MEMORANDUM

To: Thomas Cummings, Holbrook Public Works Superintendent

Date: February 17, 2011

From: Chen-Yuan Wang and Efi Pagitsas

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

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

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

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

INTERSECTION LAYOUT AND TRAFFIC CONTROL

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

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

CTPS

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

Safety and Operations Improvements at Selected Intersections

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

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

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

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

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

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

ISSUES AND CONCERNS

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

---

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

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

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

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

CRASH DATA ANALYSIS

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

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

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

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

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

Several factors could contribute to these collisions, including:

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

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

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

INTERSECTION CAPACITY ANALYSIS

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

---

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

[3] The average crash rates estimated by the MassDOT Highway Division (as of January 29, 2010) are based upon a database that contains intersection crash rates submitted to MassDOT as part of the review process for an Environmental Impact Report or Functional Design Report. The most recent average crash rates, which are updated on a nearly yearly basis, are based on all entries in the database, not just those entries made within the past year.

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

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

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

TABLE 3
Intersection Capacity Analysis, Existing Conditions

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

PRELIMINARY ANALYSIS OF TRAFFIC SIGNAL WARRANTS

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

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

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

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

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

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

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

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

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

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

TABLE 4
Summary of Hourly Volumes and Warrant Fulfillment

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

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

ANALYSIS OF TRAFFIC SIGNAL ALTERNATIVE

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

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

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

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

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

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

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

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

REVIEW OF ROUNDABOUT OPTION

Another improvement option considered for this intersection is the installation of a modern roundabout. This section examines if and how a modern roundabout would work at this intersection.

Synchro tests of a single-lane roundabout under the existing traffic conditions indicate that a modern roundabout would operate satisfactorily in both AM and PM peak hours. All the approaches would operate at less than 85% of the estimated capacity, which is regarded as the threshold for roundabout operations.[7] Detailed analyses of individual approaches for both peak hours are shown in Appendix F.

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

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

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

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

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

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

RECOMMENDATIONS AND DISCUSSION

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

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

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

---

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

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

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

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

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

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

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

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

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

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

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

Step 3: Install a Traffic Signal with Necessary Intersection Modifications

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

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

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

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

Appendix A

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

Moving Massachusetts Forward. massDOT Highway

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Holbrook COUNT DATE : 6/9/09

DISTRICT : 5 UNSIGNALIZED : X SIGNALIZED :

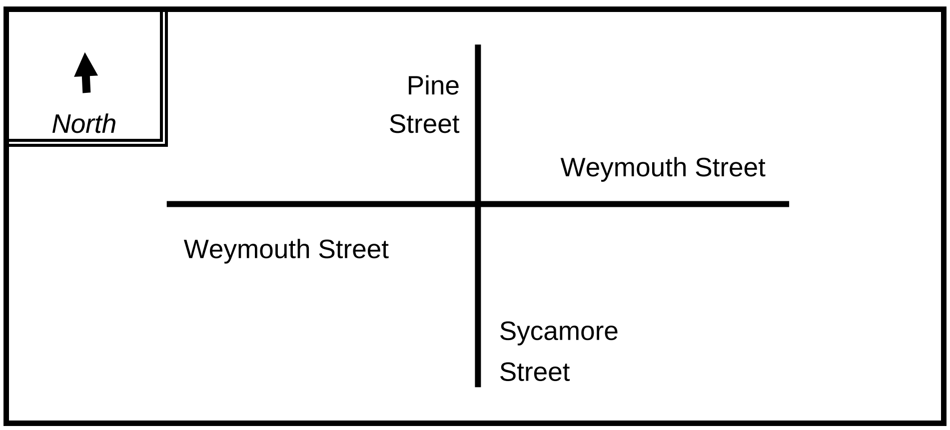
~ INTERSECTION DATA ~

MAJOR STREET : Weymouth Street

MINOR STREET(S) : Pine Street

Sycamore Street

INTERSECTION DIAGRAM (Label Approaches)



PEAK HOUR VOLUMES

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

" K " FACTOR : **0.090** INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **15,222**

TOTAL # OF CRASHES : 16 # OF YEARS : 2 AVERAGE # OF CRASHES PER YEAR (**A**) : **8.00**

CRASH RATE CALCULATION : **1.44** RATE = $\frac{(A * 1{,}000{,}000)}{(V * 365)}$

Comments :

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

Appendix B

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

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

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

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

HCM Unsignalized Analysis
Weymouth St @ Sycamore/Pine St, Holbrook

6/22/2010

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

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

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

Appendix C

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

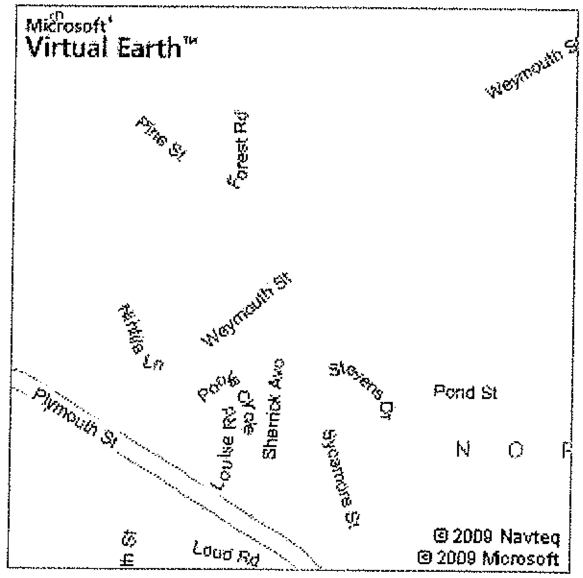
Live Search Maps

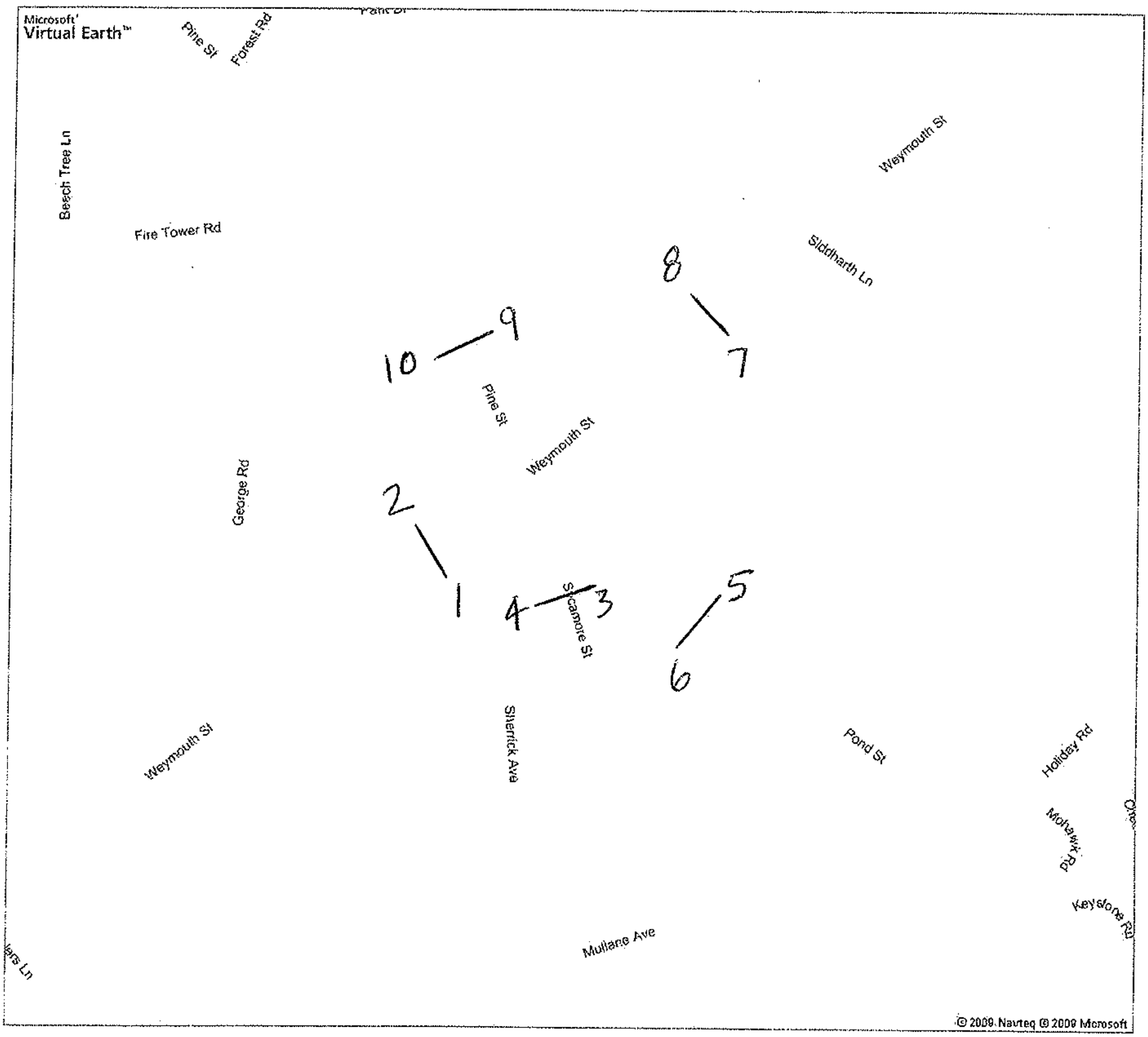
My Notes

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

N

HOLBROOK





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

STA. 1 EB

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

File: 103.prn
City: HOLBROOK
County: VOL

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

u5

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

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

STA. 2 WB

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

File: 204.prn
City: HOLBROOK
County: VOL

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

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

STA. 3NB

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

File: 301402.prn
City: HOLBROOK
County: VOL

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

u6

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

STA. 4SB

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

File: 301402.prn
City: HOLBROOK
County: VOL

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

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

STA. 5 NB

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

File: 501.prn
City: HOLBROOK
County: VOL

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

uo

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

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

STA. 6 SB

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

File: 602.prn
City: HOLBROOK
County: VOL

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

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

STA. 7 EB

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

File: 703.prn
City: HOLBROOK
County: VOL

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

u5

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

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

STA. 8 WB

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

File: 804.prn
City: HOLBROOK
County: VOL

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

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

STA. 9 NB

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

File: 901.prn
City: HOLBROOK
County: VOL

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

u5

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

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

STA. 10 SB

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

File: 1002.prn
City: HOLBROOK
County: VOL

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

Appendix D

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

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

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

Splits and Phases: 1: Sycamore & Weymouth

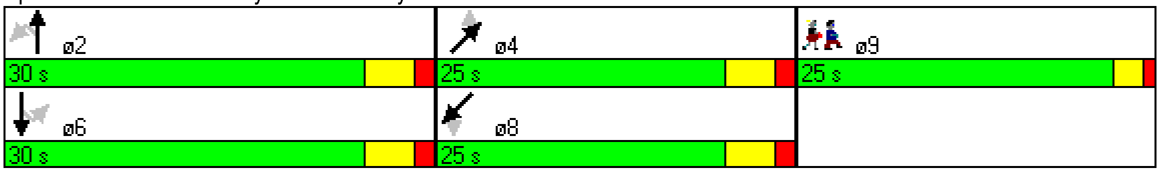
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch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

Intersection Summary

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

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

Splits and Phases: 1: Sycamore & Weymouth



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

Intersection Summary

Appendix E

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

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

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

Splits and Phases: 1: Sycamore & Weymouth

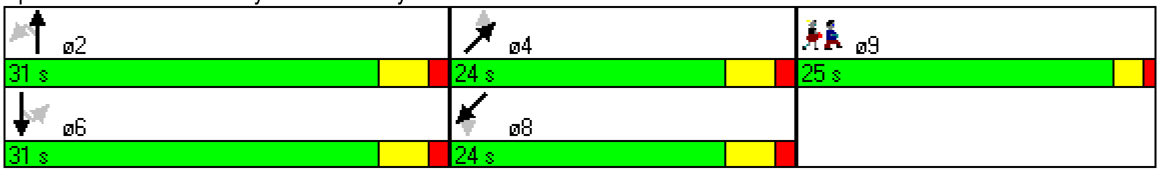
Lane Group	ø9
Lane Configurations	
Volume (vph)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	9
Permitted Phases	
Detector Phase	
Switch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

Intersection Summary

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

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

Splits and Phases: 1: Sycamore & Weymouth



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

Intersection Summary

Appendix F

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

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

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

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

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

Appendix G

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

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

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

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

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