCM Average Control Delay	24.4	HCM Level of Service	C
HCM Volume to Capacity ratio	0.87		
Actuated Cycle Length (s)	65.9	Sum of lost time (s)	8.0
Intersection Capacity Utilization	77.1%	ICU Level of Service	D
Analysis Period (min)	15		

Description: Union Avenue at Mt. Wayte Avenue, Framingham

c Critical Lane Group

Summary of All Intervals

Run Number	1	2	3	4	5	Avg
Start Time	4:42	4:42	4:42	4:42	4:42	4:42
End Time	5:15	5:15	5:15	5:15	5:15	5:15
Total Time (min)	33	33	33	33	33	33
Time Recorded (min)	30	30	30	30	30	30
# of Intervals	2	2	2	2	2	2
# of Recorded Intvls	1	1	1	1	1	1
Vehs Entered	1040	1039	1030	1001	963	1014
Vehs Exited	1043	1034	1021	993	950	1008
Starting Vehs	31	31	25	24	21	27
Ending Vehs	28	36	34	32	34	33
Denied Entry Before	4	1	1	1	5	2
Denied Entry After	6	0	3	1	1	3
Travel Distance (mi)	289	289	285	278	266	281
Travel Time (hr)	22.7	18.9	26.6	16.9	16.1	20.2
Total Delay (hr)	12.4	8.7	16.5	7.1	6.7	10.3
Total Stops	999	770	1204	709	663	867
Fuel Used (gal)	134.7	122.9	143.4	116.4	109.2	125.3

Interval #0 Information Seeding

Start Time	4:42
End Time	4:45
Total Time (min)	3

Volumes adjusted by Growth Factors.

No data recorded this interval.

Interval #1 Information Recording

Start Time	4:45
End Time	5:15
Total Time (min)	30

Volumes adjusted by Growth Factors.

Run Number	1	2	3	4	5	Avg
Vehs Entered	1040	1039	1030	1001	963	1014
Vehs Exited	1043	1034	1021	993	950	1008
Starting Vehs	31	31	25	24	21	27
Ending Vehs	28	36	34	32	34	33
Denied Entry Before	4	1	1	1	5	2
Denied Entry After	6	0	3	1	1	3
Travel Distance (mi)	289	289	285	278	266	281
Travel Time (hr)	22.7	18.9	26.6	16.9	16.1	20.2
Total Delay (hr)	12.4	8.7	16.5	7.1	6.7	10.3
Total Stops	999	770	1204	709	663	867
Fuel Used (gal)	134.7	122.9	143.4	116.4	109.2	125.3

3: Mt. Wayte Ave & Union Ave Performance by movement

Movement	EBL	EBT	EBR	NBL	NBT	NBR	SBL	SBT	SBR	All
Total Delay (hr)	0.5	1.3	0.1	3.1	3.1	0.1	0.2	1.4	0.2	9.8
Delay / Veh (s)	39.5	38.6	5.5	52.6	33.8	33.9	32.0	24.5	19.1	34.9
Total Stops	45	123	34	265	191	6	19	157	27	867
Travel Dist (mi)	5.4	15.6	5.9	31.9	49.2	1.5	2.2	25.7	4.3	141.7
Travel Time (hr)	0.7	1.8	0.3	4.3	4.8	0.2	0.2	2.3	0.4	14.8
Avg Speed (mph)	8	9	20	10	15	15	10	11	12	12
Fuel Used (gal)	2.8	8.1	1.7	16.0	21.3	0.6	1.0	11.0	1.7	64.3
HC Emissions (g)	0	0	0	1	1	0	0	1	0	4
CO Emissions (g)	56	195	44	273	407	6	36	369	43	1428
NOx Emissions (g)	0	2	0	3	5	0	0	4	0	15
Vehicles Entered	41	118	44	215	332	10	17	203	34	1014
Vehicles Exited	41	118	45	214	331	10	17	202	34	1012
Hourly Exit Rate	82	236	90	428	662	20	34	404	68	2024
Input Volume	88	220	84	418	658	17	31	407	72	1995
% of Volume	93	107	107	102	101	118	110	99	94	101
Denied Entry Before	0	0	0	1	1	0	0	0	0	2
Denied Entry After	0	0	0	2	1	0	0	0	0	3

Total Network Performance

Total Delay (hr)	10.3
Delay / Veh (s)	36.7
Total Stops	867
Travel Dist (mi)	281.4
Travel Time (hr)	20.2
Avg Speed (mph)	16
Fuel Used (gal)	125.3
HC Emissions (g)	11
CO Emissions (g)	3695
NOx Emissions (g)	39
Vehicles Entered	1014
Vehicles Exited	1008
Hourly Exit Rate	2016
Input Volume	3990
% of Volume	51
Denied Entry Before	2
Denied Entry After	3

Intersection: 3: Mt. Wayte Ave & Union Ave

Movement	EB	EB	NB	NB	SB	SB
Directions Served	LT	R	L	TR	L	TR
Maximum Queue (ft)	291	57	228	529	96	350
Average Queue (ft)	171	32	159	275	29	198
95th Queue (ft)	279	58	248	641	87	331
Link Distance (ft)	696	696		782		667
Upstream Blk Time (%)				1		
Queuing Penalty (veh)				0		
Storage Bay Dist (ft)			150		60	
Storage Blk Time (%)			17	6	0	39
Queuing Penalty (veh)			114	27	1	12

Network Summary

Network wide Queuing Penalty: 154

Intersection: 3: Mt. Wayte Ave & Union Ave

Phase	2	4	5	6
Movement(s) Served	NBTL	EBTL	NBL	SBTL
Maximum Green (s)	44.0	16.0	13.0	28.0
Minimum Green (s)	4.0	4.0	1.0	4.0
Recall	Ped	Ped	None	Ped
Avg. Green (s)	42.4	16.4	13.1	26.7
g/C Ratio	0.61	0.23	0.19	0.38
Cycles Skipped (%)	0	0	0	0
Cycles @ Minimum (%)	0	0	0	0
Cycles Maxed Out (%)	69	88	96	69
Cycles with Peds (%)	100	100	0	100

Controller Summary
Average Cycle Length (s): 69.9
Number of Complete Cycles : 25

APPENDIX G

MassDOT Project Implementation Process

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, the 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, the 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. The 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, the 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 MassDOT's statewide priorities and criteria. If the result is positive, the 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 a 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 Long-Range 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, the 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, the 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. The MassDOT Highway Division can apply what is learned in this process to future projects.

APPENDIX H

Comments and Recommendations from:

Joseph Frawley, P.E.
District 3 Traffic Engineer
MassDOT, Highway Division

From: Frawley, Joseph (DOT) <joseph.frawley@state.ma.us>
Sent: Tuesday, January 24, 2012 11:26 AM
To: Seth Asante
Cc: Efi Pagitsas; Steven Andrews; Chen-Yuan Wang; Bruce, Michael (DOT); Sullivan, Ann (DOT)
Subject: RE: Framingham Intersection Study: Union Avenue at Mt. Wayte Avenue

Seth,

The District has reviewed the draft report for the intersection of Union Avenue and Mt. Wayte Avenue in the Town of Framingham. I have provided some comments below for your consideration before the report is submitted to the Boston Region MPO for approval.

The recommendation of the report is to replace the existing traffic signal equipment with a fully-actuated traffic signal. The cost of this improvement is estimated in the report to be between $400,000 (not including potential right-of-way costs associated with upgrading the wheelchair ramps to current ADA/AAB standards or permanent easements to locate the new traffic signal equipment). Given our experience with past signalization projects, the cost will likely be in $1,000,000+ range for MassDOT to construct. The report recommends that the Town work with the MassDOT District 3 office to initiate a project to upgrade the traffic signal, with the Town seeking funding support from the State by working through the project implementation process. The District is willing to work closely with the Town. However, if the Town decides to pursue a project to upgrade the traffic signal, they may want to consider other funding sources, including using Town funds or funds from private development mitigation. The Town should be aware that they will be responsible for acquiring any right-of-way needed to re-construct the traffic signal.

We have a couple of additional comments:

1) One of the recommendations is to lengthen the northbound left-turn lane. I agree that, given the high left-turn volume, a longer left-turn lane would be beneficial. The study states that the extended left-turn lane would fit within the existing roadway width (32 feet). If a 10' wide left-turn lane is striped, the through lanes on Union Avenue would be 11 feet wide to the face of curb. The Town should determine if bicycle accommodation is desired on Union Avenue. To provide bicycle accommodation, roadway widening would be required.
2) Our site visit noted that there are no signal indications for northbound drivers making them aware of the "lead" protected northbound left-turn phase. This may be a factor in some angle crashes that occur at the intersection, as drivers making the northbound left-turn are not given any indication (such as a yellow left arrow) that the protected phase is ending. As a shorter-term recommendation, the Town should, if feasible, provide a 5-section signal head with green and yellow left arrows for Union Avenue northbound.
3) The report notes that there could be some conflicts when large vehicles are making a right or left-turn at the intersection. Given the high percentage of heavy vehicles shown in the morning peak hour capacity analysis results, this should be evaluated before the scope of a project is developed.

If there are significant conflicts due to turning vehicles (especially school buses or single-unit trucks), turning radius improvements may be needed at the intersection corners.

Thank you for providing us with the opportunity to review the draft report and provide comments. If you have any questions please feel free to give me a call.

Joe

Joseph Frawley, P.E.
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From: Seth Asante (sasante@ctps.org)
Sent: Wednesday, January 11, 2012 9:32 AM
To: Frawley, Joseph (DOT)
Cc: Efi Pagitsas; Steven Andrews; Chen-Yuan Wang
Subject: Framingham Intersection Study: Union Avenue at Mt. Wayte Avenue

Hi Joe,

The Boston Region MPO staff recently completed the analyses and improvement recommendations for the intersection of Union Avenue at Mt. Wayte Avenue in Framingham. Attached please find a draft memo of the study for review. The report is a preliminary draft and your comments within 2 weeks are much appreciated. After receiving your comments, we will include them and modify the report if necessary. We plan to submit it to the Boston Region MPO for approval soon after your view and then we can release the final report. If you have any questions about the study, please contact me or Steven Andrews. Thank you.

Seth

Seth A. Asante | Chief Transportation Planner
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