Montachusett Regional Planning Commission

Traffic Report: Intersection of Patriots Road (Route 2A/101) & Gardner Road (Route 101) at North/South Main Street

Town of Templeton, Massachusetts

Prepared by:
Montachusett Regional Planning Commission (MRPC)
R1427 Water Street,
Fitchburg, MA 01420
October, 2007

MONTACHUSETT REGIONAL PLANNING COMMISSION

COMMUNITY	APPOINTED BY SELECTMEN OR MAYOR	APPOINTED BY PLANNING BOARD (one of its members)
Ashburnham	Christopher Gagnon	Bruce Whitney
Ashby	Wayne Stacy	Alan Pease
Athol		James W. Meehan
Ayer	Shaun Suhoski	Pat Walsh
Clinton	Don Lowe	Richard Freel
Devens*		
Fitchburg		Paula Caron
Gardner	Robert Grubb	Alan Gross
Groton	John Saball	Joshua Degen
Harvard	Lucy Wallace	Kara Minar
Hubbardston	Paul Hale	Linda Brisbois
Lancaster	Eugene Christoph	Victor Koivumaki
Leominster	Jack Raymond	
Lunenburg	Robert Bowen	Deborah Seeley
Petersham	Ellen Anderson	
Phillipston	Ronald Recos	
Royalston	Linda Alger	Vyto Andreliunas
Shirley	Joseph Lynch	J. Tim Bresnahan
Sterling	Robert Spencer	Michael Padula
Templeton	Robert Columbus	Robert Rose, Jr.
Townsend	Pat McLoy	Louis Kiklis
Westminster	Andrew Sears	
Winchendon		John White

* Peter Lowitt, Non voting

MONTACHUSETT REGIONAL PLANNING COMMISSION OFFICERS

Victor Koivumaki, Chairman	Lancaster
Vyto Andreliunas, Vice Chairman	Royalston
John White, Secretary	Winchendon
James Meehan, Treasurer	Athol
Robert Grubb, Assistant Treasurer	Gardner

MONTACHUSETT METROPOLITAN PLANNING ORGANIZATION SIGNATORIES

EOT Secretary	Bernard Cohen
MHD Commissioner	Luisa Paiewonsky
MRPC Chairman	Victor Koivumaki
Mayor City of Leominster	Mayor Dean Mazzarella
MART Chairman	Mayor Dan Mylott
Mayor City of Gardner	Mayor Gerald E. St. Hilaire
Chairperson, Ayer Board of Selectmen	Subregion 4 - Frank Maxant Chairperson,
Townsend Board of Selectmen	Subregion 5 - Robert Plamondon
Chairperson, Winchendon Board of Selectmen	Subregion 6 - Burton Gould
Chairperson, Lancaster Board of Selectmen	Subregion 7 - David Dunn

MPO SUB-SIGNATORY COMMITTEE MEMBERS

Thomas Cahir, Deputy Secretary for Transportation Programs EOT, for Secretary Cohen
David Mohler, Deputy Secretary for Planning OTP for Commissioner Paiewonsky
Glenn Eaton, Executive Director, MRPC, for Chairman Koivumaki
Mohammed H. Khan, Administrator, MART, for Chairman Mayor Mylott

EXOFFICIO MEMBERS

Promise Otaluka	FHWA
Andrew Motter	FTA

MONTACHUSETT JOINT TRANSPORTATION COMMITTEE OFFICERS

Joseph Lynch, Chairman	Shirley
Paula Caron, Vice Chairman	Fitchburg
Mary Krapf, Secretary	Ashby

MONTACHUSETT REGIONAL PLANNING COMMISSION STAFF

Glenn Eaton, Executive Director
Brad Harris, Transportation Project Director
George Kahale, Transit Project Director
Shelly Hatch, Director of Community Development
John Hume, Principal Planner
Linda Parmenter, Principal Planner
George Snow, Principal Planner
Sheri Dufour, Transportation Planner
Brian Doherty, Transportation Planner
Ann Carabba, Regional Planner
Nancy Belliveau, Fiscal Manager
Bobbi Jo Johnson, Fiscal Assistant
Jason Stanton, GIS Analyst
Stephanie Brow, Administrative Secretary

Communities of the Montachusett Regional Planning Commission

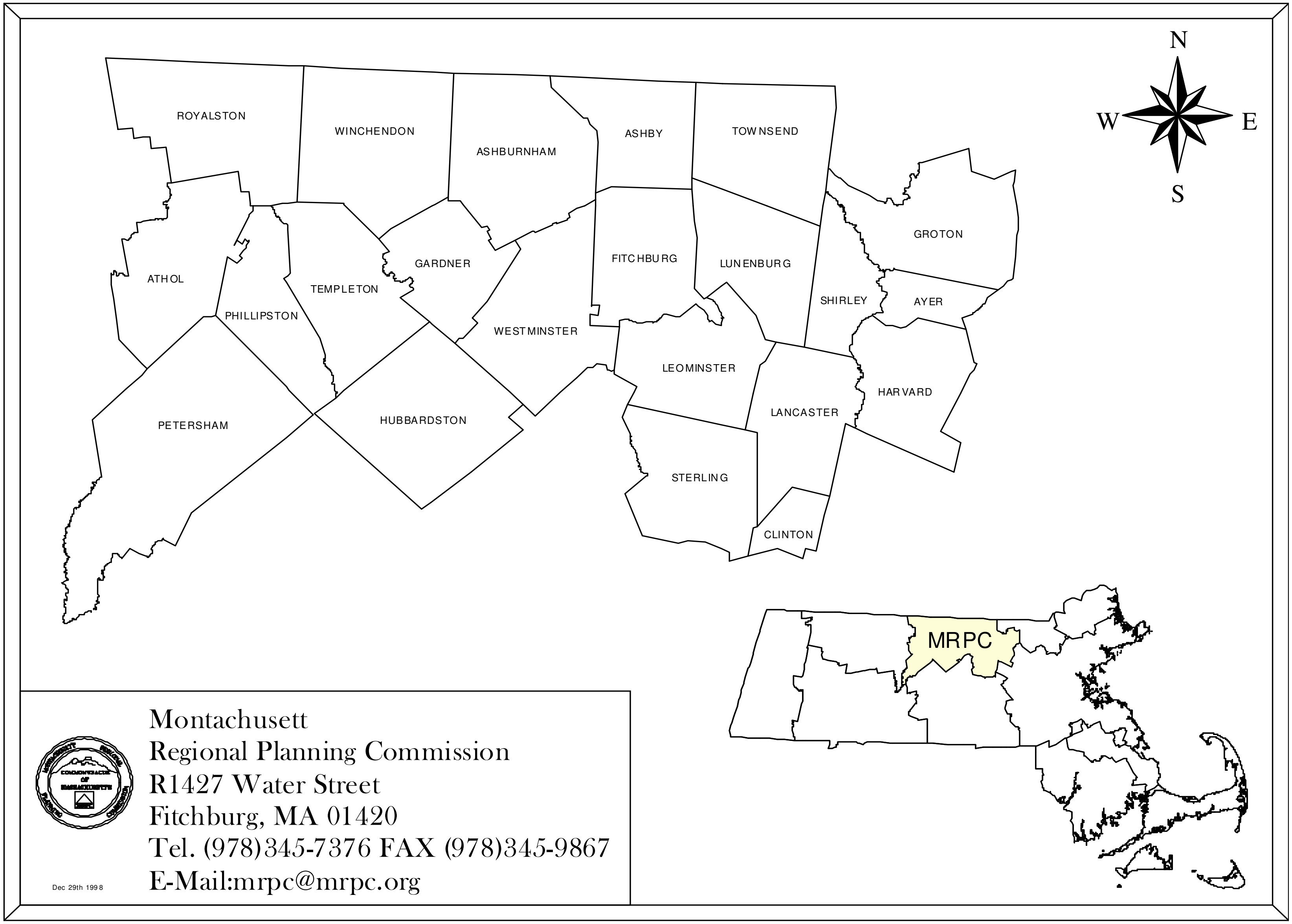


Table of Contents

EXECUTIVE SUMMARY

This traffic report on the intersection of Patriots Road (Route 2A/101) & Gardner Road (Route 101) at North/South Main Street is being presented to the Town of Templeton to be used for possible traffic flow and safety improvements to the intersection. The report provides the Town with some updated traffic and safety data, data analysis, maps and photos, and studies the feasibility of the roundabout alternative (alternative 3) of the 2004 EO418 project.

The major problem at the intersection is the five approach geometry that creates confusion among drivers using the intersection. Safety is a considerable problem at this intersection. The crash rate is significantly higher than the MassHighway District 3 crash rate for unsignalized intersections and 1/3rd of the crashes result in injuries. Angle crashes accounted for the highest number of total crashes and injury crashes. This situation indicates that safety improvements should be undertaken at the intersection.

In this report you will find the details on the identified traffic and safety conditions, improvement alternatives, and recommendations. The MRPC is available to assist the Town as it determines alternatives and recommendations for implementation. If the Town has any questions about this report, please contact George Snow at 978-345-7376 ext 312 or by e-mail at gsnow@mrpc.org.

Introduction

This report provides the Town of Templeton with two major updates for the Patriots Road (Rte 2A/101)/Gardner Road (Rte 101) and North Main Street/South Main Street intersection that was last studied in 2004 as part of the EO418 project (see **Appendix E**). First, updated data and analyses are provided that can be used to decide future actions. Second, the feasibility of the roundabout alternative (Alternative 3) of the EO418 study is examined. The updates include:

- 2007 twenty-four traffic counts taken on approaches to the intersection
- Changes or improvements to the intersection since 2004
- 2020 projected PM peak hour turning movement volumes
- Safety analysis
- Conceptual drawing of the roundabout alternative (Alternative 3)
- Roundabout capacity analysis
- Potential operational and safety improvements at proposed roundabout based on findings compiled by the Federal Highway Administration (FHWA)

Study Area

The Patriots Road (Rte 2A & 101)/Gardner Road (Rte 101SWB) & North Main Street/South Main Street Intersection

This intersection has five approaches:

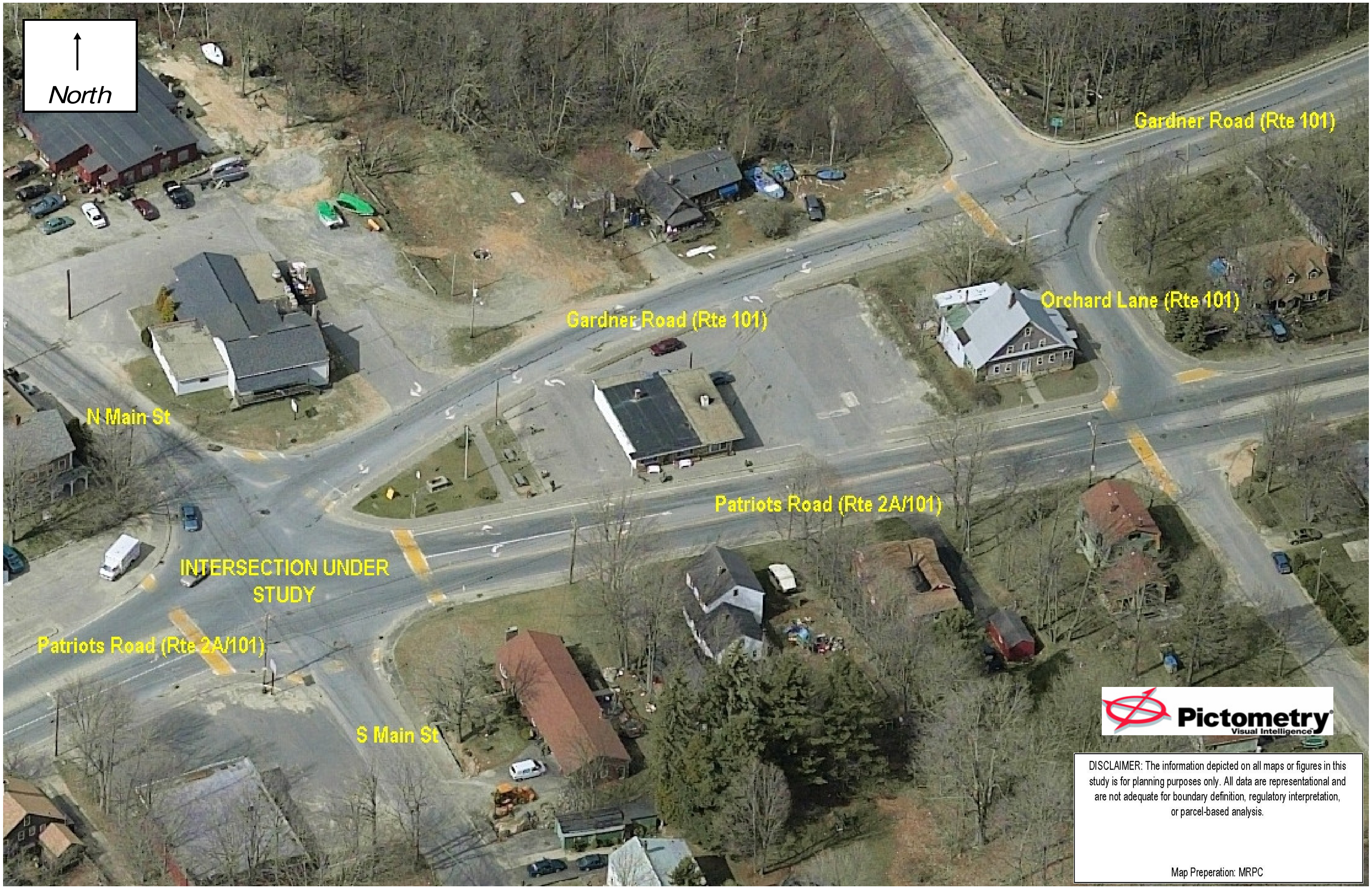
- Patriots Road (Rte 2A/101) - runs westbound (WB)
- Patriots Road (Rte 2A/101) - runs eastbound (EB)
- Gardner Road (Rte 101) - runs southwest bound (SWB)
- North Main Street - runs southbound (SB)
- South Main Street - runs northbound (NB)

Patriots Road (Rte 2A/101EB-WB), the major road, is a two-lane arterial with auxiliary left turn lanes on each approach, and it has no traffic control devices. The Patriots Road (Rte 2A/101) EB approach is divided by a narrow textured and painted median. Gardner Road (Rte 101SWB) is a two-lane road/one-way approach to the intersection indicated by ONE WAY signs and is stop controlled by two STOP signs. North and South Main Streets are two-lane roads controlled by one STOP sign each.

Although truck traffic was not counted for the original 2004 study, field observations indicate that it is a significant percentage of total traffic at this intersection. Since 2004 new pavement markings have been painted at the intersection. **Figure 1** is an oblique aerial photo of the intersection taken in 2002 that includes Orchard Lane. **Figure 2** shows geometric conditions, STOP sign locations, and pavement markings of the intersection as they appeared in 2004. **Figures 3** through **7** are recent photographs of the five approaches.

The major problem apparent at this intersection is the presence of five approaches. Vehicles stopped at the STOP controlled North or South Main Street or Gardner Road (Rte 101SWB) approaches have numerous conflicting flows of traffic to avoid while making a maneuver through the intersection, and there is obvious confusion about right of way among vehicles on these approaches.

Figure 1 – Study Area



Overview of Analyses

Operational Analyses

An intersection may be improved to address poor traffic operation conditions. Operational conditions at an intersection are assessed based on the traffic flow that occurs during the peak hour (i.e., highest-volume hour) of a typical weekday. Analyses of current conditions are based on traffic data collected in the current year. For analyses of future conditions, a regional traffic growth factor based on historical trends in traffic volumes recorded in the MRPC region is used to predict future volumes.

The Level Of Service (LOS) of a roadway traffic facility represents the quality of traffic flow and is used to assess the operation of that traffic facility. LOS analyses are based on the methods in the *Highway Capacity Manual (2000)* (HCM). LOS is defined differently for each type of traffic facility, such as an unsignalized intersection, signalized intersection, two-lane road, or multi-lane road. For intersections, the LOS criteria are defined by the average amount of delay experienced by a vehicle at the intersection due to the traffic controls (i.e., signs or signals). Usually each approach is assessed independently, since the LOS of the major and minor approaches may differ greatly. **Table 1** summarizes the LOS average control delay criteria for intersections controlled by STOP signs and those controlled by traffic signals.

Where appropriate in evaluating improvement alternatives, LOS values and average control delay were estimated for each alternative and compared.

Table 1 - Average Control Delay

LOS	*Average Control Delay (seconds per vehicle)*	
	Stop-Controlled	*Signalized*
A	≤10.0	≤10.0
B	10.1 – 15.0	10.1 – 20.0
C	15.1 – 25.0	20.1 – 35.0
D	25.1 – 35.0	35.1 – 55.0
E	35.1 – 50.0	55.1 – 80.0
F	>50.0	>80.0

The following LOS descriptions apply to intersections:

- **LOS A** describes operations with little or no delay due to very low major street traffic with many acceptable gaps and traffic flows easily.
- **LOS B** describes operations where stopped vehicles experience short traffic delays but there are still many acceptable gaps in the major street traffic.
- **LOS C** describes operations where stopped vehicles experience average traffic delays due to less frequent acceptable gaps in the major street traffic.
- **LOS D** describes operations where stopped vehicles experience long traffic delays due to a limited number of acceptable gaps in the major street traffic.
- **LOS E** describes operations where stopped vehicles experience very long traffic delays due to a very small number of acceptable gaps in the major street traffic. This level is considered by many agencies to be the limit of acceptable delay.
- **LOS F** describes operations where stopped vehicles experience extreme traffic delays due to virtually no acceptable gaps in the major street traffic. This level, considered to be unacceptable to most drivers, often occurs with ***oversaturation***, that is, when arrival flow rates exceed the capacity of the intersection.

Safety Analyses

An intersection may be improved to address poor safety conditions. The MRPC usually conducts a preliminary safety conditions assessment based on relevant crash data from the Massachusetts Highway Department (MHD). The most important piece of required information for a crash record to be relevant is that it has accurate location information. The MHD crash data for a minimum of the three most recent years is identified for the intersection in question. The data is then examined for certain crash trends which at a minimum include obtaining the total number, severity, and manner. The total number of crashes and traffic volume count data are used to calculate an intersection crash rate for the intersection. Calculating the intersection crash rate is an effective tool for identifying and measuring safety problems at an intersection because it provides the probability that a crash will occur. A high intersection crash rate equals a greater chance of a crash occurring. An intersection crash rate is expressed as "crashes per million entering vehicles". For an intersection in question, the intersection crash rate is calculated as follows:

$$\frac{\text{Average \# of Crashes for 12 Month Period X 1,000,000 Entering Vehicles}}{\text{Average Daily Traffic (ADT) X 365 Days}}$$

After calculating the intersection crash rate it is then compared to the applicable MHD District average crash rates for unsignalized or signalized intersections. The MRPC has two sets of MHD District average crash rates because communities within the MRPC region fall in either MHD District 2 or 3. If the intersection crash rate is above the District average rate, it usually indicates a safety problem exists and further study of the safety conditions at the intersection should be undertaken if improvements are sought. Relevant crash reports from the police department of the community where the intersection is located will need to be reviewed and gathered to determine the full extent of the safety problem. An intersection site visit is also conducted.

Figure 2 – Patriots Rd (Rte 2A/101)/Gardner Rd (Rte 101)/N Main St/S Main St in 2004

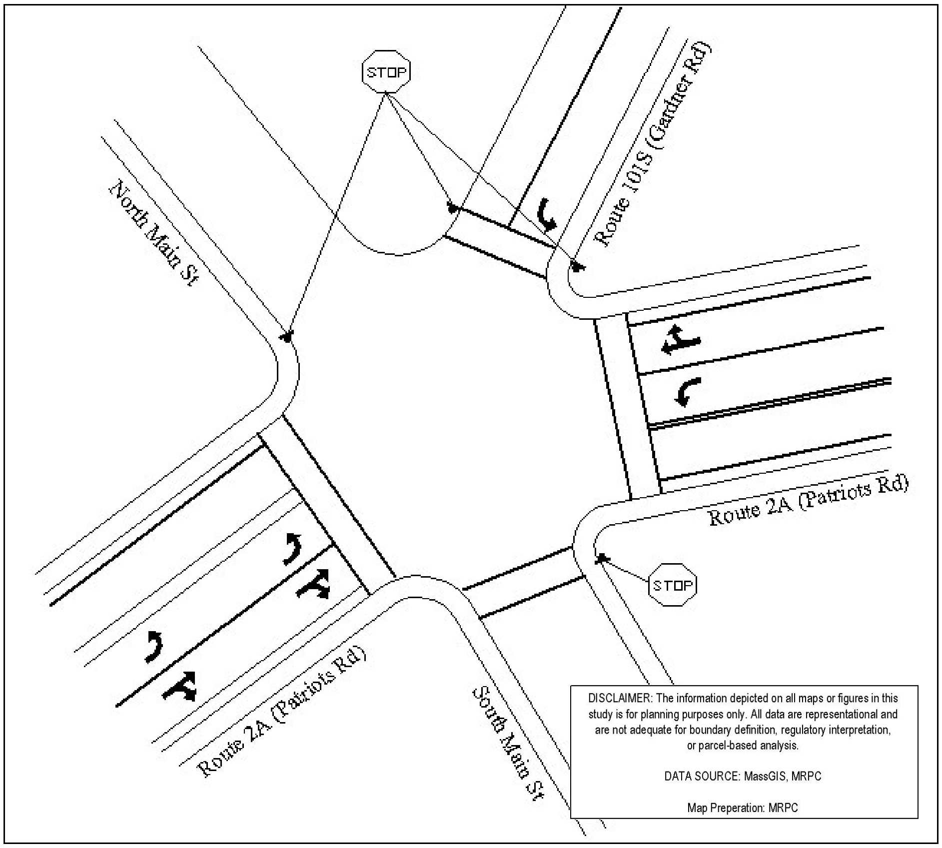


Figure 3 – Approaching the Intersection on South Main Street from the South

Figure 4A – Approaching the Intersection on Patriots Rd from the West
(from south side of Patriots Rd)

Figure 4B – Patriots Rd Westbound Lane Leaving the Intersection
(from north side of Patriots Rd)

Figure 5 – Approaching the Intersection on North Main Street from the North

Figure 6 – Approaching the Intersection on Gardner Road from the Northeast

Figure 7 – Approaching the Intersection on Patriots from the East

Operational Analyses

This analysis has not been updated because the 2003 and the projected 2010 analysis are still valid at this time. Turning movement volumes collected during the afternoon peak hour (4:00-5:00 PM) in 2003 are shown in **Table 2**, and projected volumes for the year 2010 are shown in **Table 3**. LOS, delay, and vehicle queue length are shown in **Table 4**. See **Appendix A** for full turning movement counts.

Table 2 - 2003 PM Peak Hour Turning Movement Volumes
(vehicles per hour)

Approach	*Left Turn*	*Through*	*Right Turn*	*Total*
South Main St - Northbound	16	15	51	82
North Main St - Southbound	67	14	48	129
Gardner Rd/101 - Southwest-bnd	18	144	37	199
Patriots Rd 2A/101 - Eastbound	78	207	36	321
Patriots Rd 2A/101 - Westbound	37	186	71	294

Table 3 - Projected 2010 PM Peak Hour Turning Movement Volumes
(vehicles per hour)

Approach	*Left Turn*	*Through*	*Right Turn*	*Total*
South Main St - Northbound	18	17	58	93
North Main St - Southbound	76	16	54	146
Gardner Rd/101 - Southwest-bnd	20	163	42	225
Patriots Rd 2A/101 - Eastbound	88	234	41	363
Patriots Rd 2A/101 - Westbound	42	210	80	332

During the afternoon peak hour, given the volumes shown in **Table 2**, the Patriots Road (Rte 2A/101) approaches both have an LOS of A, which is the best possible value. The South Main Street and Gardner Road (Rte 101SWB) approaches both have an LOS of C, which indicates acceptable delays. The North Main Street approach has an LOS of E, which indicates long delays. For the projected traffic flow in 2010 shown in **Table 3**, the LOS of the South Main Street and Gardner Road (Rte 101SWB) approaches would drop to D, and the LOS of the North Main Street approach would drop to F, which indicates an unacceptably long delay. See **Table 4** below for delay and queue length.

Table 4 – 2003 & Projected 2010 PM Peak LOS, Delay, Vehicle Queue Length

Approach	*LOS*		*Delay (seconds per vehicle)*		*Vehicle Queue Length*	
	2003	*2010*	*2003*	*2010*	*2003*	*2010*
South Main St - Northbound	C	D	21.8	32.3	1.6	2.7
North Main St - Southbound	E	F	45.3	104.3	4.1	7.6
Gardner Rd/101 - Southwest-bnd	C	D	19.8	26.9	2.6	4.0
Patriots Rd 2A/101 - Eastbound	A	A	8.1	8.2	0.3	0.3
Patriots Rd 2A/101 - Westbound	A	A	7.9	8.1	0.1	0.2

Safety Analyses

Over a four-year period from 2002-2005 this intersection experienced a total of twenty-one crashes. **Table 5** shows the crash summary (see **Appendix B** for full crash table). However, it is highly likely that more crashes occurred here as there are twenty-nine crashes in the MHD data with incomplete location information that, if available, may place several at this intersection. Of the four years, 2005 accounts for the highest percentage of total crashes at 38% and saw the total number of crashes increase by 100% over year 2004. Of the twenty-one crashes that were located with certainty, fourteen (66.7%) were property damage only crashes and seven (33.3%) were nonfatal injury (NFI) crashes. No fatal crashes occurred.

According to the following statistics from the *Massachusetts Strategic Highway Safety Plan (*MSHSP), for years 2002-2004 (3-year period) intersection crashes accounted for:

1. 39% of all crashes that result in fatalities and (incapacitating) injuries in Massachusetts.
2. Of those crashes, nearly 35% occurred at intersections with no controls, 27.4% occurred at STOP controlled intersections, 32% occurred at intersections controlled by traffic signals, and 6% occurred at intersections controlled by other types of traffic control.

Table 5 – 2002-2005 Crash Summary

		Crash Severity			*Crash Manner*					
Year of Crashes / *Percent or Avg Injuries Per Injury Crash*	*Total # of Crashes*	*Property Damage Only*	*Nonfatal Injury*	*# of Nonfatal Injuries*	*Angle*	*Sideswipe*	*Rear-end*	*Head-on*	*Single Vehicle*	*Not Reported/ Unknown*
2005	8	5	3	6	3	2	2	0	1	0
% or Avg	38.1%	62.5%	37.5%	2.00	37.5%	25.0%	25.0%	0.0%	12.5%	0.0%
2004	4	3	1	1	1	1	0	0	1	1
% or Avg	19.0%	75.0%	25.0%	1.00	25.0%	25.0%	0.0%	0.0%	25.0%	25.0%
2003	4	2	2	3	2	0	0	1	0	1
% or Avg	19.0%	50.0%	50.0%	1.50	50.0%	0.0%	0.0%	25.0%	0.0%	25.0%
2002	5	4	1	2	3	0	2	0	0	0
% or Avg	23.8%	80.0%	20.0%	2.00	60.0%	0.0%	40.0%	0.0%	0.0%	0.0%
4 YR Totals	**21**	**14**	**7**	**12**	**9**	**3**	**4**	**1**	**2**	**2**
% or Avg		**66.7%**	**33.3%**	**1.71**	**42.9%**	**14.3%**	**19.0%**	**4.8%**	**9.5%**	**9.5%**

# of Nonfatal Injuries per Crash Manner			
Angle	*Rear-end*	*Single Vehicle*	*Not Reported/ Unknown*
7	**2**	**2**	**1**
58.3%	**16.7%**	**16.7%**	**8.3%**

Compared to the above MSHSP statistics, this intersection is:

- Approximately 6% lower than injury statistic #1 - 33.3% vs. 39%.
- Approximately 6% higher than injury statistic #2 - 33.3% vs. 27.4%.

NFI crashes produced twelve injuries for an average of nearly two injuries (1.71) per NFI crash. Year 2005 saw the number of NFI crashes increase by 50% and the number of injuries that resulted increase by 100% over year 2003, the previous highest year.

The crash manner types were as follows: *angle crashes* (meaning crashes involving at least one turning vehicle) accounted for nine (43%) crashes, four (19%) were *rear-end* crashes, three (14.3%) were *sideswipe* crashes, two (9.5%) were *single vehicle crashes*, one (4.8%) was a head-on crash, and the crash manner was *Not Reported* or *Unknown* for two crashes (9.5%). *Angle crashes* also accounted for the highest number of NFI crashes and injuries as follows:

The number of NFI crashes by crash manner types:

- Angle crashes accounted for 43% (3 of 7)
- Single vehicle crashes accounted for 29% (2 of 7)
- Rear-end crashes accounted for 14% (1 of 7)
- Not reported/Unknown crashes accounted for 14% (1 of 7)

The number of injuries by crash manner types:

- Angle crashes accounted for 58% (7 of 12)
- Rear-end crashes accounted for 17% (2 of 12)
- Single vehicle crashes accounted for 17% (2 of 12)
- Not reported/Unknown crashes accounted for 8% (1 of 12)

According to the crash rate analyses based on MHD crash data, the crash rate at this intersection during 2002-2005 was 1.26 crashes per million entering vehicles. As mentioned in the ***Introduction***, this intersection is STOP controlled (unsignalized). This rate exceeds the MHD District 2 average unsignalized intersection crash rate of 0.85 crashes per million entering vehicles, which indicates the existence of a safety problem. Further study of the safety conditions at this intersection should be undertaken if safety improvements are sought. Relevant crash reports from the Templeton Police Department will need to be reviewed and gathered to analyze the full extent of the safety problem. See **Appendix B** for full crash rate analyses.

The existing five-way approach geometry of the intersection is most likely the major contributing factor to the problematic crash rate and injury statistics. Vehicles entering the intersection have numerous conflicting flows of traffic to avoid while making maneuvers through the intersection and there is confusion about right of way among vehicles traversing the intersection. Sight distance appears to be sufficient except to the right for the North Main Street approach where vehicles using the approach have been observed pulling forward into the intersection to obtain an adequate view. This is caused by the vegetation, permitted parking, dumpster near the corner, and the existing corner geometry (see **Figures 3, 4A, 5, 7**).

Alternatives

The EO418 project examined three alternatives to improve intersection layout and traffic flow based on projected 2010 traffic conditions. Alternative 3 has been updated and includes projected 2020 traffic conditions and elements of Alternative 2. The projected PM LOS analysis results are summarized in **Table 6**. See **Appendix C** for full LOS analysis summaries.

Table 6 - 2010 Projected PM Peak LOS and Delay for Alternatives

Approach	LOS				Delay (seconds per vehicle)			
	No change	Alt 1	Alt 2	Alt 3	No change	Alt 1	Alt 2	Alt 3
South Main St - Northbound	D	C	C	n/c	32.3	32.1	24.7	n/a
North Main St - Southbound	F	D	F	n/c	104.3	40.5	54.1	n/a
Gardner Rd/101 - Southwest-bnd	D	C	n/a	n/c	26.9	28.5	n/a	n/a
Patriots Rd 2A/101 - Eastbound	A	C	A	n/c	8.2	21.7	8.2	n/a
Patriots Rd 2A/101 - Westbound	A	C	A	n/c	8.1	21.7	8.1	n/a

Alternative 1:

Install a traffic signal at this intersection

A formal traffic control signal warrant study was not conducted. However the LOS analysis shows the following. Installing a signal would decrease the delay to traffic on North Main Street but increase delay to traffic on Patriots Road (Rte 2A/101). The traffic on South Main Street and Gardner Road (Rte 101SWB) would have approximately the same delay as without a signal, but the LOS would improve because the delay would be caused by a signal. Future study should include a signal warrant study to fully compare the alternatives.

Alternative 2:

Convert the intersection into a four-way intersection by eliminating the one-way Gardner Road (Rte 101SWB) approach.

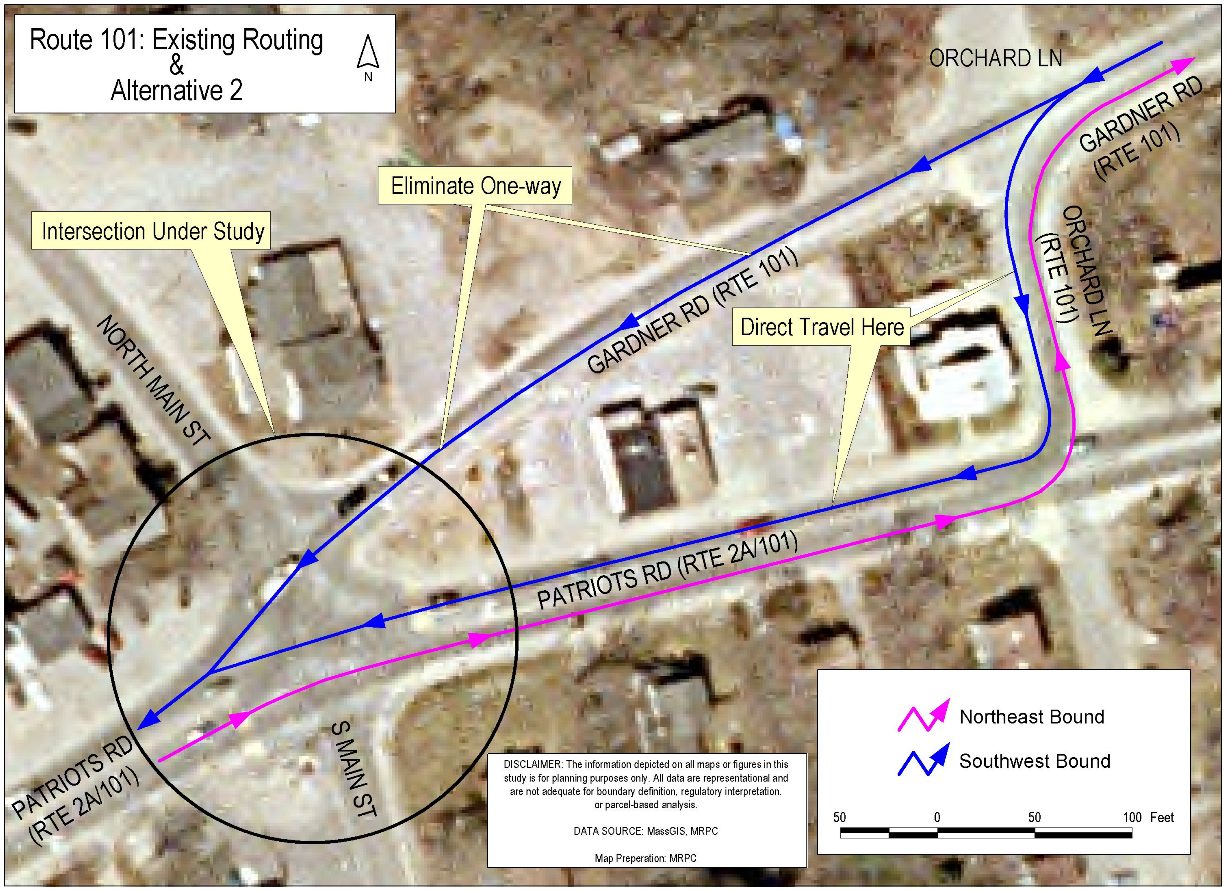
Figure 8 shows the existing and proposed routing for Route 101. Currently, Routes 2A/101EB (Patriots Road) and 101SWB (Gardner Road) follow different paths near the intersection. Route 101NEB intersects Route 2A further to the east, following Orchard Lane. In this alternative, Gardner Road (Rte 101SWB) traffic is directed to travel on Orchard Lane (Route 101). The LOS of the South Main Street approach would be improved from D to C by this alternative, and the delay to traffic on North Main Street would be cut in half, although the LOS would not change. The Patriots Road (Rte 2A/101) approaches would be basically unaffected. Additionally, the eliminated segment of Gardner Road (Rte 101SWB) would need to be altered to prevent westbound traffic from utilizing it instead of the reconfigured Route 101 layout as described.

If implemented, the radius of the turns between Orchard Lane (Rte 101) and Patriots Road (Rte 2A/101) and Gardner Road (Rte 101) and Orchard Lane (Rte 101) should be checked to ensure they will accommodate the trucks that travel on Route 101 through Templeton. **Table 7**, excerpted from *A Policy on Geometric Design of Highways and Streets* by the *American Association of State Highway and Transportation Officials*, shows the design values for a 90-degree turn at an intersection to allow for various vehicles.

Table 7 - Curve Radii for Various Design Vehicles at a 90-Degree Turn

Design vehicle	Simple curve radius (ft)	Simple curve radius with taper		
		Radius (ft)	Offset (ft)	Taper
Passenger car	30	20	2.5	10:1
Single-unit truck	50	40	2.0	10:1
WB-40 (46' semi)	--	45	4.0	10:1
WB-50 (55' semi)	--	60	4.0	15:1

Figure 8 - Existing Routing Of Rte 101 and Alternative 2



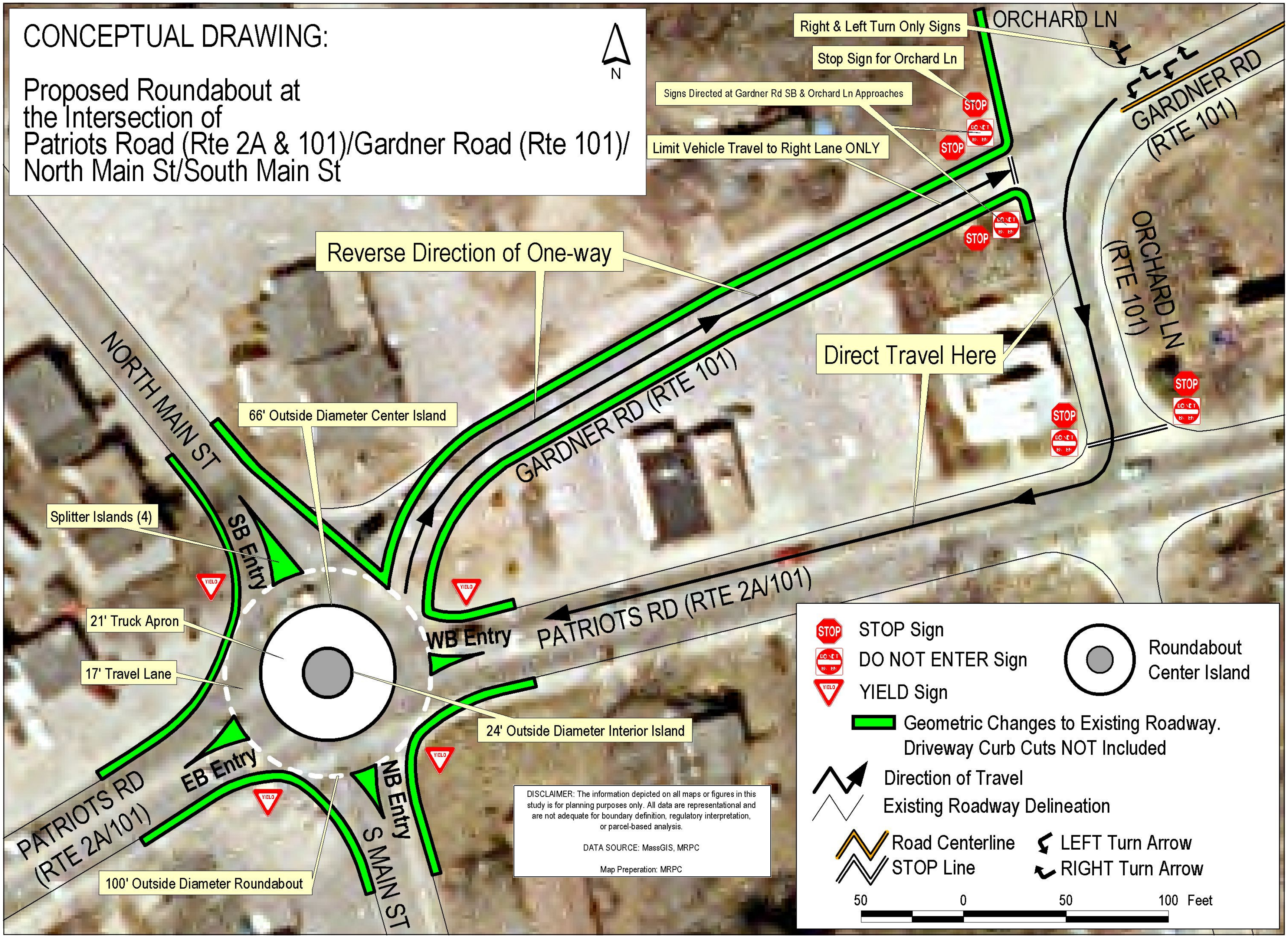
Alternative 3:

Convert the five-way intersection into a four-way single-lane roundabout with a new exit for Gardner Road NEB traffic (reverse the Rte 101SWB one-way approach to the northeast) and uses routing elements from Alternative 2.

<u>Modern Roundabout Description</u>

- It is a form of intersection that consists of a center island, one or more lanes circulating around the island, and entry/exit points with triangular splitter islands to direct the traffic.
- Vehicles enter and exit the roundabout by turning right at slow speeds and the entering traffic yields to circulating traffic. Truck traffic is able to negotiate circulating through the roundabout through the use of truck aprons on the center island.
- Proper roundabout design includes speed reduction through deflection which contribute to safer merging, easier navigation of the intersection, less frequent and less severe crashes, and greater pedestrian safety.
- Roundabouts also require less maintenance and longer service life than traffic signals, and they provide an opportunity for attractive landscaping.

Figure 9 - Alternative 3: Proposed Roundabout



Proposed Roundabout Description

Figure 9 is a conceptual drawing of the proposed roundabout. The existing intersection footprint would easily accommodate this proposed roundabout as opposed to a five-way roundabout which would most likely need a larger footprint that may require property takings. Please note that this proposal serves as a **model only** and that there are other roundabout design options for this intersection.

The proposed roundabout would have the following dimensions:

- The outside diameter of the roundabout would be 100 feet.
- The circular one-lane travel lane within the roundabout would be 17 feet wide.
- The center island outside diameter would be 66 feet.
- The truck apron would be 21 feet wide.

Proposed design elements include:

- Four of the five existing approaches to the intersection would have one entry lane and one exit lane. Each entry/exit would be divided by splitter islands.
- The existing one-way direction of the Gardner Road (Rte 101SWB) approach (see **Figures 2 or 8**) would be reversed to the northeast making it an exit from the roundabout for NEB traffic. Vehicle travel would be limited to the right lane to align with the Gardner Road (Rte 101) NEB lane east of Orchard Lane. The new direction of this road would entail converting its approach with Orchard Lane to a STOP controlled approach.
- Vehicle travel on the Gardner Road (Rte 101SWB) approach east of Orchard Lane would be directed onto Orchard Lane SB as in Alternative 2. The traffic destined for Patriots Road (Rte 2AEB & 2A/101WB) from this approach would have the right-of-way over the new Gardner Road (Rte 101) NEB approach at the intersection for two reasons:
    1. According to the 2007 24-hour traffic count, the traffic volume for the SWB approach is nearly 400 vehicles higher than the NEB approach. See **Appendix A** for full 24-hour counts.
    2. This proposal calls for the Orchard Lane SB approach with Patriots Road to be converted to a STOP controlled approach. If both the SWB and SB approaches were to become STOP controlled, vehicle delay would be considerable as a result of vehicles stopping twice within a short distance of only 200 feet.
- The Route 101 section of Orchard Lane would be changed into a SB one-way road.
- These changes would eliminate many turn movements for the Patriots Road at Orchard Lane and Gardner Road at Orchard Lane intersections thereby eliminating many traffic conflicts that would help improve safety conditions and traffic flow at these intersections.

Operational Analysis for Proposed Roundabout

2020 Projections & New Westbound Traffic Volume

Table 8 builds on the peak hour traffic volumes found in **Tables 2** and **3**. It shows the traffic volume increase for the WB Patriots Road (Rte 2A/101) approach if either Alternatives 2 or 3 were to be implemented and provides 2020 traffic volume projections for all approaches. See the Operational Analyses overview above for the method used to calculate the 2020 projections.

The record (or row) titled ***New Westbound Volume*** moves traffic volumes from the SWB Gardner Road (Rte 101) approach to the WB Patriots Road (Rte 2A/101) approach. In 2003, the traffic volume increase would have been 199 vehicles. For 2010 and 2020, the traffic volume increases are projected to be 225 and 290 vehicles respectfully. The volume data in this table will be adjusted and used in the roundabout capacity analysis below.

Table 8 – New WB 2003 & Projected 2010 & 2020 PM Peak Hour Turning Movement Volumes
(vehicles per hour)

2003 Volumes	Turn Movements			
Approach	*Left Turn*	*Through*	*Right Turn*	*Total*
Northbound (South Main St)	16	15	51	82
Southbound (North Main St)	67	14	48	129
Southwest-bnd (Gardner Rd/101)	**18**	**144**	**37**	**199**
Eastbound (Patriots Rd 2A/101)	78	207	36	321
Westbound (Patriots Rd 2A/101)	**37**	**186**	**71**	**294**
New Westbound Volume	**55**	**330**	**108**	**493**
2010 Volumes	Turn Movements			
Approach	*Left Turn*	*Through*	*Right Turn*	*Total*
Northbound (South Main St)	18	17	58	93
Southbound (North Main St)	76	16	54	146
Southwest-bnd (Gardner Rd/101)	**20**	**163**	**42**	**225**
Eastbound (Patriots Rd 2A/101)	88	234	41	363
Westbound (Patriots Rd 2A/101)	**42**	**210**	**80**	**332**
New Westbound Volume	**62**	**373**	**122**	**557**
2020 Volumes	Turn Movements			
Approach	*Left Turn*	*Through*	*Right Turn*	*Total*
Northbound (South Main St)	21	20	67	108
Southbound (North Main St)	88	18	63	169
Southwest-bnd (Gardner Rd/101)	**23.6**	**188.9**	**48.5**	**261.1**
Eastbound (Patriots Rd 2A/101)	102	272	47	421
Westbound (Patriots Rd 2A/101)	**48.5**	**244.0**	**93.1**	**385.7**
New Westbound Volume	**72**	**433**	**142**	**647**

Estimated Traffic Volume for new Gardner Rd NEB Exit (or destination)

Based on an estimate from 2003 and 2007 traffic volumes, the PM peak hour traffic volumes for years 2003, 2010, and 2020 that would use the new Gardner Road (Rte 101) NEB exit are estimated to be 149, 168, and 195 vehicles respectfully. See **Appendix C** to see how the estimate was determined. The traffic volume for this new exit will contribute to the circulating traffic volume affecting the capacity of the Patriots Road (Rte 2A/101) WB entry approach.

Capacity Analysis of the Proposed Roundabout

Roundabout LOS analysis methodology has not yet been established in the HCM. This is reflected in **Table 6** as the LOS and delay values for Alternative 3 are noted as “n/c” for “*not calculated*”. However, the HCM has established single-lane roundabout capacity analysis which is applied below. The analysis was completed using *HCS+* software which implements HCM methodologies.

The *MassHighway Project Development & Design Guide* defines intersection capacity as the maximum flow rate of motor vehicles that can be accommodated through an intersection. For roundabouts, “*motor vehicle capacity is governed by the ability of entering traffic to enter the stream of motor vehicles in the circulating roadway*.” In other words, the capacity of each entry approach is analyzed separately and is affected by the circulating flow traffic volume. When capacity is reached vehicles trying to enter the roundabout from an entry approach find it difficult to impossible to do so. Motor vehicle capacity is stated in terms of vehicles per hour.

Table 9 shows the results of the first step of the proposed roundabout capacity analysis. The traffic volumes in **Table 8** have been adjusted for each entry approach and are used to calculate the capacity and assess performance by using the volume-to-capacity (V/C) ratio formula.

Table 9 – 2003 & Predicted 2010 & 2020 Roundabout Circulation & Approach Entry Traffic Flow Volumes (vehicles per hour)

Entry Approach	Entry Approach Flow Volumes			Origins & Destinations of Circulating Flow Volumes Affecting Approach Capacity									Total Circulating Flow Volume Affecting Approach Capacity		
Eastbound: Patriots Rd (Rte 2A/101)	(combines all movements)			Westbound Left Turn Movement			Southbound Left Turn Movement			Southbound Thru Movement					
Years	2003	2010	2020	2003	2010	2020	2003	2010	2020	2003	2010	2020	2003	2010	2020
Adjusted Volumes	396	446	517	64	72	83	75	86	99	24	27	30	163	185	212
Westbound: Patriots Rd (Rte 2A/101)	(combines all movements)			Eastbound Left Turn Movement			Northbound Left Turn Movement			Northbound Thru Movement & Gardner Rd NEB					
Years	2003	2010	2020	2003	2010	2020	2003	2010	2020	2003	2010	2020	2003	2010	2020
Adjusted Volumes	563	636	739	100	112	130	28	31	36	175	198	230	303	341	396
Northbound: South Main St	(combines all movements)			Eastbound Left Turn Movement			Eastbound Thru Movement			Southbound Left Turn Movement					
Years	2003	2010	2020	2003	2010	2020	2003	2010	2020	2003	2010	2020	2003	2010	2020
Adjusted Volumes	118	134	157	100	112	130	244	275	320	75	86	99	419	473	549
Southbound: North Main St	(combines all movements)			Westbound Left Turn Movement			Westbound Thru Movement			Northbound Left Turn Movement					
Years	2003	2010	2020	2003	2010	2020	2003	2010	2020	2003	2010	2020	2003	2010	2020
Adjusted Volumes	155	176	202	64	72	83	372	420	488	28	31	36	464	523	607

Description of **Table 9**:

- The “Entry Approach” column lists the four entry approaches to the roundabout (see approaches in **Figure 9**).
- The “Entry Approach Flow Volumes” column lists the adjusted hourly total entry traffic volumes for each entry approach for each analyses year. These volumes are used as the numerator in the V/C ratio formula.
- The three sub-columns under the heading “Origins & Destinations of Circulating Flow Volumes Affecting Approach Capacity” list the traffic origins and destinations that

circulate in front of each entry approach and their adjusted hourly total entry traffic volume for years 2003, 2010, and 2020. The "Northern Thru Movement & Gardner Rd NEB" sub-column lists the results of combining the NB thru traffic volume with the estimated NEB traffic volume that affect the WB entry approach capacity.

- The "Total Circulating Flow Volume Affecting Approach Capacity" column totals the adjusted hourly total traffic volume of the traffic destinations that circulate in front of each entry approach for years 2003, 2010, and 2020. For example, the 2003 volume of 163 vehicles combines the volumes of the "Westbound Left Turn" (64 vehicles), "Southbound Left Turn" (75 vehicles), and "Southbound Thru" (24 vehicles) destinations.

Table 10 shows the capacity and performance assessment results of each entry approach to the proposed roundabout. Both results show an upper-bound solution and lower-bound solution. The lower-bound solutions present lower capacity results and performance levels move closer to capacity. Because there is limited experience with roundabouts in North America, it is recommended that the lower-bound results be used to represent the capacity and performance assessment results. The capacity traffic volumes are used as the denominator in the V/C ratio formula. See **Appendix C** for capacity analysis summaries.

Table 10 –Roundabout Capacity and Performance Assessment Results
(capacity in vehicles per hour)

		Eastbound: Patriots Rd (Rte 2A/101)	Westbound: Patriots Rd (Rte 2A/101)	Northbound: South Main St	Southbound: North Main St
Year 2003					
Capacity	Upper bound	1,219	1,090	995	960
	Lower bound	1,010	895	809	780
Performance (v/c Ratio)	Upper bound	0.32	0.51	0.12	0.16
	Lower bound	0.39	0.63	0.15	0.20
Year 2010					
Capacity	Upper bound	1,198	1,059	953	917
	Lower bound	991	866	772	739
Performance (v/c Ratio)	Upper bound	0.37	0.60	0.14	0.19
	Lower bound	0.45	0.73	0.17	0.24
Year 2020					
Capacity	Upper bound	1,171	1,014	897	858
	Lower bound	967	825	722	687
Performance (v/c Ratio)	Upper bound	0.44	0.73	0.17	0.24
	Lower bound	0.53	0.89	0.22	0.30

- The "Eastbound", "Northbound", and "Southbound" entry approaches perform well under capacity until at least year 2020. This translates into a traffic flow that will freely enter the circulating traffic flow. It may be suggested that LOS for these entry approaches will be very acceptable to drivers.
- By year 2010, the "Westbound" entry approach will perform under capacity. This translates into a traffic flow that will be stable with only very slight delays. It may be suggested that LOS for this entry approach will be acceptable.
- By year 2020, the "Westbound" entry approach will perform near capacity. This translates into a traffic flow that will be dense but stable with higher delays. It may be suggested that LOS for this entry approach will be acceptable but delays will be noticeable.

Improved Safety at the Proposed Roundabout

Two Safety Benefits

1. *A measurable reduction in crash severity.*

There is a significant safety problem at this intersection which is described above. Although there is not a method of predicting crash and crash severity reduction as a result of the construction of a roundabout, there is nationwide data that shows a significant reduction can occur when one is constructed. The following statement is comes from the FHWA:

> "A 2000 study by the Insurance Institute for Highway Safety and several other organizations evaluated 24 intersections in California, Colorado, Florida, Kansas, Maine, Maryland, South Carolina, and Vermont before and after construction of roundabouts. The study revealed a 39-percent decrease in crashes, a 76-percent decrease in injury crashes, and a 90-percent reduction in crashes involving fatal or incapacitating injuries. A December 2002 study of 15 single-lane roundabouts in Maryland showed a 60-percent decrease in total crash rates, an 82-percent reduction in injury crash rates, a 100-percent decrease in the fatal crash rate, and a 27-percent reduction in property-damage-only (PDO) crash rates."

2. *Roundabouts incorporate safety design.*

Roundabouts are considered to be an innovative safety design by the FHWA to improve intersection safety and operational problems. Roundabout design is described above. Because the design creates deflection that slows entering and circulating vehicles, the lower vehicle speeds produce lower impact forces when a crash occurs. Also, when compared to a simple four-way intersection, this geometry produces far fewer conflict points that simplifies decision making for drivers. A four-way intersection can have up to 32 vehicle to vehicle conflict points, whereas a four-way roundabout has only 8 vehicle to vehicle conflict points. A description and diagram of vehicle conflict points can be found in section 5.2 of the safety chapter of the FHWA publication *Roundabouts: An Informational Guide*.

It is highly likely that the construction of a roundabout at this intersection will result in a measurable safety improvement similar to the national data described above.

Recommendations

To improve the traffic flow and safety conditions at this intersection, the following improvements are recommended:

Short term recommendation:

- Remove vegetation and dumpster and restrict parking at the corner of Patriots Road and North Main Street to improve sight distance for vehicles trying to enter the intersection.

Long term recommendation:

- The above analysis demonstrates that a roundabout is feasible at this intersection. The operational analyses shows that the intersection will operate under capacity at least until 2020 and that safety will improve. Converting the intersection into a modern roundabout as indicated in Alternative 3 for long term improvements should be considered.
- More information about the benefits of roundabouts can be found in the FHWA publication:

Roundabouts: An Informational Guide at: *www.tfhrc.gov/safety/00068.htm*
See Chapter 4 at: *http://www.tfhrc.gov/safety/00-0674.pdf*
See Chapter 5 at: *http://www.tfhrc.gov/safety/00-0675.pdf*

See **Appendix D** for these chapters.

NEXT STEPS & PROJECT DEVELOPMENT

Future study should include:

- Future study should include a complete and thorough comparative analysis of the alternatives for better decision making.
- Conduct an intersection LOS analysis on the projected 2020 pm peak hour turning movement volumes for the **Operational Analyses** section above.
- Conduct a signal warrant study of the intersection for alternative 1 and alternative comparative analyses.
- Determine proposed roundabout LOS. This is possible through at least two software packages (**aaSIDRA** and **Rodel**) that apply LOS criteria to roundabouts.

The *Project Development Process* is found in **Appendix E**:

The document in this appendix is Chapter 2 of the *MassHighway Project Development & Design Guide*. It provides the procedures that a community must take if it decides to seek state or federal funds to pay for a roadway project. Due to the magnitude of the recommendations, coordination with MassHighway is strongly recommended. Reconstruction of the intersection geometrics should be eligible for state or federal funding assistance, therefore requests need to go through MassHighway.

MRPC Contact: Please contact George Snow at 978-345-7376 ext 312 or by email at gsnow@mrpc.org with any questions concerning this report.

APPENDIX A

Traffic Counts

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Site Code: 29420073854
Station ID:
Counter # 16642

Community: Templeton
Street: Gardner Road
Location: E. of N. Main St
Function Class: U-5

Latitude: 0' 0.000 Undefined

Start	11-Jul-07	East		Hour Totals		West		Hour Totals		Combined Totals	
Time	Wed	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		2	49			3	36				
12:15		2	31			0	36				
12:30		1	45			1	42				
12:45		0	44	5	169	0	31	4	145	9	314
01:00		2	32			1	46				
01:15		1	33			3	32				
01:30		2	39			1	63				
01:45		2	34	7	138	0	39	5	180	12	318
02:00		1	34			3	40				
02:15		1	34			1	42				
02:30		0	50			1	48				
02:45		3	46	5	164	1	44	6	174	11	338
03:00		0	48			2	35				
03:15		0	36			1	51				
03:30		2	41			0	56				
03:45		0	59	2	184	0	34	3	176	5	360
04:00		3	33			1	59				
04:15		3	32			2	46				
04:30		2	41			7	39				
04:45		6	54	14	160	3	35	13	179	27	339
05:00		6	41			4	35				
05:15		5	40			19	35				
05:30		8	41			27	35				
05:45		9	38	28	160	16	27	66	132	94	292
06:00		14	29			10	38				
06:15		15	47			44	22				
06:30		26	46			39	32				
06:45		24	30	79	152	23	22	116	114	195	266
07:00		24	17			43	34				
07:15		27	27			37	14				
07:30		28	23			65	29				
07:45		25	27	104	94	40	38	185	115	289	209
08:00		22	20			45	32				
08:15		23	20			50	21				
08:30		27	10			40	21				
08:45		19	18	91	68	51	16	186	90	277	158
09:00		34	14			41	9				
09:15		31	15			38	9				
09:30		35	11			39	8				
09:45		25	10	125	50	30	10	148	36	273	86
10:00		37	7			32	8				
10:15		30	4			43	10				
10:30		28	8			29	15				
10:45		32	1	127	20	44	13	148	46	275	66
11:00		22	5			47	4				
11:15		23	8			44	3				
11:30		18	5			48	6				
11:45		33	4	96	22	39	8	178	21	274	43
Total		683	1381			1058	1408			1741	2789
Percent		33.1%	66.9%			42.9%	57.1%			38.4%	61.6%

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Site Code: 2942007923
Station ID:
Counter # 18131

Community: Templeton
Street: North Main Street
Location: N. of Gardner Rd (Rt.101)
Function Class: U-6
Latitude: 0' 0.000 Undefined

Start	11-Jul-07	North		Hour Totals		South		Hour Totals		Combined Totals	
Time	Wed	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		6	45			2	31				
12:15		5	30			3	34				
12:30		4	39			3	35				
12:45		5	35	20	149	3	30	11	130	31	279
01:00		2	30			1	28				
01:15		1	34			1	38				
01:30		1	34			1	30				
01:45		0	39	4	137	0	34	3	130	7	267
02:00		0	28			2	33				
02:15		1	24			0	33				
02:30		1	33			1	15				
02:45		3	43	5	128	0	38	3	119	8	247
03:00		0	26			1	32				
03:15		0	43			0	29				
03:30		0	51			0	30				
03:45		1	54	1	174	3	30	4	121	5	295
04:00		0	53			0	35				
04:15		0	55			1	25				
04:30		0	51			0	25				
04:45		1	52	1	211	4	31	5	116	6	327
05:00		2	54			3	29				
05:15		3	34			5	39				
05:30		2	56			15	28				
05:45		3	40	10	184	19	26	42	122	52	306
06:00		6	43			21	16				
06:15		5	54			26	23				
06:30		9	38			47	24				
06:45		13	49	33	184	30	29	124	92	157	276
07:00		18	31			52	26				
07:15		27	28			35	29				
07:30		20	29			32	21				
07:45		25	25	90	113	38	33	157	109	247	222
08:00		17	26			39	27				
08:15		28	30			38	12				
08:30		21	25			31	19				
08:45		13	23	79	104	22	23	130	81	209	185
09:00		17	24			20	28				
09:15		20	13			31	12				
09:30		23	18			37	15				
09:45		28	18	88	73	31	3	119	58	207	131
10:00		24	13			26	13				
10:15		24	14			22	17				
10:30		23	18			29	12				
10:45		29	9	100	54	32	5	109	47	209	101
11:00		32	7			31	7				
11:15		33	6			26	2				
11:30		27	7			24	11				
11:45		37	12	129	32	20	3	101	23	230	55
Total		560	1543			808	1148			1368	2691
Percent		26.6%	73.4%			41.3%	58.7%			33.7%	66.3%

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Community: Templeton
Street: North Main Street
Location: N. of Gardner Rd (Rt.101)
Function Class: U-6

Site Code: 2942007923
Station ID:
Counter # 18131
Latitude: 0' 0.000 Undefined

Start	12-Jul-07	North		Hour Totals		South		Hour Totals		Combined Totals	
Time	Thu	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		6	*			2	*				
12:15		5	*			3	*				
12:30		4	*			3	*				
12:45		5	*	20	0	3	*	11	0	31	0
01:00		2	*			1	*				
01:15		1	*			1	*				
01:30		1	*			1	*				
01:45		0	*	4	0	0	*	3	0	7	0
02:00		0	*			2	*				
02:15		1	*			0	*				
02:30		1	*			1	*				
02:45		3	*	5	0	0	*	3	0	8	0
03:00		0	*			1	*				
03:15		0	*			0	*				
03:30		0	*			0	*				
03:45		1	*	1	0	3	*	4	0	5	0
04:00		0	*			0	*				
04:15		0	*			1	*				
04:30		0	*			0	*				
04:45		1	*	1	0	4	*	5	0	6	0
05:00		2	*			3	*				
05:15		3	*			5	*				
05:30		2	*			15	*				
05:45		3	*	10	0	19	*	42	0	52	0
06:00		6	*			21	*				
06:15		5	*			26	*				
06:30		9	*			47	*				
06:45		13	*	33	0	30	*	124	0	157	0
07:00		18	*			52	*				
07:15		27	*			35	*				
07:30		20	*			32	*				
07:45		25	*	90	0	38	*	157	0	247	0
08:00		17	*			39	*				
08:15		28	*			38	*				
08:30		21	*			31	*				
08:45		13	*	79	0	22	*	130	0	209	0
09:00		17	*			20	*				
09:15		20	*			31	*				
09:30		23	*			37	*				
09:45		28	*	88	0	31	*	119	0	207	0
10:00		24	*			26	*				
10:15		24	*			22	*				
10:30		27	*			25	*				
10:45		28	*	103	0	25	*	98	0	201	0
11:00		35	*			36	*				
11:15		22	*			32	*				
11:30		33	*			37	*				
11:45		40	*	130	0	22	*	127	0	257	0
Total		564	0			823	0			1387	0
Percent		100.0%	0.0%			100.0%	0.0%			100.0%	0.0%
Grand Total		1124	1543			1631	1148			2755	2691
Percent		42.1%	57.9%			58.7%	41.3%			50.6%	49.4%

ADT Not Calculated

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Site Code: 29420073854
Station ID:
Counter # 16642

Community: Templeton
Street: Gardner Road
Location: E. of N. Main St
Function Class: U-5

Latitude: 0' 0.000 Undefined

Start	12-Jul-07	East		Hour Totals		West		Hour Totals		Combined Totals	
Time	Thu	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		2	*			3	*				
12:15		2	*			0	*				
12:30		1	*			1	*				
12:45		0	*	5	0	0	*	4	0	9	0
01:00		2	*			1	*				
01:15		1	*			3	*				
01:30		2	*			1	*				
01:45		2	*	7	0	0	*	5	0	12	0
02:00		1	*			3	*				
02:15		1	*			1	*				
02:30		0	*			1	*				
02:45		3	*	5	0	1	*	6	0	11	0
03:00		0	*			2	*				
03:15		0	*			1	*				
03:30		2	*			0	*				
03:45		0	*	2	0	0	*	3	0	5	0
04:00		3	*			1	*				
04:15		3	*			2	*				
04:30		2	*			7	*				
04:45		6	*	14	0	3	*	13	0	27	0
05:00		6	*			4	*				
05:15		5	*			19	*				
05:30		8	*			27	*				
05:45		9	*	28	0	16	*	66	0	94	0
06:00		14	*			10	*				
06:15		15	*			44	*				
06:30		26	*			39	*				
06:45		24	*	79	0	23	*	116	0	195	0
07:00		24	*			43	*				
07:15		27	*			37	*				
07:30		28	*			65	*				
07:45		25	*	104	0	40	*	185	0	289	0
08:00		22	*			45	*				
08:15		23	*			50	*				
08:30		27	*			40	*				
08:45		19	*	91	0	51	*	186	0	277	0
09:00		34	*			41	*				
09:15		31	*			38	*				
09:30		35	*			39	*				
09:45		19	*	119	0	31	*	149	0	268	0
10:00		27	*			31	*				
10:15		35	*			34	*				
10:30		30	*			40	*				
10:45		34	*	126	0	41	*	146	0	272	0
11:00		28	*			40	*				
11:15		*	*			*	*				
11:30		*	*	*	*	*	*	*	*	*	*
11:45		*	*	*	*	*	*	*	*	*	*
Total		608	0			919	0			1459	0
Percent		100.0%	0.0%			100.0%	0.0%			100.0%	0.0%
Grand Total		1291	1381			1977	1408			3200	2789
Percent		48.3%	51.7%			58.4%	41.6%			53.4%	46.6%

ADT Not Calculated

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Site Code: 002942007916
Station ID:
Counter # 3545

Community: Templeton
Street: Patriots Road (Rt.2A)
Location: E. of S. Main Street
Function Class: U-3

Latitude: 0' 0.000 Undefined

Start	11-Jul-07	East		Hour Totals		West		Hour Totals		Combined Totals	
Time	Wed	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		3	42			4	53				
12:15		1	46			2	55				
12:30		2	51			5	53				
12:45		0	47	6	186	0	59	11	220	17	406
01:00		4	49			2	49				
01:15		0	46			0	64				
01:30		1	47			0	41				
01:45		3	54	8	196	3	49	5	203	13	399
02:00		1	54			1	52				
02:15		0	63			0	55				
02:30		1	95			2	48				
02:45		3	69	5	281	3	47	6	202	11	483
03:00		1	116			1	59				
03:15		1	93			1	63				
03:30		1	95			2	60				
03:45		5	88	8	392	5	44	9	226	17	618
04:00		3	101			6	45				
04:15		2	75			10	43				
04:30		4	95			12	47				
04:45		14	79	23	350	20	49	48	184	71	534
05:00		5	74			27	63				
05:15		3	85			10	59				
05:30		22	70			25	43				
05:45		20	75	50	304	52	50	114	215	164	519
06:00		18	60			44	46				
06:15		25	60			43	31				
06:30		15	65			42	38				
06:45		29	59	87	244	41	36	170	151	257	395
07:00		26	40			47	46				
07:15		24	54			52	23				
07:30		33	37			52	45				
07:45		28	50	111	181	38	29	189	143	300	324
08:00		43	36			50	26				
08:15		24	42			50	23				
08:30		42	38			52	16				
08:45		53	19	162	135	49	17	201	82	363	217
09:00		34	20			43	11				
09:15		36	39			63	14				
09:30		37	21			51	16				
09:45		36	9	143	89	72	8	229	49	372	138
10:00		36	12			47	3				
10:15		50	5			39	3				
10:30		51	14			43	14				
10:45		52	8	189	39	36	4	165	24	354	63
11:00		61	10			66	2				
11:15		62	11			64	2				
11:30		62	3			53	5				
11:45		47	4	232	28	50	3	233	12	465	40
Total		1024	2425			1380	1711			2404	4136
Percent		29.7%	70.3%			44.6%	55.4%			36.8%	63.2%

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Site Code: 002942007916
Station ID:
Counter # 3545

Community: Templeton
Street: Patriots Road (Rt.2A)
Location: E. of S. Main Street
Function Class: U-3

Latitude: 0' 0.000 Undefined

Start	12-Jul-07	East		Hour Totals		West		Hour Totals		Combined Totals	
Time	Thu	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		3	*			4	*				
12:15		1	*			2	*				
12:30		2	*			5	*				
12:45		0	*	6	0	0	*	11	0	17	0
01:00		4	*			2	*				
01:15		0	*			0	*				
01:30		1	*			0	*				
01:45		3	*	8	0	3	*	5	0	13	0
02:00		1	*			1	*				
02:15		0	*			0	*				
02:30		1	*			2	*				
02:45		3	*	5	0	3	*	6	0	11	0
03:00		1	*			1	*				
03:15		1	*			1	*				
03:30		1	*			2	*				
03:45		5	*	8	0	5	*	9	0	17	0
04:00		3	*			6	*				
04:15		2	*			10	*				
04:30		4	*			12	*				
04:45		14	*	23	0	20	*	48	0	71	0
05:00		5	*			27	*				
05:15		3	*			10	*				
05:30		22	*			25	*				
05:45		20	*	50	0	52	*	114	0	164	0
06:00		18	*			44	*				
06:15		25	*			43	*				
06:30		15	*			42	*				
06:45		29	*	87	0	41	*	170	0	257	0
07:00		26	*			47	*				
07:15		24	*			52	*				
07:30		33	*			52	*				
07:45		28	*	111	0	38	*	189	0	300	0
08:00		43	*			50	*				
08:15		24	*			50	*				
08:30		42	*			52	*				
08:45		53	*	162	0	49	*	201	0	363	0
09:00		34	*			43	*				
09:15		32	*			47	*				
09:30		47	*			41	*				
09:45		43	*	156	0	37	*	168	0	324	0
10:00		57	*			43	*				
10:15		49	*			36	*				
10:30		70	*			45	*				
10:45		*	*	176	0	*	*	124	0	300	0
11:00		*	*	*	*	*	*	*	*	*	*
11:15		*	*	*	*	*	*	*	*	*	*
11:30		*	*	*	*	*	*	*	*	*	*
11:45		*	*	*	*	*	*	*	*	*	*
Total		792	0			1045	0			1837	0
Percent		100.0%	0.0%			100.0%	0.0%			100.0%	0.0%
Grand Total		1816	2425			2425	1711			4241	4136
Percent		42.8%	57.2%			58.6%	41.4%			50.6%	49.4%
ADT		Not Calculated									

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Community: Templeton
Street: Patriots Rd (Rt.2A)
Location: W. of N. Main St
Function Class: U-5

Site Code: 002942007921
Station ID:
Counter # 7137
Latitude: 0' 0.000 Undefined

Start	11-Jul-07	East		Hour Totals		West		Hour Totals		Combined Totals	
Time	Wed	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		3	84			10	96				
12:15		4	79			4	80				
12:30		3	76			2	67				
12:45		2	60	12	299	5	73	21	316	33	615
01:00		5	79			1	69				
01:15		0	57			2	64				
01:30		3	67			4	76				
01:45		2	85	10	288	4	90	11	299	21	587
02:00		0	58			3	70				
02:15		5	82			2	72				
02:30		0	80			1	88				
02:45		1	86	6	306	0	79	6	309	12	615
03:00		2	96			5	107				
03:15		3	86			4	104				
03:30		1	81			1	124				
03:45		0	83	6	346	4	118	14	453	20	799
04:00		2	82			3	108				
04:15		5	104			6	110				
04:30		7	86			8	103				
04:45		15	69	29	341	7	80	24	401	53	742
05:00		6	73			25	131				
05:15		19	71			38	88				
05:30		38	105			34	91				
05:45		29	92	92	341	31	94	128	404	220	745
06:00		35	64			55	74				
06:15		43	92			53	87				
06:30		65	60			65	84				
06:45		71	51	214	267	58	100	231	345	445	612
07:00		46	51			52	75				
07:15		72	58			73	66				
07:30		81	42			85	57				
07:45		78	53	277	204	54	56	264	254	541	458
08:00		57	74			57	67				
08:15		81	41			52	59				
08:30		64	48			60	43				
08:45		77	29	279	192	58	44	227	213	506	405
09:00		74	33			56	41				
09:15		60	28			69	31				
09:30		72	19			51	22				
09:45		58	18	264	98	70	30	246	124	510	222
10:00		61	19			70	25				
10:15		80	10			75	12				
10:30		60	9			81	20				
10:45		63	12	264	50	57	8	283	65	547	115
11:00		63	6			62	23				
11:15		68	9			76	16				
11:30		76	5			79	7				
11:45		66	6	273	26	90	12	307	58	580	84
Total		1726	2758			1762	3241			3488	5999
Percent		38.5%	61.5%			35.2%	64.8%			36.8%	63.2%

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Site Code: 002942007921
Station ID:
Counter # 7137

Community: Templeton
Street: Patriots Rd (Rt.2A)
Location: W. of N. Main St
Function Class: U-5

Latitude: 0' 0.000 Undefined

Start	12-Jul-07	East		Hour Totals		West		Hour Totals		Combined Totals	
Time	Thu	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		3	*			10	*				
12:15		4	*			4	*				
12:30		3	*			2	*				
12:45		2	*	12	0	5	*	21	0	33	0
01:00		5	*			1	*				
01:15		0	*			2	*				
01:30		3	*			4	*				
01:45		2	*	10	0	4	*	11	0	21	0
02:00		0	*			3	*				
02:15		5	*			2	*				
02:30		0	*			1	*				
02:45		1	*	6	0	0	*	6	0	12	0
03:00		2	*			5	*				
03:15		3	*			4	*				
03:30		1	*			1	*				
03:45		0	*	6	0	4	*	14	0	20	0
04:00		2	*			3	*				
04:15		5	*			6	*				
04:30		7	*			8	*				
04:45		15	*	29	0	7	*	24	0	53	0
05:00		6	*			25	*				
05:15		19	*			38	*				
05:30		38	*			34	*				
05:45		29	*	92	0	31	*	128	0	220	0
06:00		35	*			55	*				
06:15		43	*			53	*				
06:30		65	*			65	*				
06:45		71	*	214	0	58	*	231	0	445	0
07:00		46	*			52	*				
07:15		72	*			73	*				
07:30		81	*			85	*				
07:45		78	*	277	0	54	*	264	0	541	0
08:00		57	*			57	*				
08:15		81	*			52	*				
08:30		64	*			60	*				
08:45		77	*	279	0	58	*	227	0	506	0
09:00		74	*			56	*				
09:15		69	*			67	*				
09:30		74	*			78	*				
09:45		72	*	289	0	58	*	259	0	548	0
10:00		62	*			57	*				
10:15		56	*			63	*				
10:30		44	*			76	*				
10:45		66	*	228	0	70	*	266	0	494	0
11:00		41	*			57	*				
11:15		*	*	*	*	*	*	*	*	*	*
11:30		*	*	*	*	*	*	*	*	*	*
11:45		*	*	*	*	*	*	*	*	*	*
Total		1483	0			1508	0			2893	0
Percent		100.0%	0.0%			100.0%	0.0%			100.0%	0.0%
Grand Total		3209	2758			3270	3241			6381	5999
Percent		53.8%	46.2%			50.2%	49.8%			51.5%	48.5%

ADT Not Calculated

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Site Code: 002942007936
Station ID:
Counter # 3697

Community: Templeton
Street: South Main Street
Location: S. of Patriots Rd (Rt.2A)
Function Class: U-6

Latitude: 0' 0.000 Undefined

Start	11-Jul-07	South		Hour Totals		North		Hour Totals		Combined Totals	
Time	Wed	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		2	14			1	14				
12:15		0	13			2	12				
12:30		1	26			0	16				
12:45		1	16	4	69	1	13	4	55	8	124
01:00		2	12			1	11				
01:15		1	21			1	14				
01:30		0	11			0	10				
01:45		0	12	3	56	2	16	4	51	7	107
02:00		1	18			0	16				
02:15		0	8			0	12				
02:30		1	22			3	19				
02:45		1	13	3	61	0	10	3	57	6	118
03:00		1	16			0	16				
03:15		1	25			2	15				
03:30		0	20			0	16				
03:45		3	25	5	86	4	17	6	64	11	150
04:00		0	26			0	16				
04:15		0	33			4	19				
04:30		3	26			9	19				
04:45		5	26	8	111	7	17	20	71	28	182
05:00		1	21			13	19				
05:15		2	22			12	19				
05:30		7	23			9	18				
05:45		6	23	16	89	14	11	48	67	64	156
06:00		9	11			18	14				
06:15		9	14			15	17				
06:30		4	22			15	2				
06:45		9	8	31	55	22	13	70	46	101	101
07:00		10	14			24	15				
07:15		5	14			30	7				
07:30		8	17			20	19				
07:45		6	20	29	65	18	5	92	46	121	111
08:00		5	20			14	7				
08:15		10	7			22	6				
08:30		8	9			12	3				
08:45		13	12	36	48	11	6	59	22	95	70
09:00		14	8			20	2				
09:15		10	11			9	9				
09:30		16	13			18	4				
09:45		26	8	66	40	22	2	69	17	135	57
10:00		11	5			14	2				
10:15		12	3			11	2				
10:30		18	4			18	4				
10:45		21	3	62	15	20	0	63	8	125	23
11:00		7	5			19	0				
11:15		20	1			14	0				
11:30		12	0			19	0				
11:45		18	2	57	8	11	2	63	2	120	10
Total		320	703			501	506			821	1209
Percent		31.3%	68.7%			49.8%	50.2%			40.4%	59.6%

Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Tel: (978) 345-7376 Email: mrpc@mrpc.org

Site Code: 002942007936
Station ID:
Counter # 3697

Community: Templeton
Street: South Main Street
Location: S. of Patriots Rd (Rt.2A)
Function Class: U-6

Latitude: 0' 0.000 Undefined

Start	12-Jul-07	South		Hour Totals		North		Hour Totals		Combined Totals	
Time	Thu	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
12:00		2	*			1	*				
12:15		0	*			2	*				
12:30		1	*			0	*				
12:45		1	*	4	0	1	*	4	0	8	0
01:00		2	*			1	*				
01:15		1	*			1	*				
01:30		0	*			0	*				
01:45		0	*	3	0	2	*	4	0	7	0
02:00		1	*			0	*				
02:15		0	*			0	*				
02:30		1	*			3	*				
02:45		1	*	3	0	0	*	3	0	6	0
03:00		1	*			0	*				
03:15		1	*			2	*				
03:30		0	*			0	*				
03:45		3	*	5	0	4	*	6	0	11	0
04:00		0	*			0	*				
04:15		0	*			4	*				
04:30		3	*			9	*				
04:45		5	*	8	0	7	*	20	0	28	0
05:00		1	*			13	*				
05:15		2	*			12	*				
05:30		7	*			9	*				
05:45		6	*	16	0	14	*	48	0	64	0
06:00		9	*			18	*				
06:15		9	*			15	*				
06:30		4	*			15	*				
06:45		9	*	31	0	22	*	70	0	101	0
07:00		10	*			24	*				
07:15		5	*			30	*				
07:30		8	*			20	*				
07:45		6	*	29	0	18	*	92	0	121	0
08:00		5	*			14	*				
08:15		10	*			22	*				
08:30		8	*			12	*				
08:45		13	*	36	0	11	*	59	0	95	0
09:00		17	*			19	*				
09:15		9	*			10	*				
09:30		12	*			10	*				
09:45		10	*	48	0	12	*	51	0	99	0
10:00		15	*			17	*				
10:15		17	*			12	*				
10:30		14	*			17	*				
10:45		*	*	46	0	*	*	46	0	92	0
11:00		*	*	*	*	*	*	*	*	*	*
11:15		*	*	*	*	*	*	*	*	*	*
11:30		*	*	*	*	*	*	*	*	*	*
11:45		*	*	*	*	*	*	*	*	*	*
Total		229	0			403	0			632	0
Percent		100.0%	0.0%			100.0%	0.0%			100.0%	0.0%
Grand Total		549	703			904	506			1453	1209
Percent		43.8%	56.2%			64.1%	35.9%			54.6%	45.4%

ADT Not Calculated

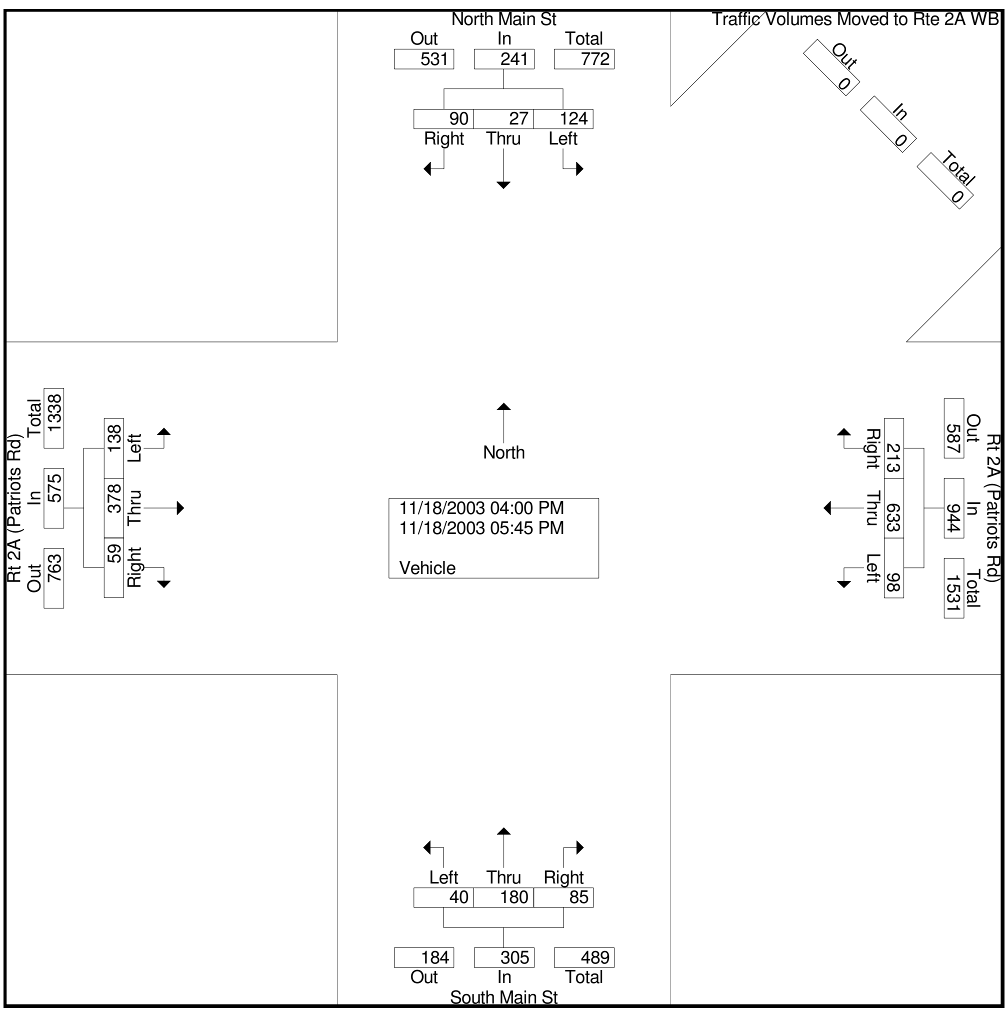
Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Turning Movement Count

Town: Templeton, MA
Street: Rt 2A (Patriots Rd)
Location: N/S Main St
Class/Type: Turning Movement Adjusted

File Name : 294RT2A&101&NSMAIN RNDB Adj
Site Code : 00867539
Start Date : 11/18/2003
Page No : 1

Groups Printed- Vehicle

	North Main St From North				Rt 2A (Patriots Rd) From East				South Main St From South				Rt 2A (Patriots Rd) From West				
Start Time	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Int. Total
04:00 PM	13	6	18	37	32	93	13	138	10	38	2	50	7	56	22	85	310
04:15 PM	10	3	19	32	26	70	11	107	16	41	3	60	13	48	25	86	285
04:30 PM	14	3	18	35	26	88	15	129	13	44	4	61	8	42	19	69	294
04:45 PM	11	2	12	25	24	79	16	119	12	41	7	60	8	61	12	81	285
Total	48	14	67	129	108	330	55	493	51	164	16	231	36	207	78	321	1174
05:00 PM	8	2	13	23	29	78	11	118	7	3	3	13	5	39	21	65	219
05:15 PM	14	7	20	41	28	83	8	119	7	6	6	19	6	48	12	66	245
05:30 PM	12	1	14	27	30	77	11	118	11	4	9	24	10	46	14	70	239
05:45 PM	8	3	10	21	18	65	13	96	9	3	6	18	2	38	13	53	188
Total	42	13	57	112	105	303	43	451	34	16	24	74	23	171	60	254	891
Grand Total	90	27	124	241	213	633	98	944	85	180	40	305	59	378	138	575	2065
Apprch %	37.3	11.2	51.5		22.6	67.1	10.4		27.9	59	13.1		10.3	65.7	24		
Total %	4.4	1.3	6	11.7	10.3	30.7	4.7	45.7	4.1	8.7	1.9	14.8	2.9	18.3	6.7	27.8	



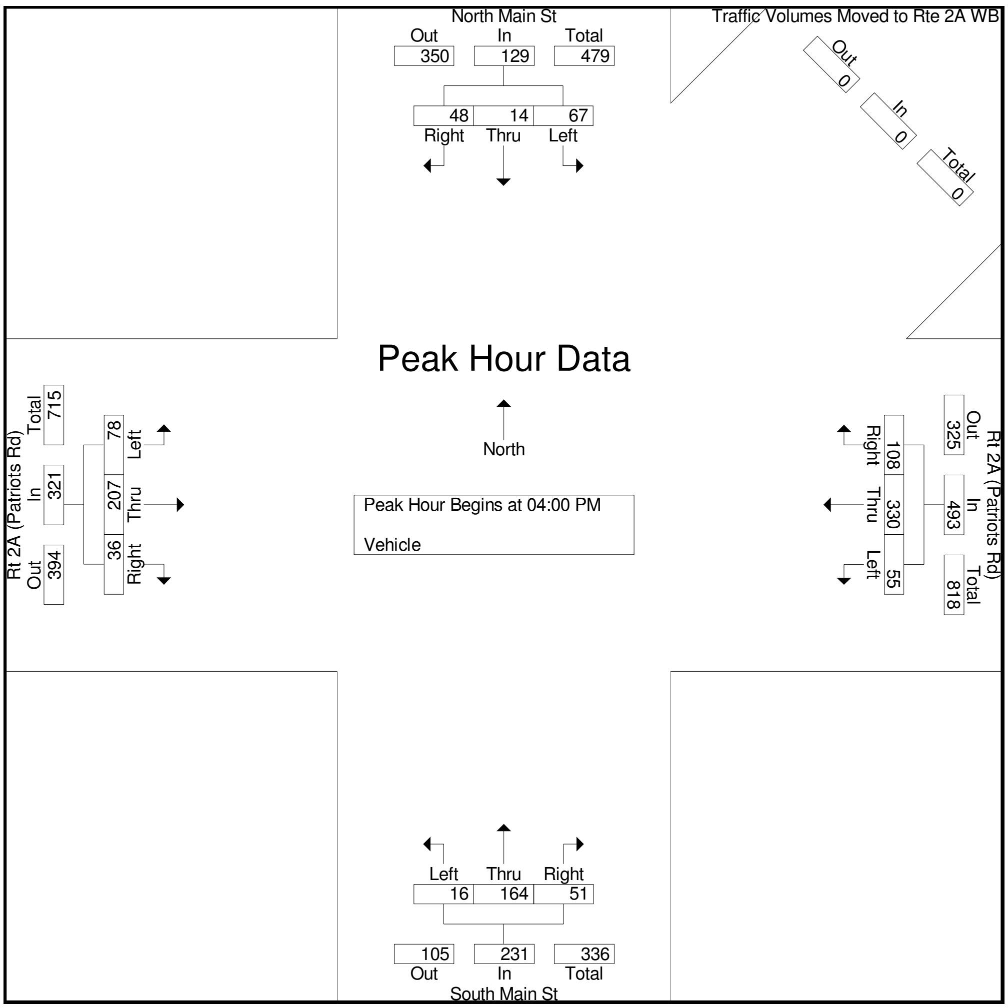
Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420

Town: Templeton, MA
Street: Rt 2A (Patriots Rd)
Location: N/S Main St
Class/Type: Turning Movement Adjusted

Turning Movement Count

File Name : 294RT2A&101&NSMAIN RNDB Adj
Site Code : 00867539
Start Date : 11/18/2003
Page No : 2

	North Main St From North				Rt 2A (Patriots Rd) From East				South Main St From South				Rt 2A (Patriots Rd) From West				
Start Time	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Int. Total
Peak Hour Analysis From 04:00 PM to 04:45 PM - Peak 1 of 1																	
Peak Hour for Entire Intersection Begins at 04:00 PM																	
04:00 PM	13	6	18	37	32	93	13	138	10	38	2	50	7	56	22	85	310
04:15 PM	10	3	19	32	26	70	11	107	16	41	3	60	13	48	25	86	285
04:30 PM	14	3	18	35	26	88	15	129	13	44	4	61	8	42	19	69	294
04:45 PM	11	2	12	25	24	79	16	119	12	41	7	60	8	61	12	81	285
Total Volume	48	14	67	129	108	330	55	493	51	164	16	231	36	207	78	321	1174
% App. Total	37.2	10.9	51.9		21.9	66.9	11.2		22.1	71	6.9		11.2	64.5	24.3		
PHF	.857	.583	.882	.872	.844	.887	.859	.893	.797	.932	.571	.947	.692	.848	.780	.933	.947



Justification for adjusting traffic volumes: Traffic origins and destinations will change due the proposed roundabout. See table named "TABLE: ESTIMATING THE CIRCULATING TRAFFIC VOLUME AFFECTING WESTBOUND ENTRY APPROACH" in Appendix C to see how traffic origins/destinations and traffic volumes will change and how they were determined.

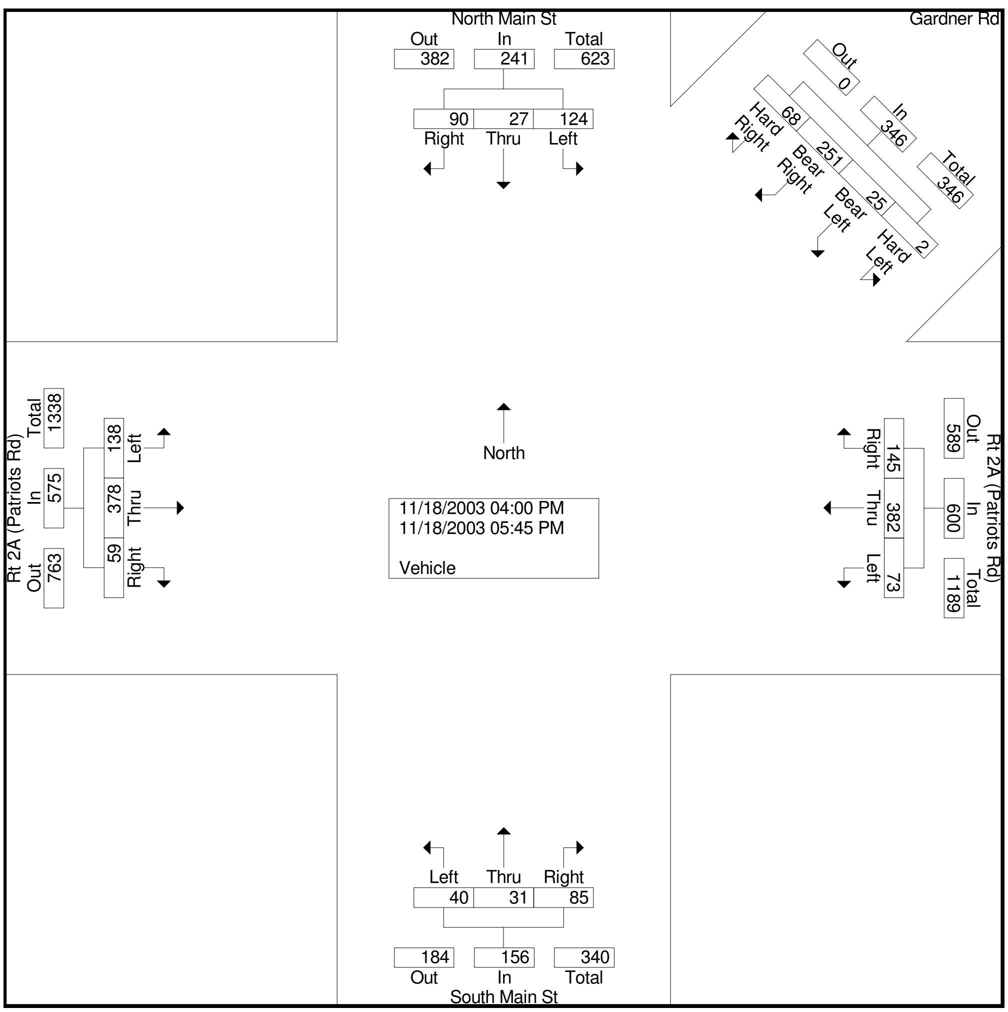
Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Turning Movement Count

Town: Templeton, MA
Street: Rt 2A (Patriots Rd)
Location: N/S Main St, Gardner Rd
Class/Type: Turning Movement

File Name : 294 RT 2A&101&NSMAIN2
Site Code : 00867539
Start Date : 11/18/2003
Page No : 1

Groups Printed- Vehicle

	North Main St From North				Gardner Rd From Northeast					Rt 2A (Patriots Rd) From East				South Main St From South				Rt 2A (Patriots Rd) From West				
Start Time	Right	Thru	Left	App. Total	Hard Right	Bear Right	Bear Left	Hard Left	App. Total	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Int. Total
04:00 PM	13	6	18	37	13	35	5	0	53	19	58	8	85	10	1	2	13	7	56	22	85	273
04:15 PM	10	3	19	32	13	35	5	0	53	13	35	6	54	16	3	3	22	13	48	25	86	247
04:30 PM	14	3	18	35	8	37	2	0	47	18	51	13	82	13	7	4	24	8	42	19	69	257
04:45 PM	11	2	12	25	3	37	6	0	46	21	42	10	73	12	4	7	23	8	61	12	81	248
Total	48	14	67	129	37	144	18	0	199	71	186	37	294	51	15	16	82	36	207	78	321	1025
05:00 PM	8	2	13	23	10	35	2	2	49	19	43	9	71	7	3	3	13	5	39	21	65	221
05:15 PM	14	7	20	41	11	31	2	0	44	17	52	6	75	7	6	6	19	6	48	12	66	245
05:30 PM	12	1	14	27	6	25	1	0	32	24	52	10	86	11	4	9	24	10	46	14	70	239
05:45 PM	8	3	10	21	4	16	2	0	22	14	49	11	74	9	3	6	18	2	38	13	53	188
Total	42	13	57	112	31	107	7	2	147	74	196	36	306	34	16	24	74	23	171	60	254	893
Grand Total	90	27	124	241	68	251	25	2	346	145	382	73	600	85	31	40	156	59	378	138	575	1918
Apprch %	37.3	11.2	51.5		19.7	72.5	7.2	0.6		24.2	63.7	12.2		54.5	19.9	25.6		10.3	65.7	24		
Total %	4.7	1.4	6.5	12.6	3.5	13.1	1.3	0.1	18	7.6	19.9	3.8	31.3	4.4	1.6	2.1	8.1	3.1	19.7	7.2	30	

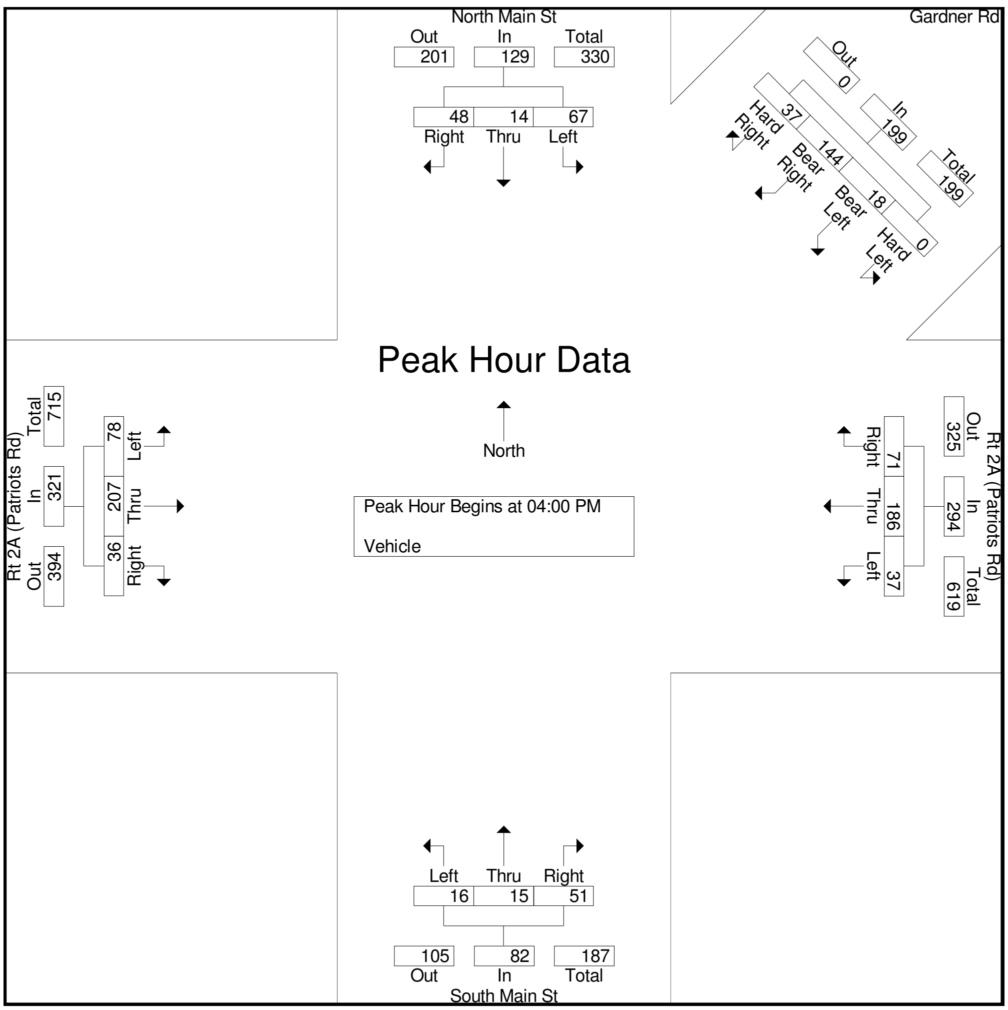


Montachusett Regional Planning Commission
R1427 Water Street
Fitchburg, MA 01420
Turning Movement Count

Town: Templeton, MA
Street: Rt 2A (Patriots Rd)
Location: N/S Main St, Gardner Rd
Class/Type: Turning Movement

File Name : 294 RT 2A&101&NSMAIN2
Site Code : 00867539
Start Date : 11/18/2003
Page No : 2

	North Main St From North				Gardner Rd From Northeast					Rt 2A (Patriots Rd) From East				South Main St From South				Rt 2A (Patriots Rd) From West				
Start Time	Right	Thru	Left	App. Total	Hard Right	Bear Right	Bear Left	Hard Left	App. Total	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Right	Thru	Left	App. Total	Int. Total
Peak Hour Analysis From 04:00 PM to 04:45 PM - Peak 1 of 1																						
Peak Hour for Entire Intersection Begins at 04:00 PM																						
04:00 PM	13	6	18	37	13	35	5	0	53	19	58	8	85	10	1	2	13	7	56	22	85	273
04:15 PM	10	3	19	32	13	35	5	0	53	13	35	6	54	16	3	3	22	13	48	25	86	247
04:30 PM	14	3	18	35	8	37	2	0	47	18	51	13	82	13	7	4	24	8	42	19	69	257
04:45 PM	11	2	12	25	3	37	6	0	46	21	42	10	73	12	4	7	23	8	61	12	81	248
Total Volume	48	14	67	129	37	144	18	0	199	71	186	37	294	51	15	16	82	36	207	78	321	1025
% App. Total	37.2	10.9	51.9		18.6	72.4	9	0		24.1	63.3	12.6		62.2	18.3	19.5		11.2	64.5	24.3		
PHF	.857	.583	.882	.872	.712	.973	.750	.000	.939	.845	.802	.712	.865	.797	.536	.571	.854	.692	.848	.780	.933	.939



APPENDIX B

Crash Table & Crash Rate Analyses

02 - 05 Crash Data for Patriots Rd/Gardner Rd/North&South Main Sts Intersection in Templeton

Year of Crash	MRPC Intersection Crash ID	MHD Crash Number	Crash Date	Crash Time	Crash Severity	Number of Vehicles	Total Nonfatal Injuries	Total Fatal Injuries	Manner of Collision	Vehicles Travel Directions	Most Harmful Events	Road Surface Condition	Ambient Light	Weather Condition	At Roadway Intersection	Distance from Nearest Roadway Intersection	Distance from Nearest Landmark	Address
2005	1-05	1847460	27-Feb-2005	12:23 PM	Non-fatal injury	2	3		Angle	V1:Eastbound / V2:Northbound	Crash with motor vehicles in traffic	Dry	Daylight	Cloudy		PATRIOTS ROAD Rte 2A / SOUTH MAIN STREET Rte 2A		PATRIOTS ROAD Rte 2A
2005	2-05	1862304	24-Mar-2005	7:05 PM	Property damage only	2			Sideswipe, opp direction	V1:Northbound / V2:Westbound	Crash with motor vehicles in traffic	Dry	Dark - rdway not lighted	Clear		15 feet W from Intersection NORTH MAIN STREET / GARDNER ROAD		NORTH MAIN STREET
2005	3-05	1872012	21-Apr-2005	3:04 PM	Property damage only	2			Angle	V1:Northbound / V2:Westbound	Crash with motor vehicles in traffic	Dry	Daylight	Clear		120 PATRIOTS ROAD / GARDNER ROAD		120 PATRIOTS ROAD
2005	4-05	1895065	28-May-2005	9:53 PM	Non-fatal injury	2	2		Rear-end	V1:Westbound / V2:Westbound	Crash with motor vehicles in traffic	Dry	Dark - lighted roadway	Cloudy		PATRIOTS ROAD / NORTH MAIN STREET		PATRIOTS ROAD
2005	5-05	1899691	17-Jun-2005	12:42 AM	Non-fatal injury	1	1		Single vehicle crash	V1:Westbound	Crash with fixed object	Wet	Dark - lighted roadway	Rain		GARDNER ROAD Rte 101 / Rte 101	TMLP 4	GARDNER ROAD Rte 101
2005	6-05	1941736	07-Oct-2005	9:30 AM	Property damage only	2			Rear-end	V1:Southbound / V2:Eastbound	Crash with motor vehicles in traffic	Dry	Daylight	Cloudy		PATRIOTS ROAD Rte 101 / Rte 101	5 CORNER INTERSECTION	PATRIOTS ROAD Rte 101
2005	7-05	1944636	17-Oct-2005	9:30 PM	Property damage only	2			Angle	V1:Eastbound / V2:Eastbound	Crash with motor vehicles in traffic	Dry	Dark - lighted roadway	Clear		PATRIOTS ROAD / NORTH MAIN STREET		PATRIOTS ROAD
2005	8-05	1952757	04-Nov-2005	10:48 AM	Property damage only	2			Sdswipe, sm direction	V1:Northbound / V2:Eastbound	Crash with motor vehicles in traffic	Dry	Daylight	Cloudy		PATRIOTS ROAD / GARDNER ROAD		PATRIOTS ROAD
2004	1-04	1687489	20-Jan-2004	4:40 PM	Property damage only	2			Angle	V1:Northbound / V2:Westbound	Crash with motor vehicles in traffic	Dry	Daylight	Clear		PATRIOTS ROAD / SOUTH MAIN STREET		PATRIOTS ROAD
2004	2-04	1690099	15-Feb-2004	1:24 AM	Non-fatal injury	1	1		Single vehicle crash	V1:Eastbound	Crash with curb	Dry	Dark - lighted roadway	Clear		N MAIN STREET / PATRIOTS ROAD	E TEMPLETON CENTER	N MAIN STREET
2004	3-04	1862686	07-Mar-2004	4:00 PM	Property damage only	2			Unknown	V1:Westbound / V2:Not reported	Not reported	Dry	Daylight	Clear	GARDNER RD Rte 101 / N MAIN ST			
2004	4-04	1769656	22-Aug-2004	1:10 PM	Property damage only	2			Sdswipe, sm direction	V1:Westbound / V2:Westbound	Crash with motor vehicles in traffic	Dry	Daylight	Clear		PATRIOTS ROAD Rte 101 / GARDNER ROAD Rte 101		PATRIOTS ROAD Rte 101
2003	1-03	1596998	10-Jun-2003	7:58 AM	Property damage only	2			Angle	V1:Westbound / V2:Northbound	Crash with motor vehicles in traffic	Dry	Daylight	Clear		10 feet S of Intersection PATRIOTS ROAD Rte 2A / N MAIN STREET		PATRIOTS RD Rte 2A E
2003	2-03	1595356	12-Jun-2003	3:24 PM	Property damage only	2			Head-on	V1:Southbound / V2:Westbound	Crash with motor vehicles in traffic	Dry	Daylight	Clear		PATRIOTS ROAD / NORTH MAIN STREET		PATRIOTS ROAD
2003	3-03	1671562	12-Dec-2003	12:37 PM	Non-fatal injury	2	1		Not reported	V1:Westbound / V2:Westbound	Crash with motor vehicles in traffic	Not reported	Not reported	Not reported		PATRIOTS ROAD / GARDNER ROAD Rte 101		PATRIOTS ROAD (FIRE PRO TECH)
2003	4-03	1674358	25-Dec-2003	3:53 PM	Non-fatal injury	2	2		Angle	V1:Eastbound / V2:Northbound	Crash with motor vehicles in traffic	Dry	Daylight	Cloudy		PATRIOTS ROAD Rte 2A / SOUTH MAIN STREET		PATRIOTS ROAD Rte 2A (E TEMPLETON CENTER)
2002	1-02	1437737	29-Jan-2002	11:07 AM	Property damage only	2			Rear-end	V1:Southbound/V2:Southbound	Crash with motor vehicles in traffic	Wet	Daylight	Cloudy				132B PATRIOTS ROAD
2002	2-02	1466009	15-Jun-2002	6:25 PM	Non-fatal injury	2	2		Angle	V1:Westbound/ V2:Northbound	Crash with motor vehicles in traffic	Wet	Daylight	Rain	GARDNER RD/ N MAIN ST / Rte 101			
2002	3-02	1471102	11-Jul-2002	12:03 PM	Property damage only	2			Rear-end	V1:Westbound/ V2:Westbound	Crash with motor vehicles in traffic	Dry	Daylight	Clear		PATRIOTS ROAD/NORTH MAIN STREET		PATRIOTS ROAD
2002	4-02	1480321	25-Aug-2002	1:40 PM	Property damage only	2			Angle	V1:Northbound/V2:Westbound	Crash with motor vehicles in traffic	Dry	Daylight	Cloudy		PATRIOTS ROAD/NORTH MAIN STREET		PATRIOTS ROAD
2002	5-02	1521339	16-Dec-2002	10:40 AM	Property damage only	2			Angle	V1:Northbound/V2:Eastbound	Crash with motor vehicles in traffic	Snow	Daylight	Snow		GARDNER ROAD/PATRIOTS ROAD		GARDNER ROAD

MassHighway

CRASH RATE WORKSHEET

CITY/TOWN :	Templeton	COUNT DATE :	Nov-03	
DISTRICT :	2	UNSIGNALIZED :	X	SIGNALIZED :

MHD USE ONLY

Source #

~ INTERSECTION DATA ~

MAJOR STREET: Patriots Rd (Rtes 2A & 101) — ST #

MINOR STREET(S): Gardner Rd (Rte 101 WB) — ST #

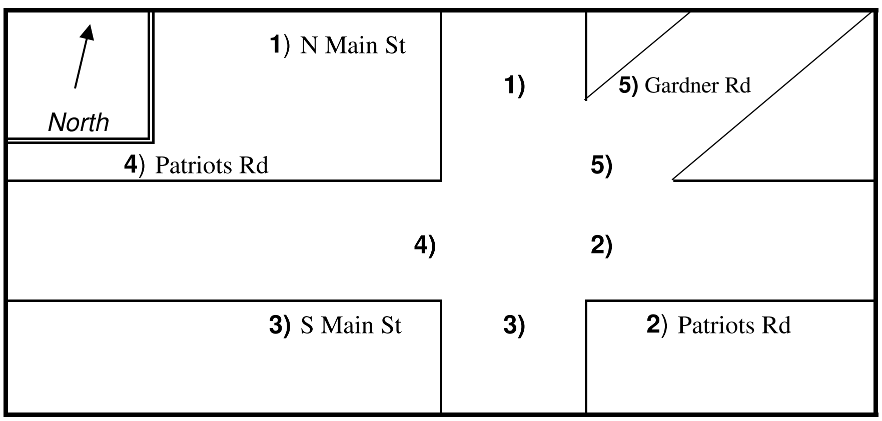
N Main St — ST #

S Main St — ST #

ST #

INTERSECTION DIAGRAM

(Label Approaches)



INTERSECTION

REF #

PM Peak Hour Volumes

APPROACH :	1	2	3	4	5	Total Entering Vehicles
DIRECTION :	SB	WB	NB	EB	WB	
VOLUMES (PM) :	129	294	82	321	199	**1,025**

" K " FACTOR : **0.090** APPROACH ADT : **11,389** **ADT** = TOTAL VOL/"K" FACT.

TOTAL # OF ACCIDENTS :	21	# OF YEARS :	4	AVERAGE # OF ACCIDENTS (**A**) :	**5.25**

CRASH RATE CALCULATION : **1.26** RATE = $\frac{(A * 1,000,000)}{(ADT * 365)}$

Comments :

Project Title & Date: Patriots Rd & Gardner Rd/N Main St/S Main St Roundabout Feasibility Report 08/07

APPENDIX C

LOS Analyses Summaries
Circulating Traffic Volume Estimate for WB Entry
Roundabout Capacity Analyses Summaries

Table: Estimating the Circulating Traffic Volume Affecting Westbound Entry Approach

2007 24 Hour Traffic Volume (Vol) Count Data

Eastbound Volume on Patriots Rd East of S Main St		Eastbound Volume on Gardner Rd East of Orchard Ln	
PM Peak Hour in 15 Minute Intervals		PM Peak Hour in 15 Minute Intervals	
4:00	101	4:00	33
4:15	75	4:15	32
4:30	95	4:30	41
4:45	79	4:45	54
Total	**350**	Total	**160**

Gardner Rd EB Volume (160) as a Percentage of Patriots Rd EB Volume (350) (160/350) equals:

46%

Assumption: 100% of Gardner EB volume East of Orchard Ln originates from Patriots Rd EB

2003 EB Peak Hour Traffic Volume & Origins for Patriots Rd E of N/S Main St							Gardner Rd	**2003 Total Volume**
EB (2A W of N/S Main St)		SB (N Main St)		NB (N Main St)		*EB Volume*	NEB Vol	**Affecting WB Entry**
Thru	*207*	*Left Turn*	*67*	*Right Turn*	*51*	*Subtotal*	***46% of***	**Approach**
				Thru*	15	*325*	*325 equals*	NB Thru + NEB total
							149	**164**

2010 EB Peak Hour Traffic Volume & Origins for Patriots Rd E of N/S Main St							Gardner Rd	**2010 Total Volume**
EB (2A W of N/S Main St)		SB (N Main St)		NB (N Main St)		*EB Volume*	NEB Vol	**Affecting WB Entry**
Thru	*234*	*Left Turn*	*76*	*Right Turn*	*58*	*Subtotal*	***46% of***	**Approach**
				Thru*	17	*368*	*368 equals*	NB Thru + NEB total
							168	**185**

2020 EB Peak Hour Traffic Volume & Origins for Patriots Rd E of N/S Main St							Gardner Rd	**2020 Total Volume**
EB (2A W of N/S Main St)		SB (N Main St)		NB (N Main St)		*EB Volume*	NEB Vol	**Affecting WB Entry**
Thru	*272*	*Left Turn*	*88*	*Right Turn*	*67*	*Subtotal*	***46% of***	**Approach**
				Thru*	20	*427*	*427 equals*	NB Thru + NEB total
							195	**215**

NOTES:

(green) percentage (46%) used to calculate Gardner Rd NEB volume for 2003, 2010, 2020

(yellow) EB & NEB volume

*not an EB destination (blue) but is a destination that affects the WB entry approach. Not added to EB volume

(blue & yellow) adds NB Thru volume to Gardner Rd NEB volume. The combined total affects the WB entry approach

Rt 2A/Rt 101/South main St/North Main St – 2003 Unsignalized 5-Way LOS Analysis

	EB			WB			NB			SB			SWB		
	L	T	R	L	T	R	L	T	R	L	T	R	L	T (bear rt)	R
V	78	207	36	37	186	71	16	15	51	67	14	48	18	144	37
PHF	0.78	0.85	0.69	0.71	0.8	0.93	0.57	0.54	0.8	0.88	0.58	0.86	0.75	0.97	0.71
v_p	100	244	52	52	233	76	28	28	64	76	24	56	24	148	52
lane group	L	TR		L	TR		LTR			LTR			LTR (2 lanes)		
$t_{c,base}$	4.1	n/a	n/a	4.1	n/a	na	7.5	6.5	6.9	7.5	6.5	6.9	7.5	6.5	6.9
t_c	4.1	n/a	n/a	4.1	n/a	na	7.5	6.5	6.9	7.5	6.5	6.9	7.5	6.5	6.9
t_f	2.2	n/a	n/a	2.2	n/a	n/a	3.5	4.0	3.3	3.5	4.0	3.3	3.5	4.0	3.3
v_c	309	n/a	n/a	296	n/a	n/a	959	470	270	1051	535	271	911	371	76
c_p	1263	n/a	n/a	1277	n/a	n/a	214	495	734	184	454	733	232	562	976
c_m	1263	n/a	n/a	1277	n/a	n/a	133	437	734	146	401	733	184	496	976
p_0	0.92	n/a	n/a	0.96	n/a	n/a	0.79	0.94	0.91	0.48	0.94	0.92	0.87	0.70	0.95
v/c_m	0.08	n/a	n/a	0.04	n/a	n/a	0.21	0.06	0.09	0.52	0.06	0.08	0.13	0.30	0.05
c	1263	n/a		1277	n/a		332			237			465		
v/c	0.08	n/a		0.04	n/a		0.36			0.66			0.48		
queue length	0.3	n/a		0.1	n/a		1.6			4.1			2.6		
control delay	8.1	n/a		7.9	n/a		21.8			45.3			19.8		
LOS	A			A			C			E			C		

Rt 2A/Rt 101/South main St/North Main St – 2010 Unsignalized 5-Way LOS Analysis

	EB			WB			NB			SB			SWB		
	L	T	R	L	T	R	L	T	R	L	T	R	L	T(bear rt)	R
V	88	234	41	42	210	80	18	17	58	76	16	54	20	163	42
PHF	0.78	0.85	0.69	0.71	0.8	0.93	0.57	0.54	0.8	0.88	0.58	0.86	0.75	0.97	0.71
v_p	113	275	59	59	263	86	32	31	73	86	28	63	27	168	59
lane group	L	TR		L	TR		LTR			LTR			LTR (2 lanes)		
$t_{c,base}$	4.1	n/a	n/a	4.1	n/a	na	7.5	6.5	6.9	7.5	6.5	6.9	7.5	6.5	6.9
t_c	4.1	n/a	n/a	4.1	n/a	na	7.5	6.5	6.9	7.5	6.5	6.9	7.5	6.5	6.9
t_f	2.2	n/a	n/a	2.2	n/a	n/a	3.5	4.0	3.3	3.5	4.0	3.3	3.5	4.0	3.3
v_c	349	n/a	n/a	334	n/a	n/a	1084	531	305	1188	606	306	1031	420	86
c_p	1221	n/a	n/a	1237	n/a	n/a	174	457	697	146	414	696	190	528	962
c_m	1221	n/a	n/a	1237	n/a	n/a	96	395	697	110	358	696	143	456	962
p_0	0.91	n/a	n/a	0.95	n/a	n/a	0.67	0.92	0.90	0.22	0.92	0.91	0.81	0.63	0.94
v/c_m	0.09	n/a	n/a	0.05	n/a	n/a	0.33	0.08	0.10	0.78	0.08	0.09	0.19	0.37	0.06
c	1221	n/a		1237	n/a		264			187			411		
v/c	0.09	n/a		0.05	n/a		0.52			0.95			0.62		
queue length	0.3	n/a		0.2	n/a		2.7			7.6			4.0		
control delay	8.2	n/a		8.1	n/a		32.3			104.3			26.9		
LOS	A			A			D			F			D		

Rt 2A/Rt 101/South main St/North Main St – 2010 Signalized 5-Way LOS Analysis

	EB			WB			NB			SB			SWB		
	L	T	R	L	T	R	L	T	R	L	T	R	L	T (bear rt)	R
V	88	234	41	42	210	80	18	17	58	76	16	54	20	163	42
PHF	0.78	0.85	0.69	0.71	0.8	0.93	0.57	0.54	0.8	0.88	0.58	0.86	0.75	0.97	0.71
v_p	113	275	59	59	263	86	32	31	73	86	28	63	27	168	59
lane group	L	TR		L	TR			LTR			LTR			LTR (2 lanes)	
s	840	1850		869	1830			1577			1457			3263	
v	113	334		59	349			136			177			254	
phase			1						2					3	
t_L			7						7					7	
g			25						13					13	
g/C			0.35						0.18					0.18	
c	292	642		302	635			285			263			589	
v/c	0.39	0.52		0.20	0.55			0.48			0.67			0.43	
v/s	0.13	0.18		0.07	**0.19**			0.09			**0.12**			**0.08**	
d_1	17.7	18.7		16.5	19.0			26.5			27.5			26.2	
d_2	3.8	3.0		1.4	3.4			5.6			12.9			2.3	
d_3	0	0		0	0			0			0			0	
d	21.6	21.7		17.9	22.4			32.1			40.5			28.5	
LOS	C	C		B	C			C			D			C	
d_A		21.7			21.7			32.1			40.5			28.5	
LOS_A		C			C			C			D			C	

Y_C	0.39
L	9
X_c	0.45

Year 2003A Roundabout Capacity Analysis Summary**					
Volume Adjustments					
4:00:00 PM Peak		EB	WB	NB	SB
Left Turn Traffic	Volume, veh/h	*78*	*55*	*16*	*67*
	Peak Hour Factor	*0.78*	*0.86*	*0.57*	*0.88*
	Flow rate, veh/h	*100*	*63*	*28*	*76*
Thru Traffic	Volume, veh/h	*207*	*330*	*15*	*14*
	Peak Hour Factor	*0.85*	*0.89*	*0.54*	*0.58*
	Flow rate, veh/h	*243*	*370*	*27*	*24*
Right Turn Traffic	Volume, veh/h	*36*	*108*	*51*	*48*
	Peak Hour Factor	*0.69*	*0.88*	*0.80*	*0.86*
	Flow rate, veh/h	*52*	*122*	*63*	*55*
Approach Flow Computation					
Approach Flow (veh/h)			Va (veh/h)		
V_{ae}			*395*		
V_{aw}			*555*		
V_{an}			*118*		
V_{as}			*155*		
Circulating Flow Computation					
Approach Flow (veh/h)			Vc (veh/h)		
V_{ce}			*163*		
V_{cw}			*155*		
V_{cn}			*419*		
V_{cs}			*461*		
Entry Approach Capacity Computation					
		EB	WB*	NB	SB
Capacity	Upper bound	*1219*		*995*	*962*
	Lower bound	*1010*		*809*	*780*
v/c Ratio	Upper bound	*0.32*		*0.12*	*0.16*
	Lower bound	*0.39*		*0.15*	*0.20*
*See Year 2003B for WB Entry Approach					
**This is a modified version of the HCS printout					

Year 2003B Roundabout Capacity Analysis Summary**					
Volume Adjustments					
4:00:00 PM Peak		EB	WB	NB	SB
Left Turn Traffic	Volume, veh/h	*78*	*55*	*16*	*67*
	Peak Hour Factor	*0.78*	*0.86*	*0.57*	*0.88*
	Flow rate, veh/h	*100*	*63*	*28*	*76*
Thru Traffic	Volume, veh/h	*207*	*330*	*164*	*14*
	Peak Hour Factor	*0.85*	*0.89*	*0.93*	*0.58*
	Flow rate, veh/h	*243*	*370*	*176*	*24*
Right Turn Traffic	Volume, veh/h	*36*	*108*	*51*	*48*
	Peak Hour Factor	*0.69*	*0.84*	*0.80*	*0.86*
	Flow rate, veh/h	*52*	*128*	*63*	*55*

Approach Flow Computation	
Approach Flow (veh/h)	Va (veh/h)
V_{ae}	*395*
V_{aw}	*561*
V_{an}	*267*
V_{as}	*155*

Circulating Flow Computation	
Approach Flow (veh/h)	Vc (veh/h)
V_{ce}	*163*
V_{cw}	*304*
V_{cn}	*419*
V_{cs}	*461*

Entry Approach Capacity Computation					
		EB	WB	NB*	SB
Capacity	Upper bound	*1219*	*1090*		*962*
	Lower bound	*1010*	*895*		*780*
v/c Ratio	Upper bound	*0.32*	*0.51*		*0.16*
	Lower bound	*0.39*	*0.63*		*0.20*
*See Year 2003A for NB Entry Approach					
**This is a modified version of the HCS printout					

Year 2010A Roundabout Capacity Analysis Summary**					
Volume Adjustments					
4:00:00 PM Peak		EB	WB	NB	SB
Left Turn Traffic	Volume, veh/h	*88*	*62*	*18*	*76*
	Peak Hour Factor	*0.78*	*0.86*	*0.57*	*0.88*
	Flow rate, veh/h	*112*	*72*	*31*	*86*
Thru Traffic	Volume, veh/h	*234*	*373*	*17*	*16*
	Peak Hour Factor	*0.85*	*0.89*	*0.54*	*0.58*
	Flow rate, veh/h	*275*	*419*	*31*	*27*
Right Turn Traffic	Volume, veh/h	*41*	*122*	*58*	*54*
	Peak Hour Factor	*0.69*	*0.84*	*0.80*	*0.86*
	Flow rate, veh/h	*59*	*145*	*72*	*62*
Approach Flow Computation					
Approach Flow (veh/h)			Va (veh/h)		
V_{ae}			*446*		
V_{aw}			*636*		
V_{an}			*134*		
V_{as}			*175*		
Circulating Flow Computation					
Approach Flow (veh/h)			Vc (veh/h)		
V_{ce}			*185*		
V_{cw}			*174*		
V_{cn}			*473*		
V_{cs}			*522*		
Entry Approach Capacity Computation					
		EB	WB*	NB	SB
Capacity	Upper bound	*1198*		*953*	*917*
	Lower bound	*991*		*772*	*739*
v/c Ratio	Upper bound	*0.37*		*0.14*	*0.19*
	Lower bound	*0.45*		*0.17*	*0.24*
*See Year 2010B for WB Entry Approach					
**This is a modified version of the HCS printout					

Year 2010B Roundabout Capacity Analysis Summary**					
Volume Adjustments					
4:00:00 PM Peak		EB	WB	NB	SB
Left Turn Traffic	Volume, veh/h	*88*	*62*	*18*	*76*
	Peak Hour Factor	*0.78*	*0.86*	*0.57*	*0.88*
	Flow rate, veh/h	*112*	*72*	*31*	*86*
Thru Traffic	Volume, veh/h	*234*	*373*	*185*	*16*
	Peak Hour Factor	*0.85*	*0.89*	*0.93*	*0.58*
	Flow rate, veh/h	*275*	*419*	*198*	*27*
Right Turn Traffic	Volume, veh/h	*41*	*122*	*58*	*54*
	Peak Hour Factor	*0.69*	*0.84*	*0.80*	*0.86*
	Flow rate, veh/h	*59*	*145*	*72*	*62*
Approach Flow Computation					
Approach Flow (veh/h)			Va (veh/h)		
V_{ae}			*446*		
V_{aw}			*636*		
V_{an}			*301*		
V_{as}			*175*		
Circulating Flow Computation					
Approach Flow (veh/h)			Vc (veh/h)		
V_{ce}			*185*		
V_{cw}			*341*		
V_{cn}			*473*		
V_{cs}			*522*		
Entry Approach Capacity Computation					
		EB	WB	NB*	SB
Capacity	Upper bound	*1198*	*1059*		*917*
	Lower bound	*991*	*866*		*739*
v/c Ratio	Upper bound	*0.37*	*0.60*		*0.19*
	Lower bound	*0.45*	*0.73*		*0.24*
*See Year 2010A for NB Entry Approach					
**This is a modified version of the HCS printout					

Year 2020A Roundabout Capacity Analysis Summary**					
Volume Adjustments					
4:00:00 PM Peak		EB	WB	NB	SB
Left Turn Traffic	Volume, veh/h	*102*	*72*	*21*	*88*
	Peak Hour Factor	*0.78*	*0.86*	*0.57*	*0.88*
	Flow rate, veh/h	*130*	*83*	*36*	*100*
Thru Traffic	Volume, veh/h	*272*	*433*	*20*	*18*
	Peak Hour Factor	*0.85*	*0.89*	*0.54*	*0.58*
	Flow rate, veh/h	*319*	*486*	*37*	*31*
Right Turn Traffic	Volume, veh/h	*47*	*142*	*67*	*63*
	Peak Hour Factor	*0.69*	*0.84*	*0.80*	*0.86*
	Flow rate, veh/h	*68*	*169*	*83*	*73*
Approach Flow Computation					
Approach Flow (veh/h)			Va (veh/h)		
V_{ae}			*517*		
V_{aw}			*738*		
V_{an}			*156*		
V_{as}			*204*		
Circulating Flow Computation					
Approach Flow (veh/h)			Vc (veh/h)		
V_{ce}			*214*		
V_{cw}			*203*		
V_{cn}			*549*		
V_{cs}			*605*		
Entry Approach Capacity Computation					
		EB	WB*	NB	SB
Capacity	Upper bound	*1171*		*897*	*858*
	Lower bound	*967*		*722*	*687*
v/c Ratio	Upper bound	*0.44*		*0.17*	*0.24*
	Lower bound	*0.53*		*0.22*	*0.30*
*See Year 2020B for WB Entry Approach					
**This is a modified version of the HCS printout					

Year 2020B Roundabout Capacity Analysis Summary**					
Volume Adjustments					
4:00:00 PM Peak		EB	WB	NB	SB
Left Turn Traffic	Volume, veh/h	*102*	*72*	*21*	*88*
	Peak Hour Factor	*0.78*	*0.86*	*0.57*	*0.88*
	Flow rate, veh/h	*130*	*83*	*36*	*100*
Thru Traffic	Volume, veh/h	*272*	*433*	*215*	*18*
	Peak Hour Factor	*0.85*	*0.89*	*0.93*	*0.58*
	Flow rate, veh/h	*319*	*486*	*231*	*31*
Right Turn Traffic	Volume, veh/h	*47*	*142*	*67*	*63*
	Peak Hour Factor	*0.69*	*0.84*	*0.80*	*0.86*
	Flow rate, veh/h	*68*	*169*	*83*	*73*
Approach Flow Computation					
Approach Flow (veh/h)			Va (veh/h)		
V_{ae}			*517*		
V_{aw}			*738*		
V_{an}			*350*		
V_{as}			*204*		
Circulating Flow Computation					
Approach Flow (veh/h)			Vc (veh/h)		
V_{ce}			*214*		
V_{cw}			*397*		
V_{cn}			*549*		
V_{cs}			*605*		
Entry Approach Capacity Computation					
		EB	WB	NB*	SB
Capacity	Upper bound	*1171*	*1013*		*858*
	Lower bound	*967*	*825*		*687*
v/c Ratio	Upper bound	*0.44*	*0.73*		*0.24*
	Lower bound	*0.53*	*0.89*		*0.30*
*See Year 2020A for NB Entry Approach					
**This is a modified version of the HCS printout					

APPENDIX D

Roundabouts: An Informational Guide

Chapter 4: Operation & Chapter 5: Safety

4 Operation

Chapter 4 Operation

This chapter presents methods for analyzing the operation of an existing or planned roundabout. The methods allow a transportation analyst to assess the operational performance of a facility, given information about the usage of the facility and its geometric design elements. An operational analysis produces two kinds of estimates: (1) the capacity of a facility, i.e., the ability of the facility to accommodate various streams of users, and (2) the level of performance, often measured in terms of one or more measures of effectiveness, such as delay and queues.

The *Highway Capacity Manual* (1) (HCM) defines the *capacity* of a facility as "the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions." While capacity is a specific measure that can be defined and estimated, *level of service* (LOS) is a qualitative measure that "characterizes operational conditions within a traffic stream and their perception by motorists and passengers." To quantify level of service, the HCM defines specific *measures of effectiveness* for each highway facility type. *Control delay* is the measure of effectiveness that is used to define level of service at intersections, as perceived by users. In addition to control delay, all intersections cause some drivers to also incur *geometric delays* when making turns. A systems analysis of a roadway network may include geometric delay because of the slower vehicle paths required for turning through intersections. An example speed profile is shown in Chapter 6 to demonstrate the speed reduction that results from geometric delay at a roundabout.

Roundabouts produce both control delay and geometric delay.

While an operational analysis can be used to evaluate the performance of an existing roundabout during a base or future year, its more common function in the U.S. may be to evaluate new roundabout designs.

This chapter:

- Describes traffic operations at roundabouts;
- Lists the data required to evaluate the performance of a roundabout;
- Presents a method to estimate the capacity of five of the six basic roundabout configurations presented in this guide;
- Describes the measures of effectiveness used to determine the performance of a roundabout and a method to estimate these measures; and
- Briefly describes the computer software packages available to implement the capacity and performance analysis procedures.

Appendix A provides background information on the various capacity relationships.

4.1 Traffic Operation at Roundabouts

4.1.1 Driver behavior and geometric elements

A roundabout brings together conflicting traffic streams, allows the streams to safely merge and traverse the roundabout, and exit the streams to their desired directions. The geometric elements of the roundabout provide guidance to drivers approaching, entering, and traveling through a roundabout.

Drivers approaching a roundabout must slow to a speed that will allow them to safely interact with other users of the roundabout, and to negotiate the roundabout. The width of the approach roadway, the curvature of the roadway, and the volume of traffic present on the approach govern this speed. As drivers approach the yield line, they must check for conflicting vehicles already on the circulating roadway and determine when it is safe and prudent to enter the circulating stream. The widths of the approach roadway and entry determine the number of vehicle streams that may form side by side at the yield line and govern the rate at which vehicles may enter the circulating roadway. The size of the inscribed circle affects the radius of the driver's path, which in turn determines the speed at which drivers travel on the roundabout. The width of the circulatory roadway determines the number of vehicles that may travel side by side on the roundabout.

Approach speed is governed by:
- **Approach roadway width**
- **Roadway curvature**
- **Approach volume**

The British (2), French (3), and German (4) analytical procedures are based on empirical relationships that directly relate capacity to both traffic characteristics and roundabout geometry. The British empirical relationships reveal that small sublane changes in the geometric parameters produce significant changes in capacity.

For instance, if some approaches are flared or have additional short lanes, these provide considerably more capacity for two reasons. First, wider entries require wider circulatory roadway widths. This provides for more opportunities for the circulatory traffic to bunch together, thus increasing the number of acceptable opportunities to enter, thereby increasing capacity. Second, the typical size of groups of drivers entering into acceptable opportunities in the circulatory traffic is quite small, so short lanes can be very effective in increasing group sizes, because the short lane is frequently able to be filled.

The British (2) use the inscribed circle diameter, the entry width, the approach (road) half width, the entry radius, and the sharpness of the flare to define the performance of a roundabout. The sharpness of the flare, *S*, is a measure of the rate at which the extra width is developed in the entry flare. Large values of *S* correspond to short, severe flares, and small values of *S* correspond to long, gradual flares (5).

Geometric elements that affect entry capacity include:
- **Approach half width**
- **Entry width**
- **Entry angle**
- **Average effective flare length**

The results of the extensive empirical British research indicate that approach half width, entry width, average effective flare length and entry angle have the most significant effect on entry capacity. Roundabouts fit into two general classes: those with a small inscribed circle diameter of less than 50m (165 ft.) and those with a diameter above 50m. The British relationships provide a means of including both of these roundabout types. The inscribed circle diameter has a relatively small effect for inscribed diameters of 50m (165 ft) or less. The entry radius has little effect on capacity provided that it is 20m (65 ft) or more. The use of perpendicular entries (70 degrees or more) and small entry radii (less than 15 m [50 ft]) will reduce capacity. The presence of the geometric parameters in the British and French models allow designers to manipulate elements of their design to determine both their operational and safety effects. German research has not been able to find the same influence of geometry, although this may be due to the relatively narrow range of geometries in Germany (4).

Perpendicular entries and small entry radii reduce capacity; inscribed circle diameters of 50 m (165 ft) or less have little effect on capacity.

Thus, the geometric elements of a roundabout, together with the volume of traffic desiring to use a roundabout at a given time, may determine the efficiency with which a roundabout operates.

4.1.2 Concept of roundabout capacity

The capacity of each entry to a roundabout is the maximum rate at which vehicles can reasonably be expected to enter the roundabout from an approach during a given time period under prevailing traffic and roadway (geometric) conditions. An operational analysis considers a precise set of geometric conditions and traffic flow rates defined for a 15-minute analysis period for each roundabout entry. While consideration of Average Annual Daily Traffic volumes (AADT) across all approaches is useful for planning purposes as provided in Exhibit 1-13 and Chapter 3, analysis of this shorter time period is critical to assessing the level of performance of the roundabout and its individual components.

Roundabout capacity defined.

Operational analyses consider 15-minute volumes, as opposed to the daily volumes used in planning analyses.

The capacity of the entire roundabout is not considered, as it depends on many terms. However, Exhibit 1-13 provides threshold average daily traffic volumes for the various categories of roundabouts, assuming four legs. Below these thresholds, a four-legged roundabout with roadways intersecting perpendicularly should have adequate capacity (provided the traffic volumes are reasonably balanced and the geometry does not deviate substantially from those shown on the design templates in Exhibits 1-7 through 1-12). The focus in this chapter on the roundabout entry is similar to the operational analysis methods used for other forms of unsignalized intersections and for signalized intersections. In each case, the capacity of the entry or approach is computed as a function of traffic on the other (conflicting) approaches, the interaction of these traffic streams, and the intersection geometry.

For a properly designed roundabout, the yield line is the relevant point for capacity analysis. The approach capacity is the capacity provided at the yield line. This is determined by a number of geometric parameters in addition to the entry width. On multilane roundabouts it is important to balance the use of each lane, because otherwise some lanes may be overloaded while others are underused. Poorly designed exits may influence driver behavior and cause lane imbalance and congestion at the opposite leg.

The approach capacity is the capacity provided at the yield line.

4.2 Data Requirements

The analysis method described in this chapter requires the specification of traffic volumes for each approach to the roundabout, including the flow rate for each directional movement. Volumes are typically expressed in passenger car vehicles per hour (vph), for a specified 15-minute analysis period. To convert other vehicle types to *passenger car equivalents* (pce), use the conversion factors given in Exhibit 4-1.

Different size vehicles have different capacity impacts; passenger cars are used as the basis for comparison.

Exhibit 4-1. Conversion factors for passenger car equivalents (pce).

Vehicle Type	Passenger Car Equivalent (pce)
Car	1.0
Single-unit truck or bus	1.5
Truck with trailer	2.0
Bicycle or motorcycle	0.5

Source: (6), (7)

Traffic volume data for an urban roundabout should be collected for each directional movement for at least the morning and evening peak periods, since the various movements, and thus approach and circulating volumes, may peak at different times. At rural roundabouts, the analyst should check the requirements of the agency with the jurisdiction of the site. The reader is referred to the *Manual of Transportation Engineering Studies* (8) for a complete discussion of traffic volume data collection methods. Typically, intersection volume counts are made at the intersection stop bar, with an observer noting the number of cars that pass that point over a specified time period. However, particularly with respect to cases in which demand exceeds capacity (when queues do not dissipate within the analysis period), it is important to note that the stop bar counts reflect only the volume that is served, not the demand volume. In this case, care must be taken to collect data upstream of the end of a queue so that true demand volumes are available for analysis.

Entry flow and circulating flow for each approach are the volumes of interest for roundabout capacity analysis, rather than turning movement volumes.

The relationship between the standard origin-to-destination turning movements at an intersection and the circulating and entry flows at a roundabout is important, yet is often complicated to compute, particularly if an intersection has more than four approaches. For conventional intersctions, traffic flow data are accumulated by directional turning movement, such as for the northbound left turn. For roundabouts, however, the data of interest for each approach are the entry flow and the circulating flow. Entry flow is simply the sum of the through, left, and right turn movements on an approach. Circulating flow is the sum of the vehicles from different movements passing in front of the adjacent upstream splitter island. At existing roundabouts, these flows can simply be measured in the field. Right turns are included in approach volumes and require capacity, but are not included in the circulating volumes downstream because they exit before the next entrance.

For proposed or planned four-legged roundabouts, Equations 4-1 through 4-4 can be applied to determine conflicting (circulating) flow rates, as shown graphically in Exhibit 4-2.

Determining circulating volumes as a function of turning movement volumes.

$$V_{EB,circ} = V_{WB,LT} + V_{SB,LT} + V_{SB,TH} + V_{NB,U\text{-}turn} + V_{WB,U\text{-}turn} + V_{SB,U\text{-}turn} \quad (4\text{-}1)$$

$$V_{WB,circ} = V_{EB,LT} + V_{NB,LT} + V_{NB,TH} + V_{SB,U\text{-}turn} + V_{EB,U\text{-}turn} + V_{NB,U\text{-}turn} \quad (4\text{-}2)$$

$$V_{NB,circ} = V_{EB,LT} + V_{EB,TH} + V_{SB,LT} + V_{WB,U\text{-}turn} + V_{SB,U\text{-}turn} + V_{EB,U\text{-}turn} \quad (4\text{-}3)$$

$$V_{SB,circ} = V_{WB,LT} + V_{WB,TH} + V_{NB,LT} + V_{EB,U\text{-}turn} + V_{NB,U\text{-}turn} + V_{WB,U\text{-}turn} \quad (4\text{-}4)$$

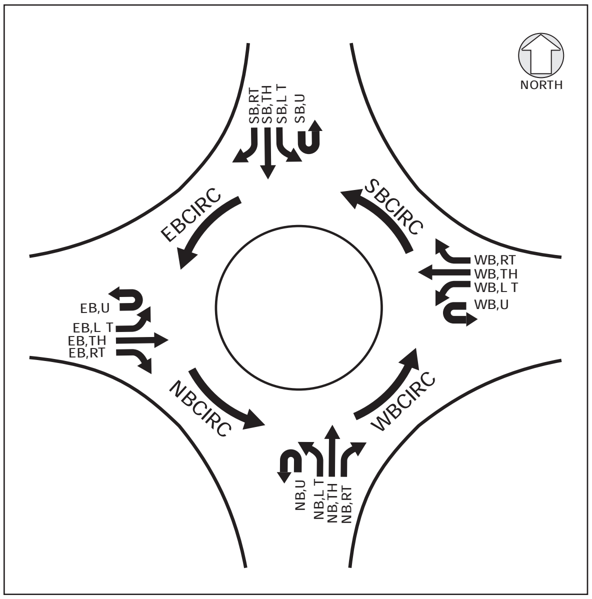


Exhibit 4-2. Traffic flow parameters.

For existing roundabouts, when approach, right-turn, circulating, and exit flows are counted, directional turning movements can be computed as shown in the following example. Equation 4-5 shows the through movement flow rate for the eastbound approach as a function of the entry flow rate for that approach, the exit flow rate for the opposing approach, the right turn flow rate for the subject approach, the right turn flow rate for the approach on the right, and the circulating flow rate for the approach on the right. Other through movement flow rates can be estimated using a similar relationship.

$$V_{EB,TH} = V_{EB,entry} + V_{WB,exit} - V_{EB,RT} - V_{NB,RT} - V_{NB,circ} \qquad (4\text{-}5)$$

The left turn flow rate for an approach is a function of the entry flow rate, the through flow rate, and the right turn flow rate for that same approach, as shown in Equation 4-6. Again, other movements' flows are estimated using similar equations.

$$V_{EB,LT} = V_{EB,entry} - V_{EB,TH} - V_{EB,RT} \qquad (4\text{-}6)$$

While this method is mathematically correct, it is somewhat sensitive to errors and inconsistencies in the input data. It is important that the counts at all of the locations in the roundabout be made simultaneously. Inconsistencies in the data from counts taken on different days can produce meaningless results, including negative volumes. At a minimum, the sum of the entering and exiting volumes should be checked and adjustments should be made if necessary to ensure that the same amount of traffic enters and leaves the roundabout.

4.3 Capacity

Roundabout approach capacity is dependent on the conflicting circulating flow and the roundabout's geometric elements.

The maximum flow rate that can be accommodated at a roundabout entry depends on two factors: the circulating flow on the roundabout that conflicts with the entry flow, and the geometric elements of the roundabout.

When the circulating flow is low, drivers at the entry are able to enter the roundabout without significant delay. The larger gaps in the circulating flow are more useful to the entering drivers and more than one vehicle may enter each gap. As the circulating flow increases, the size of the gaps in the circulating flow decrease, and the rate at which vehicles can enter also decreases. Note that when computing the capacity of a particular leg, the actual circulating flow to use may be less than demand flows, if the entry capacity of one leg contributing to the circulating flow is less than demand on that leg.

Roundabouts should be designed to operate at no more than 85 percent of their estimated capacity. Beyond this threshold, delays and queues vary significantly from their mean values.

The geometric elements of the roundabout also affect the rate of entry flow. The most important geometric element is the width of the entry and circulatory roadways, or the number of lanes at the entry and on the roundabout. Two entry lanes permit nearly twice the rate of entry flow as does one lane. Wider circulatory roadways allow vehicles to travel alongside, or follow, each other in tighter bunches and so provide longer gaps between bunches of vehicles. The flare length also affects the capacity. The inscribed circle diameter and the entry angle have minor effects on capacity.

As at other forms of unsignalized intersection, when traffic flows on an approach exceed approximately 85 percent of capacity, delays and queue lengths vary significantly about their mean values (with standard deviations of similar magnitude as the means). For this reason, the analysis procedures in some countries (Australia, Germany, and the United Kingdom), and this guide, recommend that roundabouts be designed to operate at no more than 85 percent of their estimated capacity.

As performance data become available for roundabouts designed according to the procedures in this guide in the United States, they will provide a basis for development of operational performance procedures specifically calibrated for U.S. conditions. Therefore, analysts should consult future editions of the *Highway Capacity Manual*.

4.3.1 Single-lane roundabout capacity

Exhibit 4-3 shows the expected capacity for a single-lane roundabout for both the urban compact and urban/rural single-lane designs. The exhibit shows the variation of maximum entry flow as a function of the circulating flow on the roundabout. The calculation of the circulating flow was described previously. The capacity forecast shown in the chart is valid for single-lane roundabouts with inscribed circle diameters of 25 m to 55 m (80 ft to 180 ft). The capacity forecast is based on simplified British regression relationships in Appendix A, which may also be derived with a gap-acceptance model by incorporating limited priority behavior.

Note that in any case, the flow rate downstream of the merge point (between the entry and the next exit) should not be allowed to exceed 1,800 veh/h. Exceeding this threshold may indicate the need for a double-lane entry.

Circulating flow should not exceed 1,800 veh/h at any point in a single-lane roundabout. Exit flows exceeding 1,200 veh/h may indicate the need for a double-lane exit.

The urban compact design is expected to have a reduced capacity, but has significant benefits of reduced vehicle speeds through the roundabout (per the German equations in Appendix A). This increases safety for pedestrians and bicyclists compared with the larger single lane roundabouts. Mini-roundabout capacities may be approximated using the daily maximum service volumes provided for them in Chapter 3, but in any case should not exceed the capacity of the urban compact design.

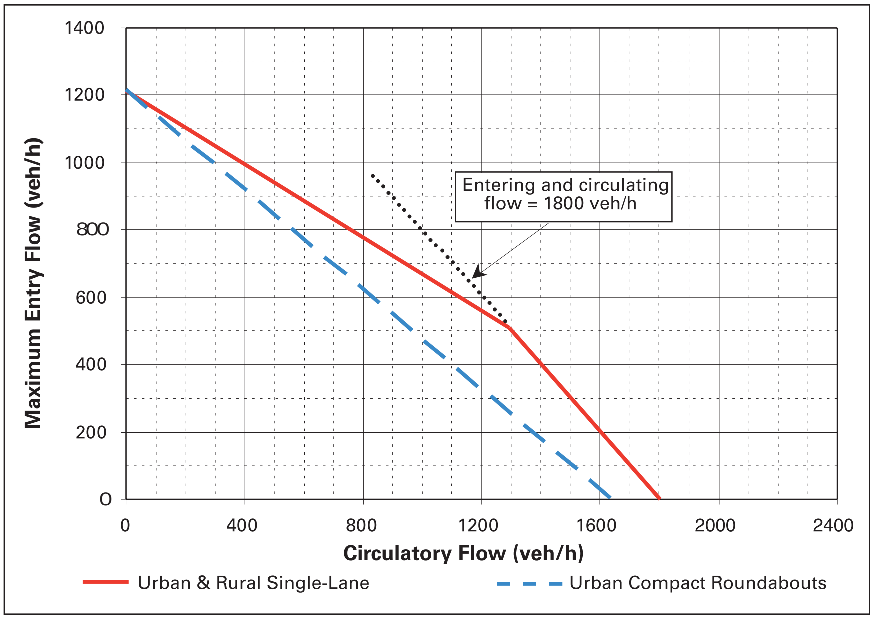


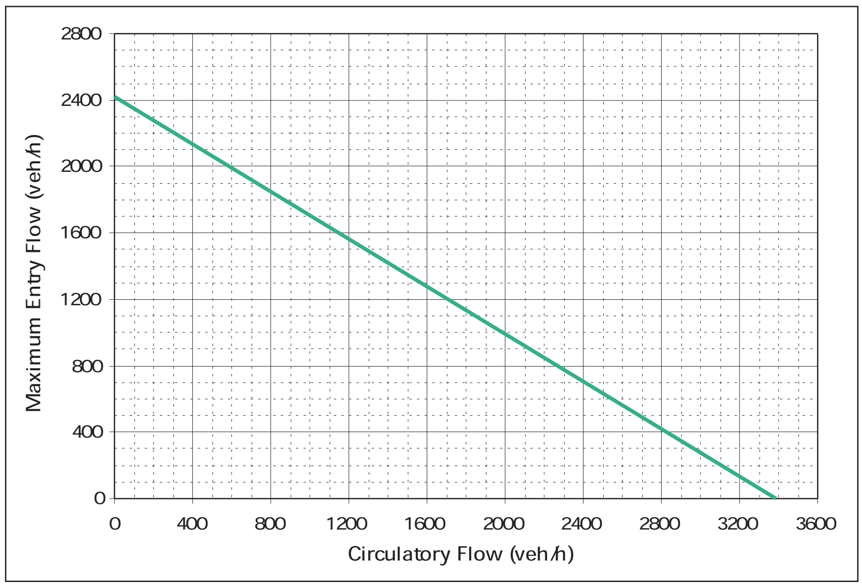
Exhibit 4-3. Approach capacity of a single-lane roundabout.

The slope of the upper line changes because circulating flow downstream from a roundabout entry should not exceed 1,800 veh/h.

4.3.2 Double-lane roundabout capacity

Exhibit 4-4 shows the expected capacity of a double-lane roundabout that is based on the design templates for the urban/rural double-lane roundabouts. The capacity forecast shown in the chart is valid for double-lane roundabouts with inscribed circle diameters of 40 m to 60 m (130 ft to 200 ft). The capacity forecast is based on simplified British regression relationships in Appendix A, which may also be derived with a gap-acceptance model by incorporating limited priority behavior. Larger inscribed diameter roundabouts are expected to have slightly higher capacities at moderate to high circulating flows.

Exhibit 4-4. Approach capacity of a double-lane roundabout.



When flared approaches are used, the circulatory road width must be widened.

See Appendix A for further information on the effects of short lanes at flared entries.

4.3.3 Capacity effect of short lanes at flared entries

By flaring an approach, short lanes may be added at the entry to improve the performance. If an additional short lane is used, it is assumed that the circulatory road width is also increased accordingly. The capacity of the entry is based on the assumption that all entry lanes will be effectively used. The capacity is given by the product of the appropriate factor in Exhibit 4-5 and the capacity of a two-lane roundabout in Exhibit 4-4. Refer to Appendix A for a derivation of these factors (9).

Exhibit 4-5. Capacity reduction factors for short lanes.

Number of vehicle spaces in the short lane, n_f	Factor (applied to double-lane approach capacity)
0*	0.500
1	0.707
2	0.794
4	0.871
6	0.906
8	0.926
10	0.939

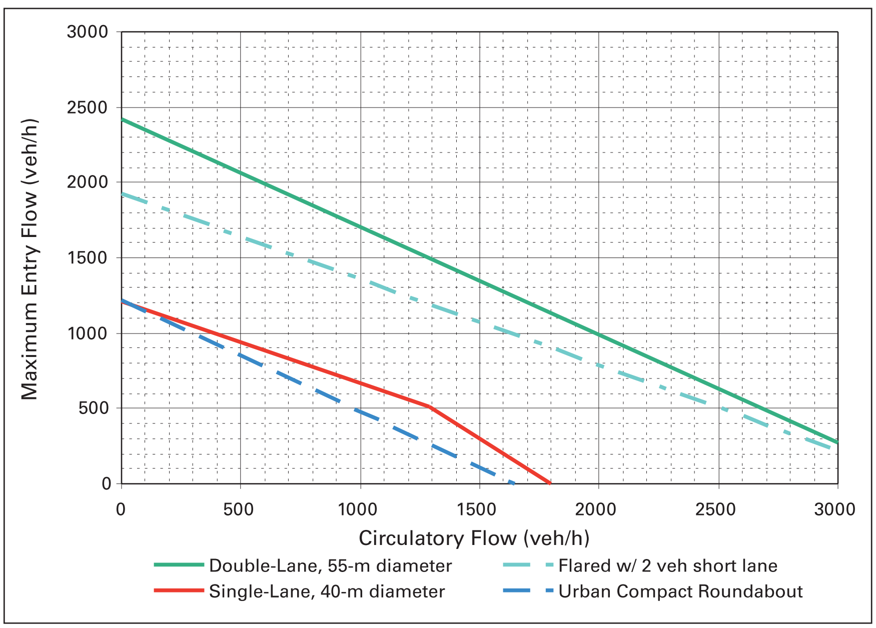
*Used for the case of a single lane entry to a double-lane roundabout.

The use of short lanes can nearly double approach capacity, without requiring a two-lane roadway prior to the roundabout.

4.3.4 Comparison of single-lane and double-lane roundabouts

Exhibit 4-6 shows a comparison of the expected capacity for both the single-lane and double-lane roundabouts. Again, it is evident that the number of lanes, or the size of the entry and circulating roadways, has a significant effect on the entry capacity.

Exhibit 4-6. Capacity comparison of single-lane and double-lane roundabouts.

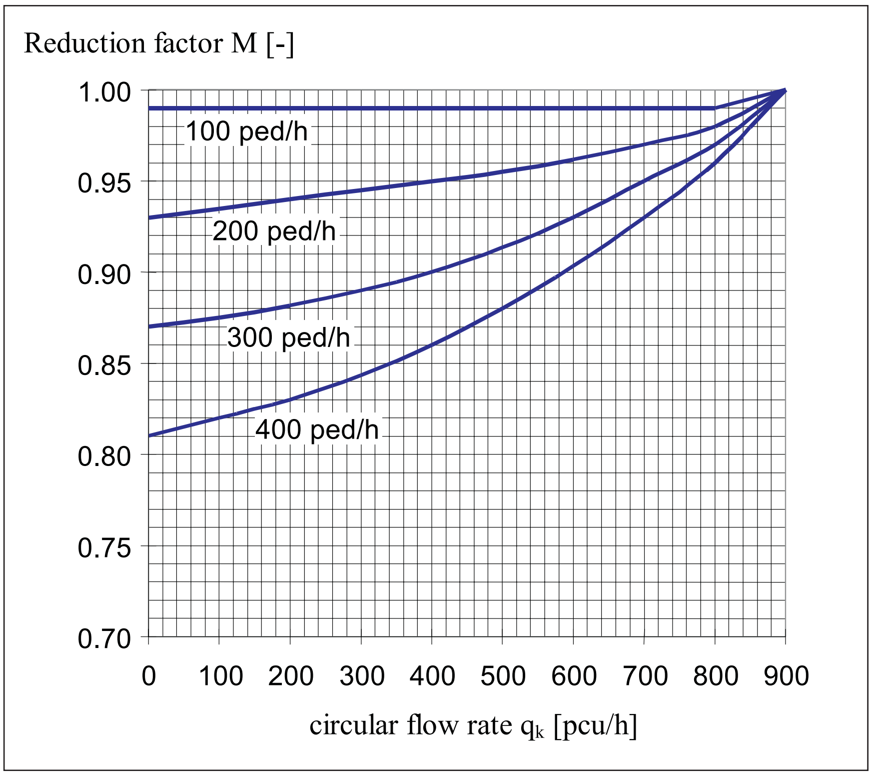


Source (10)

4.3.5 Pedestrian effects on entry capacity

Pedestrians crossing at a marked crosswalk that gives them priority over entering motor vehicles can have a significant effect on the entry capacity. In such cases, if the pedestrian crossing volume and circulating volume are known, the vehicular capacity should be factored (multiply by *M*) according to the relationship shown in Exhibit 4-7 or Exhibit 4-8 for single-lane and double-lane roundabouts, respectively. Note that the pedestrian impedance decreases as the conflicting vehicle flow increases. The *Highway Capacity Manual* (1) provides additional guidance on the capacity of pedestrian crossings and should be consulted if the capacity of the crosswalk itself is an issue.

Exhibit 4-7. Capacity reduction factor *M* for a single-lane roundabout assuming pedestrian priority.



Source: (10)

The effects of conflicting pedestrians on approach capacity decrease as conflicting vehicular volumes increase, as entering vehicles become more likely to have to stop regardless of whether pedestrians are present.

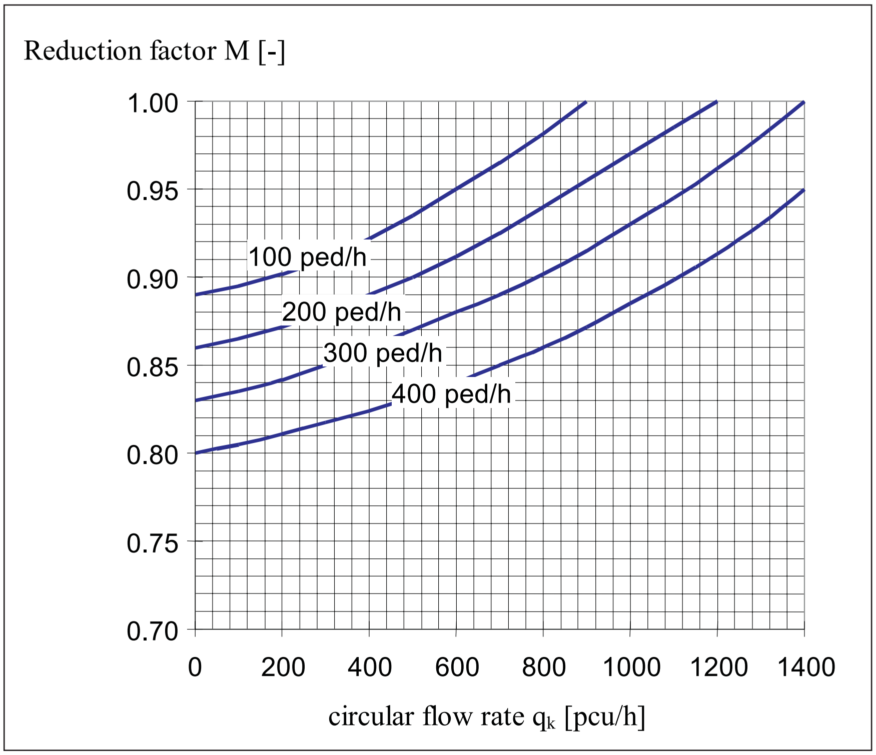


Exhibit 4-8. Capacity reduction factor *M* for a double-lane roundabout assuming pedestrian priority.

Source: (10)

4.3.6 Exit capacity

An exit flow on a single lane of more than 1,400 veh/h, even under good operating conditions for vehicles (i.e., tangential alignment, and no pedestrians and bicyclists) is difficult to achieve. Under normal urban conditions, the exit lane capacity is in the range of 1,200 to 1,300 veh/h. Therefore, exit flows exceeding 1,200 veh/h may indicate the need for a double-lane exit (11).

4.4 Performance Analysis

Three performance measures are typically used to estimate the performance of a given roundabout design: degree of saturation, delay, and queue length. Each measure provides a unique perspective on the quality of service at which a roundabout will perform under a given set of traffic and geometric conditions. Whenever possible, the analyst should estimate as many of these parameters as possible to obtain the broadest possible evaluation of the performance of a given roundabout design. In all cases, a capacity estimate must be obtained for an entry to the roundabout before a specific performance measure can be computed.

Key performance measures for roundabouts:

- **Degree of saturation**
- **Delay**
- **Queue length**

4.4.1 Degree of saturation

Degree of saturation is the ratio of the demand at the roundabout entry to the capacity of the entry. It provides a direct assessment of the sufficiency of a given design. While there are no absolute standards for degree of saturation, the Australian design procedure suggests that the degree of saturation for an entry lane should be less than 0.85 for satisfactory operation. When the degree of saturation exceeds this range, the operation of the roundabout will likely deteriorate rapidly, particularly over short periods of time. Queues may form and delay begins to increase exponentially.

4.4.2 Delay

Delay is a standard parameter used to measure the performance of an intersection. The *Highway Capacity Manual* (1) identifies delay as the primary measure of effectiveness for both signalized and unsignalized intersections, with level of service determined from the delay estimate. Currently, however, the *Highway Capacity Manual* only includes control delay, the delay attributable to the control device. Control delay is the time that a driver spends queuing and then waiting for an acceptable gap in the circulating flow while at the front of the queue. The formula for computing this delay is given in Equation 4-7 (12, based on 13; see also 14). Exhibit 4-9 shows how control delay at an entry varies with entry capacity and circulating flow. Each curve for control delay ends at a volume-to-capacity ratio of 1.0, with the curve projected beyond that point as a dashed line.

$$d = \frac{3600}{c_{m,x}} + 900T \times \left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{450T}} \right] \tag{4-7}$$

where: d = average control delay, sec/veh;
v_x = flow rate for movement x, veh/h;
c_{mx} = capacity of movement x, veh/h; and
T = analysis time period, h (T = 0.25 for a 15-minute period).

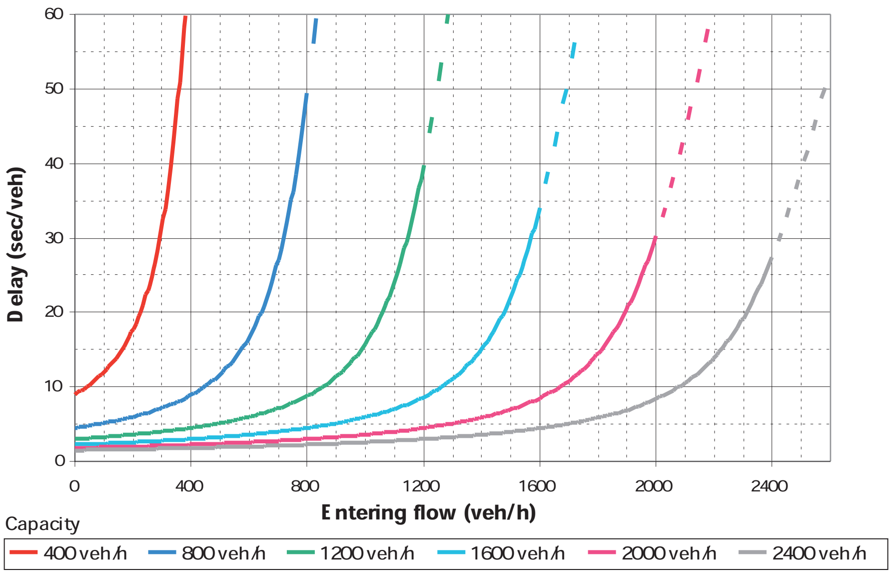


Exhibit 4-9. Control delay as a function of capacity and entering flow.

Note that as volumes approach capacity, control delay increases exponentially, with small changes in volume having large effects on delay. An accurate analysis of delay under conditions near or over saturation requires consideration of the following factors:

- *The effect of residual queues.* Roundabout entries operating near or over capacity can generate significant residual queues that must be accounted for between consecutive time periods. The method presented above does not account for these residual queues. These factors are accounted for in the delay formulae developed by Kimber and Hollis (15); however, these formulae are difficult to use manually.

- *The metering effect of upstream oversaturated entries.* When an upstream entry is operating over capacity, the circulating volume in front of a downstream entry is less than the true demand. As a result, the capacity of the downstream entry is higher than what would be predicted from analyzing actual demand.

For most design applications where target degrees of saturation are no more than 0.85, the procedures presented in this section are sufficient. In cases where it is desired to more accurately estimate performance in conditions near or over capacity, the use of software that accounts for the above factors is recommended.

Geometric delay is the additional time that a single vehicle with no conflicting flows spends slowing down to the negotiation speed, proceeding through the intersection, and accelerating back to normal operating speed. Geometric delay may be an important consideration in network planning (possibly affecting route travel times and choices) or when comparing operations of alternative intersection types. While geometric delay is often negligible for through movements at a signalized or stop-controlled intersection, it can be more significant for turning movements such as those through a roundabout. Calculation of geometric delay requires an estimate of the proportion of vehicles that must stop at the yield line, as well as knowledge of the roundabout geometry as it affects vehicle speeds during entry, negotiation, and exit. Procedures for calculating the number of stops and geometric delay are given in the Australian design guide (16).

4.4.3 Queue length

Queue length is important when assessing the adequacy of the geometric design of the roundabout approaches.

The average queue length (L vehicles) can be calculated by Little's rule, as shown in Equation 4-8 (17):

$$L = v \cdot d / 3600 \tag{4-8}$$

where: v = entry flow, veh/h
d = average delay, seconds/veh

Average queue length is equivalent to the vehicle-hours of delay per hour on an approach. It is useful for comparing roundabout performance with other intersection forms, and other planning procedures that use intersection delay as an input.

For design purposes, Exhibit 4-10 shows how the 95th-percentile queue length varies with the degree of saturation of an approach (18, 19). The x-axis of the graph is the degree of saturation, or the ratio of the entry flow to the entry capacity. Individual lines are shown for the product of T and entry capacity. To determine the 95th-percentile queue length during time T, enter the graph at the computed degree of saturation. Move vertically until the computed curve line is reached. Then move horizontally to the left to determine the 95th-percentile queue length. Alternatively, Equation 4-8 can be used to approximate the 95th-percentile queue. Note that the graph and equation are only valid where the volume-to-capacity ratio immediately before and immediately after the study period is no greater than 0.85 (in other words, the residual queues are negligible).

$$Q_{95} \approx 900T\left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(1 - \frac{v_x}{c_{m,x}}\right)^2 + \frac{\left(\frac{3600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{150T}}\right]\left(\frac{c_{m,x}}{3600}\right) \tag{4-9}$$

where: Q_{95} = 95th percentile queue, veh,
v_x = flow rate for movement x, veh/h,
$c_{m,x}$ = capacity of movement x, veh/h, and
T = analysis time period, h (0.25 for 15-minute period).

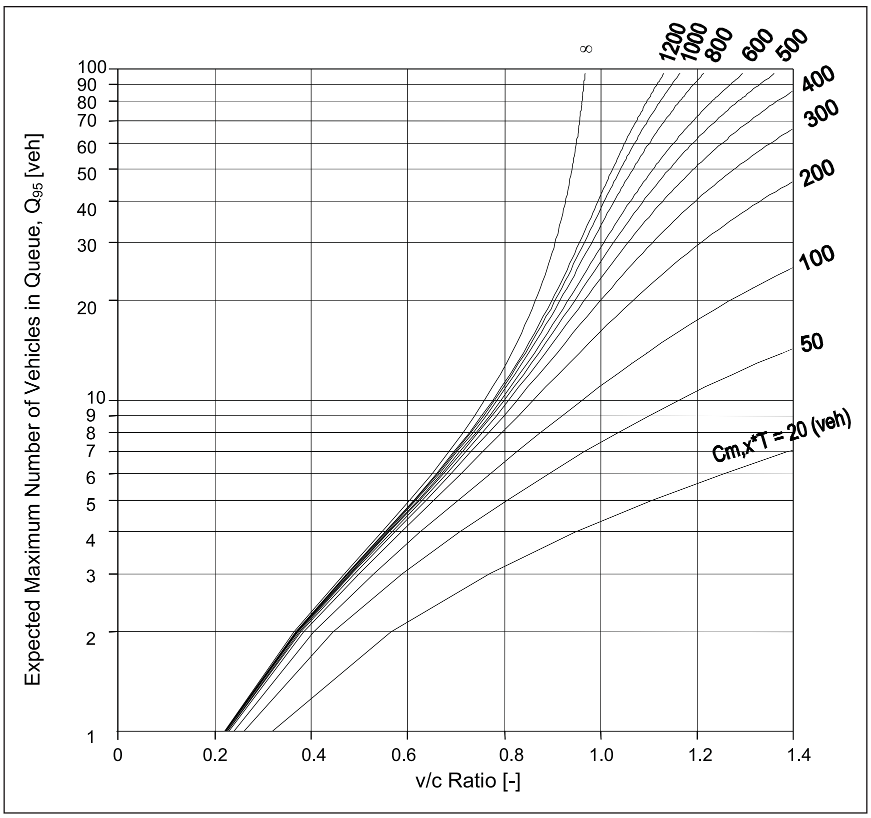


Exhibit 4-10. 95th-percentile queue length estimation.

Source: (19)

4.4.4 Field observations

The analyst may evaluate an existing roundabout to determine its performance and whether changes to its design are needed. Measurements of vehicle delay and queuing can be made using standard traffic engineering techniques. In addition, the analyst can perform a qualitative assessment of the roundabout performance. The following list indicates conditions for which corrective design measures should be taken (20). If the answers to these questions are negative, no corrective actions need be taken.

Points to consider for a qualitative assessment of roundabout performance.

- Do drivers stop unnecessarily at the yield point?
- Do drivers stop unnecessarily within the circulating roadway?
- Do any vehicles pass on the wrong side of the central island?
- Do queues from an external bottleneck back up into the roundabout from an exit road?
- Does the actual number of entry lanes differ from those intended by the design?
- Do smaller vehicles encroach on the truck apron?
- Is there evidence of damage to any of the signs in the roundabout?
- Is there any pedestrian activity on the central island?
- Do pedestrians and cyclists fail to use the roundabout as intended?
- Are there tire marks on any of the curb surfaces to indicate vehicle contact?
- Is there any evidence of minor accidents, such as broken glass, pieces of rim, etc., on the approaches or the circulating roadway?
- Is there any gravel or other debris collected in nontraveled areas that could be a hazard to bicycles or motorcyclists?
- Are the vehicle speeds appropriate?

4.5 Computer Software for Roundabouts

While the analytical procedures of different countries are not very complex, they are repetitive and time consuming, so most of these procedures have been implemented in software. A summary of current (as of 1999) software products and the analytical procedures that they implement is presented in Exhibit 4-11. The reader is also advised to consult the latest version of the U.S. *Highway Capacity Manual*. While the procedures provided in this chapter are recommended for most applications covered by this guide, models such as ARCADY, RODEL, SIDRA, KREISEL, or GIRABASE may be consulted to determine the effects of geometric parameters, particularly for multilane roundabouts outside the realm of this guide, or for fine-tuning designs to improve performance. Note that many of these models represent different underlying data or theories and will thus produce different results. Chapter 8 provides some information on microscopic simulation modeling which may be useful alternatives analysis in systems context.

Exhibit 4-11. Summary of roundabout software products for operational analysis.

Name	Scope	Application and Qualities (1999 versions)
ARCADY	All configurations	British method (50 percent confidence limits). Capacity, delay, and queuing. Includes projected number of crashes per year. Data were collected at extensive field studies and from experiments involving drivers at temporary roundabouts. Empirical relationships were developed from the data and incorporated into ARCADY. This model reflects British driving behavior and British roundabout designs. A prime attribute is that the capacities it predicts have been measured.
RODEL	All configurations including multiple roundabout interactions	British method (user-specified confidence limits). Capacity, delay, and queuing. Includes both an evaluation mode (geometric parameters specified) and a design mode (performance targets specified). Includes a crash prediction model. RODEL uses the British empirical equations. It also assists the user in developing an appropriate roundabout for the traffic conditions.
SIDRA	All configurations and other control types	Australian method, with analytical extensions. Capacity, delay, queue, fuel, and environmental measures. Also evaluates two-way stop-controlled, all-way stop controlled, and signalized intersections. It also gives roundabout capacities from U.S. HCM 1997 and German procedures. SIDRA is based on gap acceptance processes. It uses field data for the gap acceptance parameters to calibrate the model. There has been limited field evaluation of the results although experience has shown that the results fit Australian and U.S. single-lane (21) roundabout conditions satisfactorily. An important attribute is that the user can alter parameters to easily reflect local driving.
HCS-3	Single-lane roundabouts with a limited range of volumes	U.S. HCM 1997 method. Limited to capacity estimation based on entering and circulating volume. Optional gap acceptance parameter values provide both a liberal and conservative estimate of capacity. The data used to calibrate the models were recorded in the U.S. The two curves given reflect the uncertainty from the results. The upper-bound average capacities are anticipated at most roundabouts. The lower bound results reflect the operation that might be expected until roundabouts become more common.
KREISEL	All configurations	Developed in Germany. Offers many user-specified options to implement the full range of procedures found in the literature from U.S. (including this chapter), Europe, Britain, and Australia. KREISEL gives the average capacity from a number of different procedures. It provides a means to compare these procedures.
GIRABASE	All configurations	French method. Capacity, delay, and queuing projections based on regression. Sensitive to geometric parameters. Gives average values.

4.6 References

1. Transportation Research Board. *Highway Capacity Manual*. Special Report 209. Washington, D.C.: Transportation Research Board, National Research Council, July 1999 (draft).

2. Kimber, R.M. *The traffic capacity of roundabouts*. TRRL Laboratory Report LR 942. Crowthorne, England: Transport and Road Research Laboratory, 1980.

3. Guichet, B. "Roundabouts In France: Development, Safety, Design, and Capacity." In *Proceedings of the Third International Symposium on Intersections Without Traffic Signals* (M. Kyte, ed.), Portland, Oregon, U.S.A. University of Idaho, 1997.

4. Brilon, W., N. Wu, and L. Bondzio. "Unsignalized Intersections in Germany—A State of the Art 1997." In *Proceedings of the Third International Symposium on Intersections without Traffic Signals* (ed: M. Kyte), Portland, Oregon, U.S.A. University of Idaho, 1997.

5. Ourston & Doctors, Inc. *Roundabout Design Guidelines*. 1995.

6. Jessen, G.D. *Ein Richtlinienvorschlag für die Behandlung der Leistungsfähigkeit von Knotenpunkten ohne Signalregelung* (A guideline suggested for capacity calculations for unsignalized intersections). Strassenverkehrstechnik, Nr. 7/8, 1968.

7. Harders, J. *Grenz-und Folgezeitlücken als Grundlage für die Berechnung der Leistungsfähigkeit von Landstrassen* (Critical gaps and follow-up times or capacity calculations at rural roads). Schriftenreihe Strassenbau und Strassenverkehrstechnik, Vol. 216, 1976.

8. Institute of Transportation Engineers. *Manual of Transportation Engineering Studies* (H.D. Robertson, J.E. Hummer, and D.C. Nelson, ed.). Englewood Cliffs, N.J.: Prentice-Hall, 1994.

9. Wu, N. "Capacity of Shared/Short Lanes at Unsignalized Intersections." In *Proceedings of the Third International Symposium on Intersections without Traffic Signals* (ed: M. Kyte), Portland, Oregon, U.S.A. University of Idaho, 1997.

10. Brilon, W., B. Stuwe, and O. Drews. *Sicherheit und Leistungsfähigkeit von Kreisverkehrsplätzen* (Safety and Capacity of Roundabouts). Research Report. Ruhr-University Bochum, 1993.

11. Brilon, W. Letter to Principal Investigator. September 18, 1999.

12. Transportation Research Board. *Highway Capacity Manual*. Special Report 209. Washington, D.C.: Transportation Research Board, National Research Council, 1994.

13. Akçelic, R., and R.J. Troutbeck. "Implementation of the Australian roundabout analysis method in SIDRA." In *Highway Capacity and Level of Service: Proceedings of the International Symposium on Highway Capacity* (U. Brannolte, ed.), Karlsruhe, Germany. Rotterdam, Germany: Balkema Publisher, 1991, pp. 17–34.

14. Transportation Research Board. *Review of International Practices Used to Evaluate Unsignalized Intersections.* Transportation Research Circular 468. Washington, D.C.: Transportation Research Board, National Research Council, April 1997.

15. Kimber, R.M. and E.M. Hollis. *Traffic queues and delays at road junctions*. TRRL Laboratory Report LR 909. Crowthorne, England: Transport and Road Research Laboratory, 1979.

16. Austroads. *Guide to Traffic Engineering Practice, Part 6—Roundabouts*. Sydney, Australia: Austroads, 1993.

17. Little, J.D.C. *A Proof of the Queueing Formula* $L = W \cdot \lambda$. Operations Research 9, S. 383–387, 1961.

18. Heidemann, D. "Queue lengths and waiting-time distributions at priority intersections." In *Transportation Research B*, Vol 25B, (4) pp. 163–174, 1991.

19. Wu, N. "An Approximation for the Distribution of Queue Lengths at Unsignalized Intersections." In *Proceedings of the Second International Symposium on Highway Capacity* (ed. R. Akçelik), Sydney, Australia. Australian Road Research Board, 1994.

20. Florida Department of Transportation. *Florida Roundabout Guide*. Florida Department of Transportation, March 1996.

21. Flannery, A., L. Elefteriadou, P. Koza, and J. McFadden. "Safety, delay and capacity of single-lane roundabouts in the United States." In *Transportation Research Record 1646*. Washington, D.C.: Transportation Research Board, National Research Council, 1998, pp. 63–70.

5 Safety

Chapter 5 Safety

Roundabouts may improve the safety of intersections by eliminating or altering conflict types, by reducing speed differentials at intersections, and by forcing drivers to decrease speeds as they proceed into and through the intersection. Though roundabout crash records in the United States are limited, the experiences of other countries can be used to help design roundabouts in this country. Understanding the sensitivity of geometric element parameters, along with the crash experience, will assist the designer in optimizing the safety of all vehicle occupants, pedestrians, and bicyclists.

Roundabouts may improve intersection safety by:

- **Eliminating or altering conflicts**
- **Decreasing speeds into and through the intersection**
- **Decreasing speed differentials**

5.1 Introduction

Many studies have found that one of the benefits of roundabout installation is the improvement in overall safety performance. Several studies in the U.S., Europe, and Australia have found that roundabouts perform better in terms of safety than other intersection forms (1, 2, 3, 4). In particular, single-lane roundabouts have been found to perform better than two-way stop-controlled (TWSC) intersections in the U.S. (5). Although the frequency of reported crashes is not always lower at roundabouts, the reduced injury rates are usually reported (6). Safety is better at small and medium capacity roundabouts than at large or multilane roundabouts (1, 7). While overall crash frequencies have been reduced, the crash reductions are most pronounced for motor vehicles, less pronounced for pedestrians, and equivocal for bicyclists, depending on the study and bicycle design treatments (4, 6, 7). Crash statistics for various user groups are reported in Section 5.3.

The reasons for the increased safety level at roundabouts are:

- Roundabouts have fewer conflict points in comparison to conventional intersections. The potential for hazardous conflicts, such as right angle and left turn head-on crashes is eliminated with roundabout use. Single-lane approach roundabouts produce greater safety benefits than multilane approaches because of fewer potential conflicts between road users, and because pedestrian crossing distances are short.
- Low absolute speeds associated with roundabouts allow drivers more time to react to potential conflicts, also helping to improve the safety performance of roundabouts.
- Since most road users travel at similar speeds through roundabouts, i.e., have low relative speeds, crash severity can be reduced compared to some traditionally controlled intersections.
- Pedestrians need only cross one direction of traffic at a time at each approach as they traverse roundabouts, as compared with unsignalized intersections. The conflict locations between vehicles and pedestrians are generally not affected by the presence of a roundabout, although conflicting vehicles come from a more defined path at roundabouts (and thus pedestrians have fewer places to check for conflicting vehicles). In addition, the speeds of motorists entering and exiting a roundabout are reduced with good design. As with other crossings

requiring acceptance of gaps, roundabouts still present visually impaired pedestrians with unique challenges, as described in Chapter 2.

For the design of a new roundabout, safety can be optimized not only by relying on recorded past performance of roundabouts in general, but primarily by applying all design knowledge proven to impact safety. For optimum roundabout safety and operational performance the following should be noted:

- Minimizing the number of potential conflicts at any geometric feature should reduce the multiple vehicle crash rate and severity.
- Minimizing the potential relative speed between two vehicles at the point of conflict will minimize the multiple vehicle crash rate and severity (it may also optimize capacity). To reduce the potential relative speed between vehicles, either the absolute speeds of both vehicles need to be reduced or the angle between the vehicle paths needs to be reduced. Commuter bicyclist speeds can range from 20 to 25 km/h (12 to 15 mph) and designs that constrain the speeds of motor vehicles to similar values will minimize the relative speeds and improve safety. Lower absolute speeds will also assist pedestrian safety.
- Limiting the maximum change in speed between successive horizontal geometric elements will minimize the single vehicle crash rate and severity.

5.2 Conflicts

Conflict points occur where one vehicle path crosses, merges or diverges with, or queues behind the path of another vehicle, pedestrian, or bicycle.

The frequency of crashes at an intersection is related to the number of *conflict points* at an intersection, as well as the magnitude of conflicting flows at each conflict point. A conflict point is a location where the paths of two motor vehicles, or a vehicle and a bicycle or pedestrian queue, diverge, merge, or cross each other.

Besides conflicts with other road users, the central island of a roundabout presents a particular hazard that may result in over-representation of single-vehicle crashes that tend to occur during periods of low traffic volumes. At cross intersections, many such violations may go unrecorded unless a collision with another vehicle occurs.

Conflicts can arise from both legal and illegal maneuvers; many of the most serious crashes are caused by failure to observe traffic control devices.

The following sections present a variety of conflicts among vehicles, bicycles, and pedestrians. Both legal conflicts (queuing at an intersection, merging into a traffic stream) and conflicts prohibited by law or by traffic control devices (failure to yield to pedestrians, running a stop sign) have been included for completeness. Even though traffic control devices can significantly reduce many conflicts, they can not eliminate them entirely due to violations of those devices. Many of the most serious crashes are caused by such violations.

As with crash analyses, conflict analyses are more than the simple enumeration of the number of conflicts. A conflict analysis should account for the following factors:

- Existence of conflict point;

- Exposure, measured by the product of the two conflicting stream volumes at a given conflict point;
- Severity, based on the relative velocities of the conflicting streams (speed and angle); and
- Vulnerability, based on the ability for a member of each conflicting stream to survive a crash.

5.2.1 Vehicle conflicts

5.2.1.1 Single-lane roundabouts

Exhibit 5-1 presents a diagram of vehicle-vehicle conflict points for a traditional three-leg ("T") intersection and a three-leg roundabout. As the figure shows, the number of vehicle-vehicle conflict points for roundabouts decreases from nine to six for three-leg intersections. Note that these diagrams do not take into account the ability to separate conflicts in space (through the use of separate left or right turning lanes) or time (through the use of traffic control devices such as stop signs or traffic signals).

Roundabouts bring the simplicity of a "T" intersection to intersections with more than three legs.

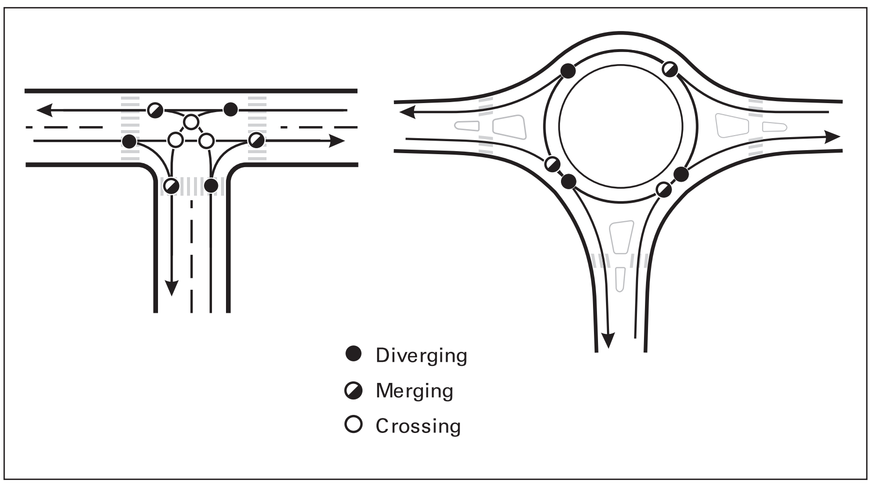
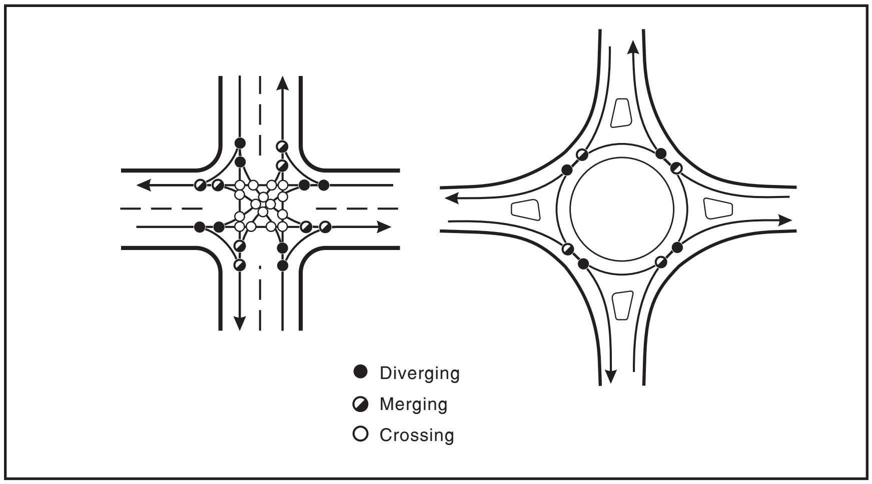


Exhibit 5-1. Vehicle conflict points for "T" Intersections with single-lane approaches.

Exhibit 5-2 presents similar diagrams for a traditional four-leg ("X" or "cross") intersection and a four-leg roundabout. As the figure shows, the number of vehicle-vehicle conflict points for roundabouts decreases from 32 to 8 for four-leg intersections.

Exhibit 5-2. Vehicle conflict point comparison for intersections with single-lane approaches.



A four-leg single-lane roundabout has 75% fewer vehicle conflict points—compared to a conventional intersection.

Conflicts can be divided into three basic categories, in which the degree of severity varies, as follows:

- *Queuing conflicts.* These conflicts are caused by a vehicle running into the back of a vehicle queue on an approach. These types of conflicts can occur at the back of a through-movement queue or where left-turning vehicles are queued waiting for gaps. These conflicts are typically the least severe of all conflicts because the collisions involve the most protected parts of the vehicle and the relative speed difference between vehicles is less than in other conflicts.
- *Merge and diverge conflicts*. These conflicts are caused by the joining or separating of two traffic streams. The most common types of crashes due to merge conflicts are sideswipes and rear-end crashes. Merge conflicts can be more severe than diverge conflicts due to the more likely possibility of collisions to the side of the vehicle, which is typically less protected than the front and rear of the vehicle.
- *Crossing conflicts.* These conflicts are caused by the intersection of two traffic streams. These are the most severe of all conflicts and the most likely to involve injuries or fatalities. Typical crash types are right-angle crashes and head-on crashes.

Crossing conflicts are the most severe and carry the highest public cost.

As Exhibit 5-1 and Exhibit 5-2 show, a roundabout reduces vehicular crossing conflicts for both three- and four-leg intersections by converting all movements to right turns. Again, separate turn lanes and traffic control (stop signs or signalization) can often reduce but not eliminate the number of crossing conflicts at a traditional intersection by separating conflicts in space and/or time. However, the most severe crashes at signalized intersections occur when there is a violation of the traffic control device designed to separate conflicts by time (e.g., a right-angle collision due to running a red light, and vehicle-pedestrian collisions). Therefore, the ability of single-lane roundabouts to reduce conflicts through physical, geometric features has been demonstrated to be more effective than the reliance on driver obedience of traffic control devices.

5.2.1.2 Double-lane roundabouts

In general, double-lane roundabouts have some of the same safety performance characteristics as their simpler single-lane counterparts. However, due to the presence of additional entry lanes and the accompanying need to provide wider circulatory and exit roadways, double lane roundabouts introduce additional conflicts not present in single-lane roundabouts. This makes it important to use the minimum required number of entry, circulating and exit lanes, subject to capacity considerations. For example, according to United Kingdom roundabout crash models, for a 10,000 entering Average Daily Traffic (ADT), flaring the entry width from one to two lanes is likely to increase injury crashes by 25 percent (8).

Double-lane roundabouts have some of the same safety performance characteristics as single-lane roundabouts, but introduce additional conflicts.

The number of vehicular and pedestrian conflicts points in both conventional intersections and roundabouts increases considerably when they have additional approach lanes. The designer is encouraged to graphically determine conflicts for a particular location, as this information can raise awareness of design issues and may be useful in public presentations.

The types of conflicts present in multilane roundabouts that do not exist in single-lane roundabouts occur when drivers use the incorrect lane or make an improper turn. These types of conflicts are depicted in Exhibit 5-3 and Exhibit 5-4, respectively. While these types of conflicts can also be present in other intersection forms, they can be prevalent with drivers who are unfamiliar with roundabout operation. The conflicts depicted in Exhibit 5-4, in particular, can be created by not providing a proper design geometry that allows vehicles to travel side-by-side throughout the entire roundabout (see Chapter 6). Crashes resulting from both types of conflicts can also be reduced through proper driver education.

Incorrect lane use and incorrect turns are multilane roundabout conflicts that do not exist in single-lane roundabouts.

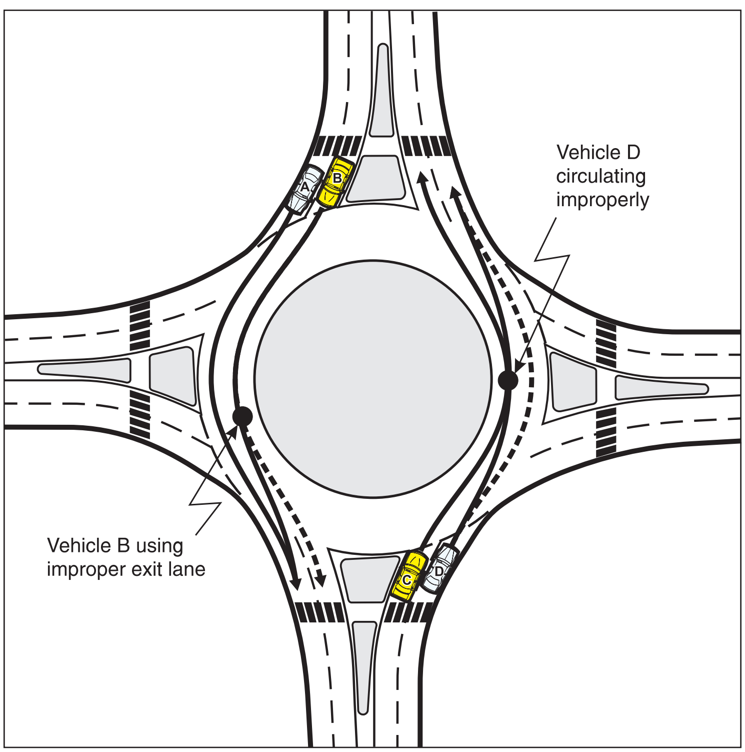
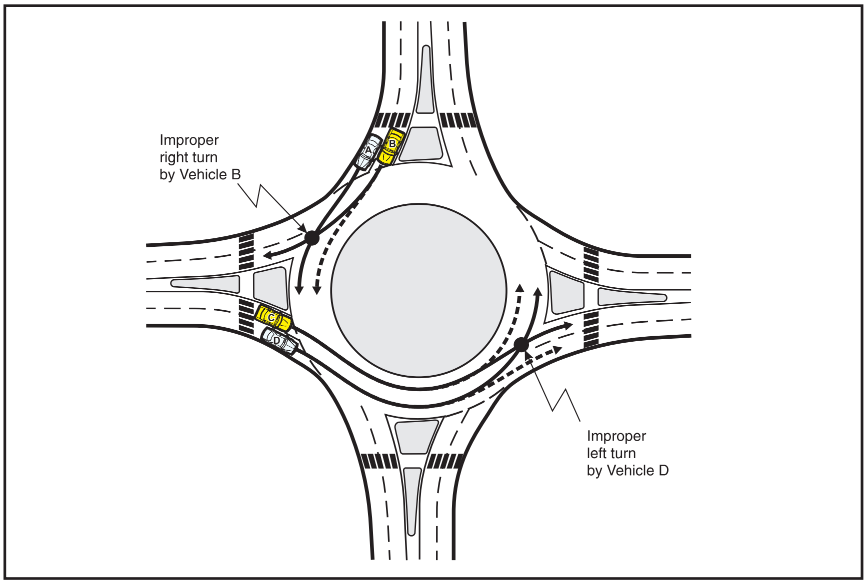


Exhibit 5-3. Improper lane-use conflicts in double-lane roundabouts.

Exhibit 5-4. Improper turn conflicts in double-lane roundabouts.



As with single-lane roundabouts, the most severe vehicular crossing conflicts are eliminated and replaced by less severe merging conflicts. The additional conflicts unique to multilane roundabouts are generally low-speed sideswipe conflicts that typically have low severity. Therefore, although the number of conflict points increases at multilane roundabouts when compared to a single lane roundabouts, the overall severity of conflicts is generally less than alternative intersection control.

5.2.2 Pedestrian conflicts

Vehicle-pedestrian conflicts can be present at every intersection, even those with minimal pedestrian volume. The following sections examine pedestrian conflicts at signalized intersections and at roundabouts.

Types of pedestrian crossing conflicts present at signalized intersections.

Signalized intersections offer the opportunity to reduce the likelihood of pedestrian-vehicle conflicts through the use of signal phasing that allows only a few movements to move legally at any given time. Exhibit 5-5 summarizes the typical pedestrian conflicts present on one approach to a signalized intersection. As the exhibit shows, a pedestrian crossing at a typical signalized intersection (permitted or protected-permitted left turns, right turns on red allowed) faces four potential vehicular conflicts, each coming from a different direction:

- Crossing movements on red (typically high-speed, illegal)
- Right turns on green (legal)
- Left turns on green (legal for protected-permitted or permitted left turn phasing)
- Right turns on red (typically legal)

In terms of exposure, the illegal movements should be accorded a lower weight than legal conflicts. However, they may be accorded an offsetting higher weight in terms of severity. For an intersection with four single-lane approaches, this results in a total of 16 pedestrian-vehicle conflicts.

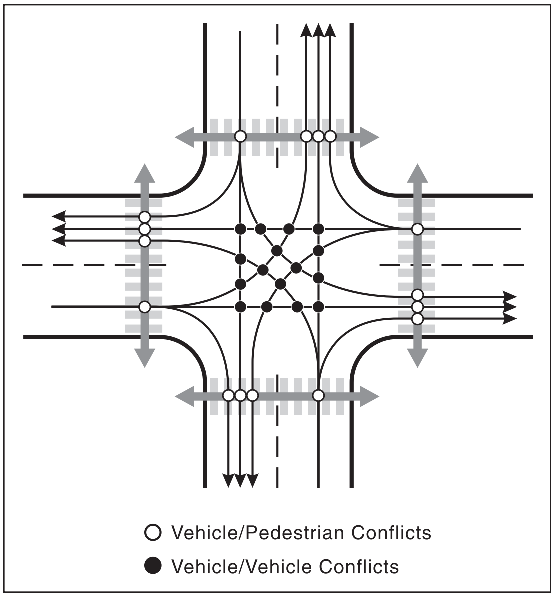


Exhibit 5-5. Vehicle-pedestrian conflicts at signalized intersections.

Pedestrians at roundabouts, on the other hand, face two conflicting vehicular movements on each approach, as depicted in Exhibit 5-6:

- Conflict with entering vehicles; and
- Conflict with exiting vehicles.

The direction conflicting vehicles will arrive from is more predictable for pedestrians at roundabouts.

At conventional and roundabout intersections with multiple approach lanes, an additional conflict is added with each additional lane that a pedestrian must cross.

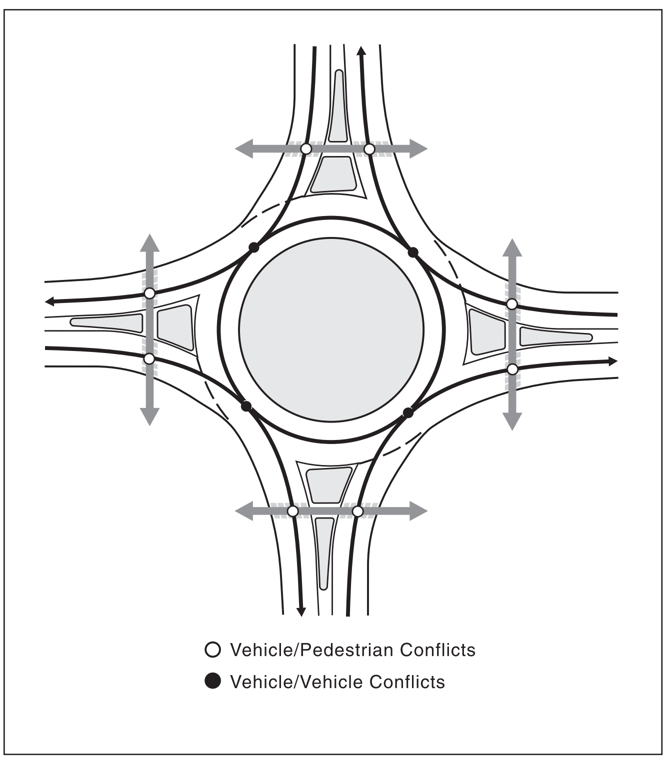
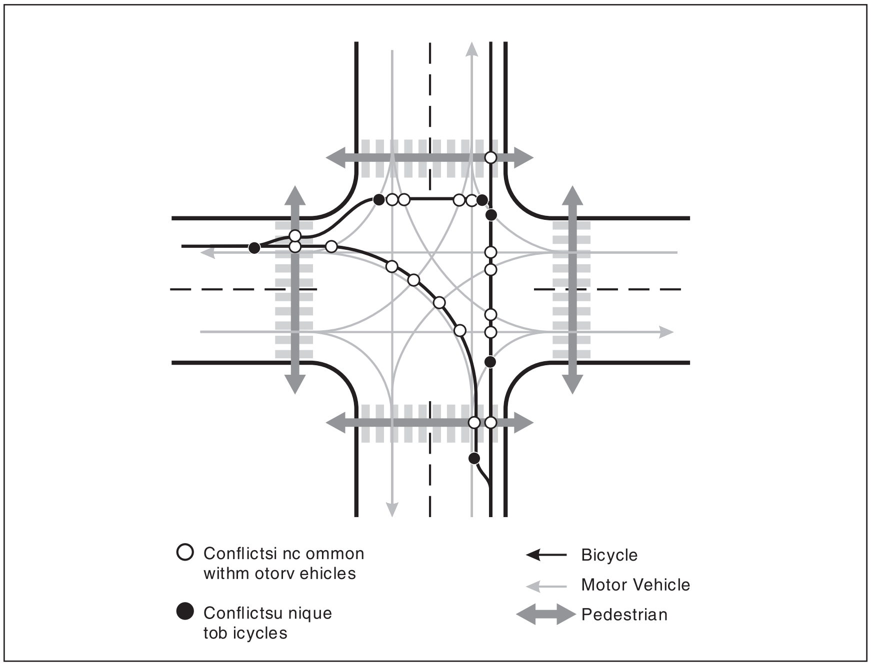


Exhibit 5-6. Vehicle-pedestrian conflicts at single-lane roundabouts.

5.2.3 Bicycle conflicts

Bicycles face similar conflicts as motor vehicles at both signalized intersections and roundabouts. However, because bicyclists typically ride on the right side of the road between intersections, they face additional conflicts due to overlapping paths with motor vehicles. Conflicts unique to bicyclists occur on each approach to conventional four-leg intersections, as depicted in Exhibit 5-7 (showing left turns like motor vehicles or left turns like pedestrians).

Exhibit 5-7. Bicycle conflicts at conventional intersections (showing two left-turn options).



Bicycles can be provided with the option of traveling as either a vehicle or a pedestrian through a roundabout.

At roundabouts, bicycles may be provided the option of traveling as a vehicle or as a pedestrian. As a result, the conflicts experienced by bicyclists are dependent on how they choose to negotiate the roundabout, as shown in Exhibit 5-8. When traveling as a vehicle at a single-lane roundabout, an additional conflict occurs at the point where the bicyclist merges into the traffic stream; the remainder are similar to those for motor vehicles. At double-lane and larger roundabouts where bicycles are typically traveling on the outside part of the circulatory roadway, bicyclists face a potential conflict with exiting vehicles where the bicyclist is continuing to circulate around the roundabout. Bicyclists may feel compelled to "negotiate" the circle (e.g., by indicating their intentions to drivers with their arms) while avoiding conflicts where possible. Bicyclists are less visible and therefore more vulnerable to the merging and exiting conflicts that happen at double-lane roundabouts.

When traveling as a pedestrian, an additional conflict for bicyclists occurs at the point where the bicyclist gets onto the sidewalk, at which point the bicyclist continues around the roundabout like a pedestrian. On shared bicycle-pedestrian paths or on sidewalks, if bicyclists continue to ride, additional bicycle-pedestrian conflicts occur wherever bicycle and pedestrian movements cross (not shown on the exhibit).

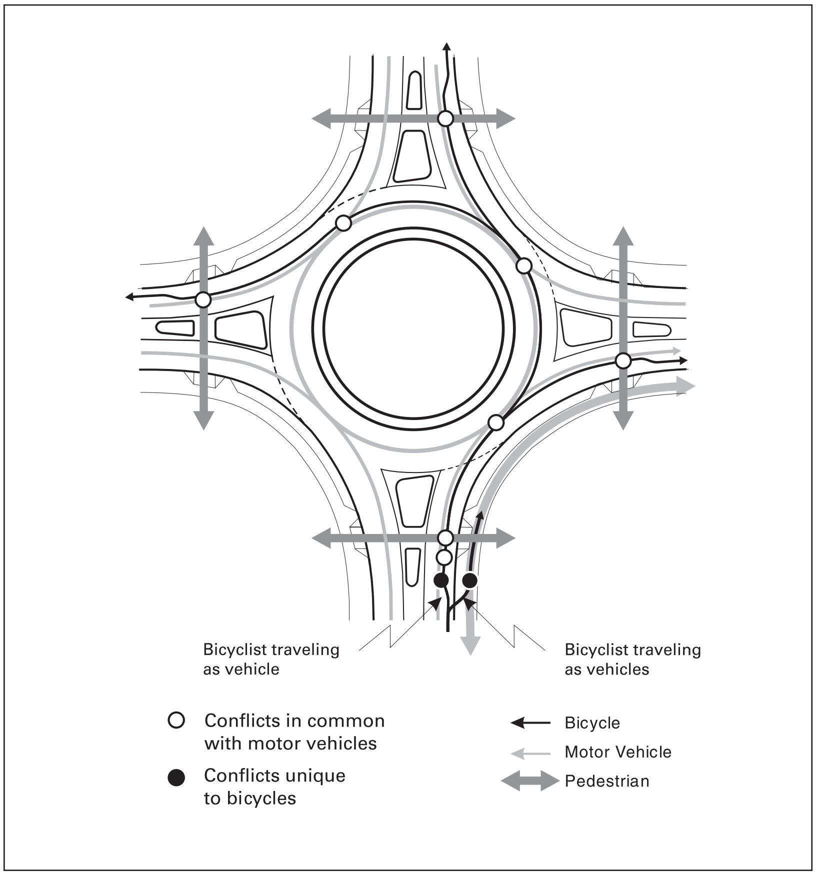


Exhibit 5-8. Bicycle conflicts at roundabouts (showing two left-turn options).

Bicycle-pedestrian conflicts can also occur on shared pathways adjacent to the roundabout.

5.3 Crash Statistics

This section summarizes the overall safety performance of roundabouts in various countries (including the U.S.) and then examines the detailed collision types experienced in France and Queensland, Australia. Pedestrian and bicycle crash statistics are discussed separately, including design issues for visually impaired pedestrians.

5.3.1 Comparisons to previous intersection treatment

Exhibit 5-9 shows the crash frequencies (average annual crashes per roundabout) experienced at eleven intersections in the U.S. that were converted to roundabouts. As the exhibit shows, both types of roundabouts showed a reduction in both injury and property-damage crashes after installation of a roundabout. It should be noted that due to the small size of the data sample, the only result that is statistically significant is the injury crash reduction for small and moderate roundabouts.

Exhibit 5-9. Average annual crash frequencies at 11 U.S. intersections converted to roundabouts.

Type of Roundabout	Sites	Before Roundabout			Roundabout			Percent Change [5]		
		Total	Inj.[3]	PDO[4]	Total	Inj.	PDO	Total	Inj.	PDO
Small/Moderate[1]	8	4.8	2.0	2.4	2.4	0.5	1.6	-51%	73%	-32%
Large[2]	3	21.5	5.8	15.7	15.3	4.0	11.3	-29%	-31%	-10%
Total	11	9.3	3.0	6.0	5.9	1.5	4.2	-37%	-51%	-29%

Notes:
1. Mostly single-lane roundabouts with an inscribed circle diameter of 30 to 35 m (100 to 115 ft).
2. Multilane roundabouts with an inscribed circle diameter greater than 50 m (165 ft).
3. Inj. = Injury crashes
4. PDO = Property Damage Only crashes
5. Only injury crash reductions for small/moderate roundabouts were statistically significant.
Source: (9)

Compared to results from Australia, France, and the United Kingdom, these crash frequencies are quite high. Annual crash frequencies in France, Australia, and United Kingdom of 0.15, 0.6, and 3.31 injury crashes per roundabout, respectively, have been reported (1, 10). The reader should note that the UK has many high-volume, multilane roundabouts.

In spite of the higher frequencies, injury crash *rates*, which account for traffic volume exposure, are significantly lower at U.S. roundabout sites. In a recent study of eight single-lane roundabouts in Maryland and Florida, the injury crash rate was found to be 0.08 crashes per million entering vehicles (5). By comparison, the injury crash rate was reported to be 0.045 crashes per million entering vehicles in France and 0.275 crashes per million entering vehicles in the United Kingdom (1, 10).

Experiences in the United States show a reduction in crashes after building a roundabout of about 37 percent for all crashes and 51 percent for injury crashes. These values correspond with international studies with much larger sample sizes, as shown in Exhibit 5-10.

Exhibit 5-10. Mean crash reductions in various countries.

Country	Mean Reduction (%)	
	All Crashes	Injury Crashes
Australia	41 - 61%	45 - 87%
France		57 - 78%
Germany	36%	
Netherlands	47%	
United Kingdom		25 - 39%
United States	37%	51%

Source: (2), France: (11)

The findings of these studies show that injury crashes are reduced more dramatically than crashes involving property damage only. This again is in part due to the configuration of roundabouts, which eliminates severe crashes such as left turn, head-on, and right angle collisions. Most of these studies also show that crash reduction in rural areas is much higher than in urban areas.

Caveats for comparing the results of crash studies.

Note that the geometry of many studied sites may not necessarily conform to good roundabout design. Improved design principles, such as an emphasis on achieving consistent speeds, may result in better safety performance. It should also be noted that these crash reductions are generally for sites where roundabouts were selected to replace problem intersections. Therefore, they do not necessarily represent a universal safety comparison with all other intersection types.

Collisions at roundabouts tend to be less severe than at conventional intersections. Most crashes reported at roundabouts are a result of drivers failing to yield on entry, referred to as entering-circulating crashes. In addition, rear-end collisions and single vehicle crashes have been reported in many studies. Exhibit 5-11 shows the percentage of the three main crash types reported in different countries.

Exhibit 5-11. Reported proportions of major crash types at roundabouts.

			Type of Crash[1]		
Country	**Crash Description**	**Type of Roundabout**	**Entering-circulating**	**Rear-end**	**Single Vehicle**
Australia	All crashes	Single and multilane	51%	22%	18%
France	Injury crashes	Single and multilane	37%	13%	28%
Germany	All crashes	Single lane	30%	28%	17%
Switzerland	All crashes	Single and multilane	46%	13%	35%
United Kingdom	Injury crashes	Single and multilane	20 - 71%	7 - 25%	8 - 30%

1. Percentages do not necessarily sum to 100% because only three major crash categories are shown.
Source: (10)

5.3.2 Collision types

It is instructive for designers to examine details of collision types and location at roundabouts. Statistics are available for roundabouts designed according to local practices in France, Queensland (Australia), and the United Kingdom. It should be noted that the reported frequencies are to some extent related to the specific design standards and reporting processes used in these countries.

Exhibit 5-12 presents a summary of the percentage of crashes by collision type. The numbered items in the list correspond to the numbers indicated on the diagrams given in Exhibit 5-13 as reported in France. The French data illustrate collision types for a sample of 202 injury crashes from 179 urban and suburban roundabouts in France for the period 1984–1988 (12). For comparison purposes, data from Queensland, Australia (13) and the United Kingdom (1) have been superimposed onto the same classification system.

The results in Exhibit 5-12 are instructive for a number of reasons:

- A variety of collision types can take place at roundabouts. A designer should be aware of these collision types when making decisions about alignment and location of fixed objects. It is recommended that these collision types be adopted as conflict types in the U.S. to conduct traffic conflict analysis and report crashes at roundabouts.
- Although reporting methodologies may vary somewhat, crash experience varies from country to country. This may be due to a combination of differences in driver behavior, and design features.

Exhibit 5-12. Comparison of collision types at roundabouts.

Collision Type	France	Queensland (Australia)	United Kingdom[1]
1. Failure to yield at entry (entering-circulating)	36.6%	50.8%	71.1%
2. Single-vehicle run off the circulatory roadway	16.3%	10.4%	8.2% [2]
3. Single vehicle loss of control at entry	11.4%	5.2%	[2]
4. Rear-end at entry	7.4%	16.9%	7.0% [3]
5. Circulating-exiting	5.9%	6.5%	
6. Pedestrian on crosswalk	5.9%		3.5% [4]
7. Single vehicle loss of control at exit	2.5%	2.6%	[2]
8. Exiting-entering	2.5%		
9. Rear-end in circulatory roadway	0.5%	1.2%	
10. Rear-end at exit	1.0%	0.2%	
11. Passing a bicycle at entry	1.0%		
12. Passing a bicycle at exit	1.0%		
13. Weaving in circulatory roadway	2.5%	2.0%	
14. Wrong direction in circulatory roadway	1.0%		
15. Pedestrian on circulatory roadway	3.5%		[4]
16. Pedestrian at approach outside crosswalk	1.0%		[4]
Other collision types		2.4%	10.2%
Other sideswipe crashes		1.6%	

Notes:
1. Data are for "small" roundabouts (curbed central islands > 4 m [13 ft] diameter, relatively large ratio of inscribed circle diameter to central island size)
2. Reported findings do not distinguish among single-vehicle crashes.
3. Reported findings do not distinguish among approaching crashes.
4. Reported findings do not distinguish among pedestrian crashes.
Sources: France (12), Australia (13), United Kingdom (1)

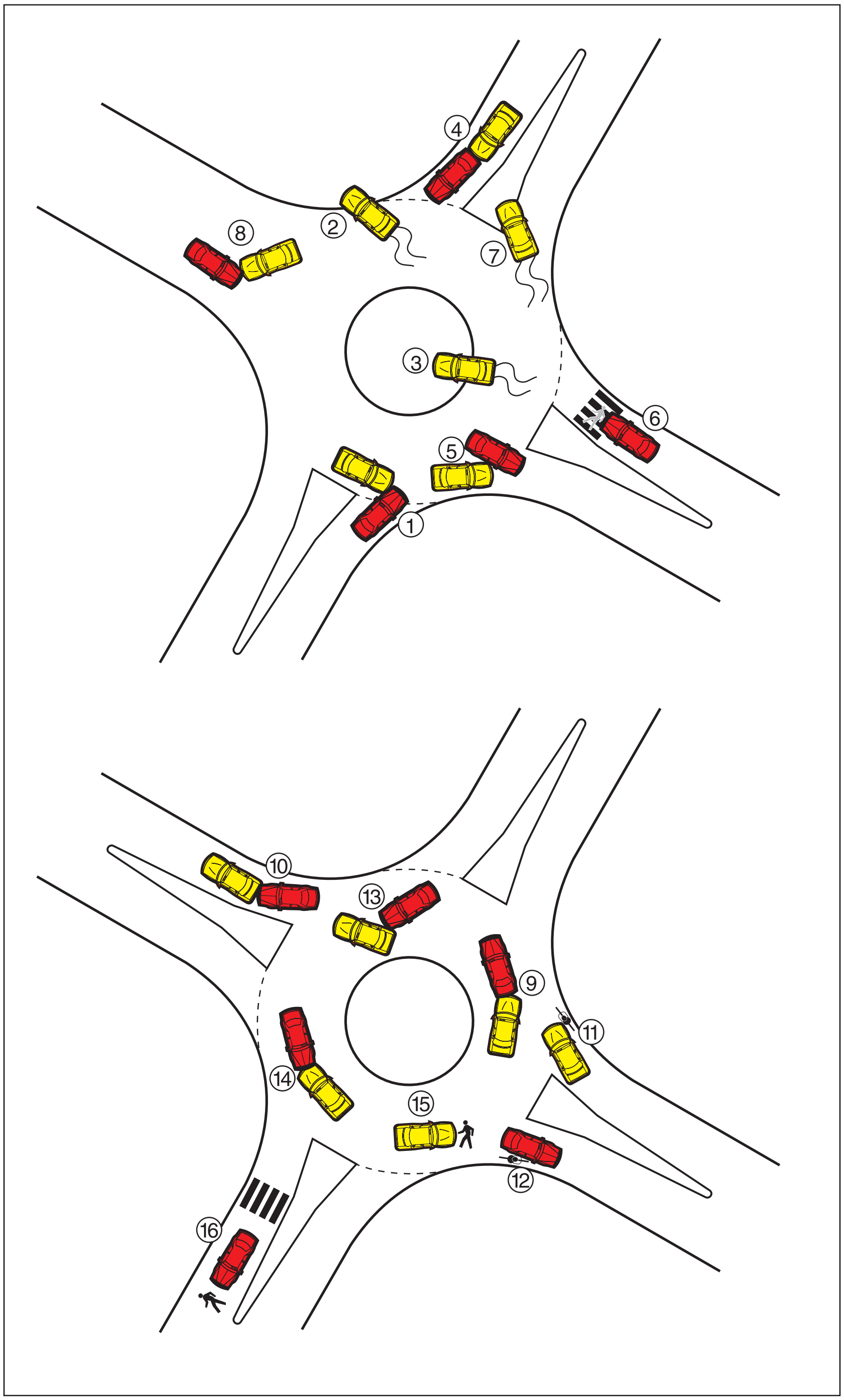


Exhibit 5-13. Graphical depiction of collision types at roundabouts.

Source (8)

Three of the predominant types of collision are: (1) failures to yield at entry to circulating vehicles, (2) single vehicle run-off the circulatory roadway, and (3) single vehicle run-into the central island. A more recent crash study (14) confirmed a high proportion of single vehicle crashes: 49 percent in rural areas, versus 21 percent in urban areas. According to crash models from the United Kingdom, single vehicle crashes range between 20 and 40 percent depending on traffic and design characteristics of sites. In the United Kingdom models, separation by urban and rural areas is not provided.

To reduce the severity of single vehicle crashes, special attention should be accorded to improving visibility and avoiding or removing any hard obstacles on the central island and splitter islands in both urban and rural environments. A French study (14) identified a number of major obstacles that caused fatalities and injuries: trees, guardrail, concrete barriers, fences, walls, piers, sign or light poles, landscaping pots or hard decorative objects, and steep cross-slopes on the central island.

In rural areas, the benefit of lighting has not yet been quantified. In France, only 36 percent of the rural sites are lighted. At these sites, 46 percent of all crashes, and 49 percent of single vehicle crashes occur at night (14).

The French study (7) in 15 towns of 202 urban roundabout crashes compared with all crossroads reported the percentage of crashes by user type, as shown in Exhibit 5-14. The percentage of crashes concerning pedestrians was similar to all crossroads. However, the percentage of crashes involving bicycles and mopeds was larger—15.4 percent for urban crossroads overall versus 24.2 percent for roundabouts, i.e., almost 60 percent more.

Exhibit 5-14. Crash percentage per type of user for urban roundabouts in 15 towns in western France.

User	All Crossroads	Roundabouts
Pedestrians	6.3%	5.6%
Bicycles	3.7%	7.3%
Mopeds	11.7%	16.9%
Motor cycles	7.4%	4.8%
Cars	65.7%	61.2%
Utility vehicles	2.0%	0.6%
Heavy goods vehicles	2.0%	3.0%
Bus/coach	0.8%	0.6%
Miscellaneous	0.4%	0.0%
Total	100.0%	100.0%

Source: (7)

5.3.3 Pedestrians

As was described previously, vehicular injury crashes normally decrease when roundabouts are installed at an existing intersection. The safety benefits of roundabouts have been found to generally carry over to pedestrians as well, as shown in British statistics of Exhibit 5-15. This may be due to the reduced speeds at roundabouts as compared with the previous intersection forms.

Exhibit 5-15. British crash rates for pedestrians at roundabouts and signalized intersections.

Intersection Type	Pedestrian Crashes per Million Trips
Mini-roundabout	0.31
Conventional roundabout	0.45
Flared roundabout	0.33
Signals	0.67

Source: (1, 15)

For pedestrians, the risk of being involved in a severe collision is lower at roundabouts than at other forms of intersections, due to the slower vehicle speeds. Likewise, the number of conflict points for pedestrians is lower at roundabouts than at other intersections, which can lower the frequency of collisions. The splitter island between entry and exit allows pedestrians to resolve conflicts with entering and exiting vehicles separately.

A Dutch study of 181 intersections converted to roundabouts (4) found reductions (percentage) in all pedestrian crashes of 73 percent and in pedestrian injury crashes of 89 percent. In this study, all modes shared in the safety benefits to greater (passenger cars) or lesser extents (bicycles), as shown in Exhibit 5-16.

Exhibit 5-16. Percentage reduction in the number of crashes by mode at 181 converted Dutch roundabouts.

Mode	All Crashes	Injury Crashes
Passenger car	63%	95%
Moped	34%	63%
Bicycle	8%	30%
Pedestrian	73%	89%
Total	51%	72%

Source: (4)

Zebra-stripe markings are recommended at most roundabouts to indicate pedestrian crossings.

A risk analysis of 59 roundabouts and 124 signalized intersections was carried out on crash data in Norway between 1985 and 1989. Altogether, 33 crashes involving personal injury were recorded at the 59 roundabouts. Only 1 of these crashes involved a pedestrian, compared with the signalized intersections, where pedestrians were involved in 20 percent of the personal injury crashes (57 of 287 injury crashes) (16).

Further, there is no quantitative evidence of increased safety for pedestrians at roundabouts with striped (zebra) crossings, where pedestrians have priority. Therefore, striped crossings have generally not been used in other countries. However, in the U.S., it is recommended that all crosswalks be striped except at rural locations with low pedestrian volumes. Although this is not their intended function, striped crosswalks may further alert approaching drivers to a change in their appropriate speed near the yield point.

Safety of visually impaired pedestrians at roundabouts requires further research.

Crash data have not been collected to indicate whether a pedestrian has a disability, and no studies have focused specifically on the safety of visually impaired pedestrians at roundabouts. This is an area requiring further research.

5.3.3.1 Information access for blind or visually impaired pedestrians

Challenges that roundabouts pose to visually impaired pedestrians.

Roundabout crossing skills may be difficult for disabled pedestrians to perform without assistance. For example, audible pedestrian-activated signals may be considered on an approach, although this treatment is not typical. Any leg of any roundabout could be equipped with a pedestrian-activated signal at the pedestrian crossing, if a balanced design requires providing assistance to pedestrians at that location. For example, motorized volume that is too heavy at times to provide a sufficient number of gaps acceptable for pedestrians may warrant a pedestrian signal equipped with audible devices to assist people with visual disabilities.

When crossing a roundabout, there are several areas of difficulty for pedestrians who are blind or visually impaired. It is desirable that a visually impaired pedestrian with good travel skills should be able to arrive at an unfamiliar intersection and cross it with pre-existing skills and without special, intersection-specific training. Roundabouts pose problems at several points of the crossing experience, from the perspective of their access to information:

- The first task of the visually impaired pedestrian is to locate the crosswalk. This can be difficult if the roundabout is not properly landscaped and if the curb edge of the ramp is not marked with a detectable warning surface (see Chapter 6). The crosswalk direction must also be unambiguous.
- Depending upon whether the visually impaired pedestrian is crossing the roundabout in a clockwise or counterclockwise direction, they must listen for a safe gap to cross either the entrance or exit lane(s). The primary problem is the sound of traffic on the roundabout, which may mask the sound of cars approaching the

crosswalk. While crossing the exit lane poses the greater hazard to the pedestrian who is visually impaired because of the higher speed of the vehicles, crossing the entrance may also pose significant problems. Entering traffic, while slower, may also be intimidating as it may not be possible to determine by sound alone whether a vehicle has actually stopped or intends to stop. Sighted pedestrians often rely upon communication through eye contact in these situations; however, that is not a useful or reliable technique for the pedestrian who is visually impaired. Both these problems are further exacerbated at roundabouts with multilane entrances and exits. In these roundabouts, a stopped car in the near lane may mask the sounds of other traffic. It may also block the view of the driver in the far lane of the cane or guide dog of a person who is visually impaired who begins to cross (this is also a problem for children and people using wheelchairs on any crossing of a multilane road).

- The third task is locating the splitter island pedestrian refuge. If this refuge is not ramped, curbed, or equipped with detectable warnings, it is not detectable by a pedestrian who is visually impaired.
- Crossing the remaining half of the crossing (see the second bullet above).
- Locating the correct walkway to either continue their path or locate the adjacent crosswalk to cross the next leg of the roundabout.

Unless these issues are addressed by a design, the intersection is "inaccessible" and may not be permissible under the ADA. Chapters 6 and 7 provide specific suggestions to assist in providing the above information. However, more research is required to develop the information jurisdictions need to determine where roundabouts may be appropriate and what design features are required for people with disabilities. Until specific standards are adopted, engineers and jurisdictions must rely on existing related research and professional judgment to design pedestrian features so that they are usable by pedestrians with disabilities.

Chapters 6 and 7 provide suggestions on designing roundabouts to accommodate persons with disabilities.

Possible design remedies for the difficulties faced by pedestrians include tight entries, raised speed tables with detectable warnings, treatments for visually impaired pedestrians to locate crosswalks, raised pavement markers with yellow flashing lights to alert drivers of crossing pedestrians, pedestrian crossings with actuated signals set sufficiently upstream of the yield line to minimize the possibility of exiting vehicle queues spilling back into the circulatory roadway (6). However, the safety of these treatments at roundabouts has not been tested in the United States.

5.3.4 Bicyclists

As shown in Exhibit 5-17, at British roundabouts bicyclists fare worse in terms of crashes at roundabouts than at signalized intersections.

Exhibit 5-17. British crash rates (crashes per million trips) for bicyclists and motorcyclists at roundabouts and signalized intersections.

Intersection Type	Bicyclists	Motorcyclists
Mini-roundabout	3.11	2.37
Conventional roundabout	2.91	2.67
Flared roundabout	7.85	2.37
Signals	1.75	2.40

Source: (1, 15)

A French study (7) compared the crashes in 1988 in 15 towns in the west of France at both signalized intersections and roundabouts, as shown in Exhibit 5-18. The conclusions from the analysis were:

- There were twice as many injury crashes per year at signalized intersections than at roundabouts;
- Two-wheel vehicles were involved in injury crashes more often (+77 percent) at signalized intersections than on roundabouts;
- People were more frequently killed and seriously injured per crash (+25 percent) on roundabouts than at signalized intersections;
- Proportionally, two-wheel vehicle users were more often involved in crashes (16 percent) on roundabouts than at signalized intersections. Furthermore, the consequences of such crashes were more serious.

Exhibit 5-18. A comparison of crashes between signalized and roundabout intersections in 1998 in 15 French towns.

	Signalized Crossroads	Roundabouts
Number of crossroads	1,238	179
Number of personal injuries	794	59
Number of crashes involving 2-wheel vehicles	278	28
Personal injury crashes/year/crossroad	0.64	0.33
2-wheel vehicle crashes/year/crossroad	0.23	0.13
Crashes to 2-wheel vehicles per 100 crashes	35.0	40.7
Serious crashes/year/crossroad	0.14	0.089
Serious crashes to 2-wheel vehicles/year/crossroad	0.06	0.045
Serious crashes/100 crashes	21.9	27.1
Serious crashes to 2-wheel vehicles/100 crashes to a 2-wheel vehicle	27.0	33.3

Source: (7)

All European countries report that a more careful design is necessary to enhance bicyclists' safety. The type of bicycle crashes depends on the bicycle facilities provided at the roundabout. If there are no bicycle facilities, or if there is a bike lane on the outer area of the circulatory roadway, crashes typically occur between entering cars and circulating bicyclists as well as between cars heading into an exit and circulating bicyclists. Improperly placed signs on the splitter island may also be a contributing factor.

Typical European practice is to provide separated bicycle facilities outside the circulatory roadway when vehicular and bicycle volumes are high.

As a result, most European countries have the following policies:

- Avoid bike lanes on the outer edge of the circulatory roadway.
- Allow bicyclists to mix with vehicle traffic without any separate facility in the circulatory roadway when traffic volumes are low, on single lane roundabouts operating at lower speeds (e.g., up to 8,000 vehicles per day in the Netherlands (4)).
- Introduce separated bicycle facilities outside the circulatory roadway when vehicular and bicycle volumes are high. These separated bicycle facilities cross the exits and entries at least one car length from the edge of the circulatory roadway lane, adjacent to the pedestrian crossings. In some countries, bicyclists have priority over entering and exiting cars, especially in urban areas (e.g., Germany). Other countries prefer to give priority to car traffic showing a yield sign to bicyclists (e.g., Netherlands). The latter solution (i.e., separate bicycle facilities with vehicular traffic priority at the crossing points) is the standard solution for rural areas in most European countries.

Speed is a fundamental risk factor in the safety of bicyclists and pedestrians. Typical bicyclist speeds are in the range of 20 to 25 km/h (12 to 15 mph), and designs that constrain the speeds of vehicles to similar values will minimize the relative speeds and thereby improve safety. Design features that slow traffic such as tightening entry curvature and entry width, and radial alignment of the legs of a roundabout, such as with the urban compact design, are considered safe treatments for bicyclists (17).

In the Netherlands, a 90 percent decrease in injury crashes was experienced with separate bicycle paths around roundabouts where bicyclists do not have right-of-way at the crossings (17).

A bicycle crash prediction model from Sweden has been validated against data for Swedish, Danish, and Dutch roundabouts (18). The model provides reasonable results for roundabouts with up to 12,000 vehicles per day and 4,000 bicycles per day. The model tends to over-predict crashes (i.e., is conservative) for roundabouts carrying more than 12,000 vehicles per day that are also designed with separate bicycle paths with crossings on the approach legs. It is calibrated for crossroad intersections as well as roundabouts. To obtain the expected cycling crashes per year at roundabouts, the value derived from the general junction model is factored by 0.71, implying that bicycle crashes at roundabouts are 71 percent less frequent than at junctions in general. However, the reader is cautioned when extrapolating European bicycling experience to the U.S., as drivers in Europe are more accustomed to interacting with bicyclists.

5.4 Crash Prediction Models

Crash prediction models have not been developed for U.S. roundabouts.

Crash prediction models have been developed for signalized intersections in the U.S., as discussed previously in Chapter 3. However, no crash prediction models exist yet for U.S. roundabouts and driver behavior. Given the relatively recent introduction of roundabouts to the U.S. and driver unfamiliarity with them, crash prediction models from other countries should be used cautiously. As reported earlier in Section 5.3, crash statistics vary from country to country, both in terms of magnitude and in terms of collision types. Consequently, the application of a crash prediction model from another country may not accurately predict crash frequencies at U.S. locations. Nonetheless, these crash prediction models from other countries can be useful in understanding the *relative* effects of various geometric features on the number of crashes that might be expected. The user is thus cautioned to use these models only for comparative purposes and for obtaining insights into the refinement of individual geometric elements, not to use them for predicting *absolute* numbers of crashes under U.S. conditions.

Crash models relating crash frequency to roundabout characteristics are available from the United Kingdom. The sample consisted of 84 four-leg roundabouts of all sizes, small to large and with various number of approach lanes and entry lanes (flared or parallel entries) (1). Approach speeds were also evenly represented between 48 to 64 km/h (30 to 40 mph) and 80 to 113 km/h (50 to 70 mph). Crash data were collected for periods of 4 to 6 years, a total of 1,427 fatal, serious, and slight injuries only. The proportion of crashes with one casualty was 83.7 percent, and those with two casualties was 12.5 percent. The models are based on generalized linear regression of the exponential form, which assumes a Poisson distribution. Their goodness of fit is expressed in terms of scaled deviations that are moderately reliable. No additional variables, other than those listed below, could further improve the models significantly (see also (8)).

The British crash prediction equations (1), for each type of crash are listed in Equations 5-1 through 5-5. Note that these equations are only valid for roundabouts with four legs. However, the use of these models for relative comparisons may still be reasonable.

Entry-Circulating: (5-1)

$$A = 0.052 Q_e^{0.7} Q_c^{0.4} \exp\left(-40C_e + 0.14e - 0.007ev - \frac{1}{1+\exp(4R-7)} + 0.2P_m - 0.01\theta\right)$$

where: A = personal injury crashes (including fatalities) per year per roundabout approach;
Q_e = entering flow (1,000s of vehicles/day)
Q_c = circulating flow (1,000s of vehicles/day)
C_e = entry curvature = $1/R_e$
e = entry width (m)
v = approach width (m)
R = ratio of inscribed circle diameter/central island diameter
P_m = proportion of motorcycles (%)
θ = angle to next leg, measured centerline to centerline (degrees)

Approaching: $A = 0.0057Q_e^{1.7}\,exp(20C_e - 0.1e)$ (5-2)

where: A = personal injury crashes (including fatalities) per year at roundabout approach or leg;
Q_e = entering flow (1,000s of vehicles/day)
C_e = entry curvature = $1/R_e$
R_e = entry path radius for the shortest vehicle path (m)
e = entry width (m)

Single Vehicle: $A = 0.0064Q_e^{0.8}\,exp(25C_e + 0.2v - 45C_a)$ (5-3)

where: A = personal injury crashes (including fatalities) per year at roundabout approach or leg
Q_e = entering flow (1,000s of vehicles/day)
C_e = entry curvature = $1/R_e$
R_e = entry path radius for the shortest vehicle path (m)
V = approach width (m)
C_a = approach curvature = $1/R_a$
R_a = approach radius (m), defined as the radius of a curve between 50 m (164 ft) and 500 m (1,640 ft) of the yield line

Other (Vehicle): $A = 0.0064Q_e^{0.8}\,exp(25C_e + 0.2v - 45C_a)$ (5-4)

where: A = personal injury crashes (including fatalities) per year at roundabout approach or leg
Q_{ec} = product $Q_e \cdot Q_c$
Q_e = entering flow (1,000s of vehicles/day)
Q_c = circulating flow (1,000s of vehicles/day)
P_m = proportion of motorcycles

Pedestrian: $A = 0.029Q_{ep}^{0.5}$ (5-5)

where: A = personal injury crashes (including fatalities) per year at roundabout approach or leg
Q_{ep} = product $(Q_e + Q_{ex}).\ Q_p$
Q_e = entering flow (1,000s of vehicles/day)
Q_{ex} = exiting flow (1,000s of vehicles/day)
Q_p = pedestrian crossing flow (1,000s of pedestrians/day)

According to the U.K. crash models, the major physical factors that were statistically significant are entry width, circulatory width, entry path radius, approach curvature, and angle between entries. Some of the effects of these parameters are as follows:

- *Entry width*: For a total entry flow of 20,000 vehicles per day, widening an entry from one lane to two lanes is expected to cause 30 percent more injury crashes. At 40,000 vehicles per day, widening an entry from two lanes to three lanes will cause a 15 percent rise in injury crashes. Moreover, the models could not take into account the added hazard to bicyclists and pedestrians who will have to travel longer exposed distances. (8)

- *Circulatory width*: Widening the circulatory roadway has less impact on crashes than entry width. Crashes are expected to rise about 5 percent for a widening of two meters. (8)
- *Entry path radius*: Entry-circulating collision type increases with entry path radius (for the fastest path), while single vehicle and approach collision types decrease. For a double-lane approach, an optimum entry path radius is 50 to 70 m (165 to 230 ft). (8)
- *Approach curvature*: Approach curvature is safer when the approach curve is to the right and less so when the curve is to the left. This implies that a design is slightly safer when reverse curves are provided to gradually slow drivers before entry. For a double-lane approach roundabout with entering flow of 50,000 vehicles per day, changing a straight approach to a right-turning curve of 200 m (650 ft) radius reduces crash frequency by 5 percent. (8)

Maximize angles between entries.

- *Angle between entries*: As the angle between entries decreases, the frequency of crashes increases. For example, an approach with an angle of 60 degrees to the next leg of the roundabout increases crash frequency by approximately 35 percent over approaches at 90-degree angles. Therefore, the angle between entries should be maximized to improve safety.

An approach suggested in Australia (13) differs from the British approach in that the independent variables are based on measures related to driver behavior. For instance, the collision rate for single vehicle crashes was found to be:

$$A_{sp} = 1.64 \times 10^{-12} \times Q^{1.17} \times L \times (S + \Delta S)^{4.12} / R^{1.91} \quad (5\text{-}6)$$

and

$$A_{sa} = 1.79 \times 10^{-9} \times Q^{0.91} \times L \times (S + \Delta S)^{1.93} / R^{0.65} \quad (5\text{-}7)$$

where: A_{sp} = the number of single vehicle crashes per year per leg for vehicle path segments prior to the yield line.
A_{sa} = the number of single vehicle crashes per year per leg for vehicle path segments after the yield line.
Q = the average annual daily traffic in the direction considered—one way traffic only (veh/d)
L = the length of the driver's path on the horizontal geometric element (m).
S = the 85th-percentile speed on the horizontal geometric element (km/h).
ΔS = the decrease in the 85th-percentile speed at the start on the horizontal geometric element (km/h). This indicates the speed change from the previous geometric element.
R = the vehicle path radius on the geometric element (m).

These equations demonstrate a direct relationship between the number of crashes, overall speed magnitudes, and the change in speed between elements. Therefore, this equation can be used to estimate the *relative* differences in safety benefits between various geometric configurations by estimating vehicle speeds through the various parts of a roundabout.

5.5 References

1. Maycock, G., and R.D. Hall. *Crashes at four-arm roundabouts*. TRRL Laboratory Report LR 1120. Crowthorne, England: Transport and Road Research Laboratory, 1984.

2. Garder, P. *The Modern Roundabouts: The Sensible Alternative for Maine*. Maine Department of Transportation, Bureau of Planning, Research and Community Services, Transportation Research Division, 1998.

3. Brilon, W. and B. Stuwe. "Capacity and Design of Traffic Circles in Germany." In *Transportation Research Record 1398*. Washington, D.C.: Transportation Research Board, National Research Council, 1993.

4. Schoon, C.C., and J. van Minnen. *Accidents on Roundabouts: II. Second study into the road hazard presented by roundabouts, particularly with regard to cyclists and moped riders*. R-93-16. The Netherlands: SWOV Institute for Road Safety Research, 1993.

5. Flannery, A. and T.K. Datta. "Modern Roundabouts and Traffic Crash Experience in the United States." In *Transportation Research Record 1553*. Washington, D.C.: Transportation Research Board, National Research Council, 1996.

6. Brown, M. *TRL State of the Art Review—The Design of Roundabouts*. London: HMSO, 1995.

7. Alphand, F., U. Noelle, and B. Guichet. "Roundabouts and Road Safety: State of the Art in France." In *Intersections without Traffic Signals II*, Springer-Verlag, Germany (W. Brilon, ed.), 1991, pp. 107–125.

8. Bared, J.G., and K. Kennedy. "Safety Impacts of Modern Roundabouts," Chapter 28, *The Traffic Safety Toolbox: A Primer on Traffic Safety,* Institute of Transportation Engineers, 2000.

9. Jacquemart, G. *Synthesis of Highway Practice 264: Modern Roundabout Practice in the United States*. National Cooperative Highway Research Program. Washington, D.C: National Academy Press, 1998.

10. Brilon, W. and L. Bondzio. White Paper: Summary of International Statistics on Roundabout Safety (unpublished), July 1998.

11. Guichet, B. "Roundabouts In France: Development, Safety, Design, and Capacity." In *Proceedings of the Third International Symposium on Intersections Without Traffic Signals* (M. Kyte, ed.), Portland, Oregon, U.S.A. University of Idaho, 1997.

12. Centre d'Etude des Transports Urbains (CETUR). "Safety of Roundabouts in Urban and Suburban Areas." Paris, 1992.

13. Arndt, O. "Road Design Incorporating Three Fundamental Safety Parameters." Technology Transfer Forum 5 and 6, Transport Technology Division, Main Roads Department, Queensland, Australia, August 1998.

14. SETRA/CETE de l'Ouest. "Safety Concerns on Roundabouts." 1998.

15. Crown, B. "An Introduction to Some Basic Principles of U.K. Roundabout Design." Presented at the ITE District 6 Conference on Roundabouts, Loveland, Colorado, October 1998.

16. Seim, K. "Use, Design and Safety of Small Roundabouts in Norway." In "Intersections Without Traffic Signals II", Springer-Verlag, Germany (W. Brilon, ed.), 1991, pp. 270–281.

17. Van Minnen, J. "Safety of Bicyclists on Roundabouts Deserves Special Attention." SWOV Institute of Road Safety Research in the Netherlands, Research Activities 5, March 1996.

18. Brude, U., and J. Larsson. *The Safety of Cyclists at Roundabouts—A Comparison Between Swedish, Danish and Dutch Results*. Swedish National Road and Transport Research Institute (VTI), Nordic Road & Transport Research No. 1, 1997.

APPENDIX E

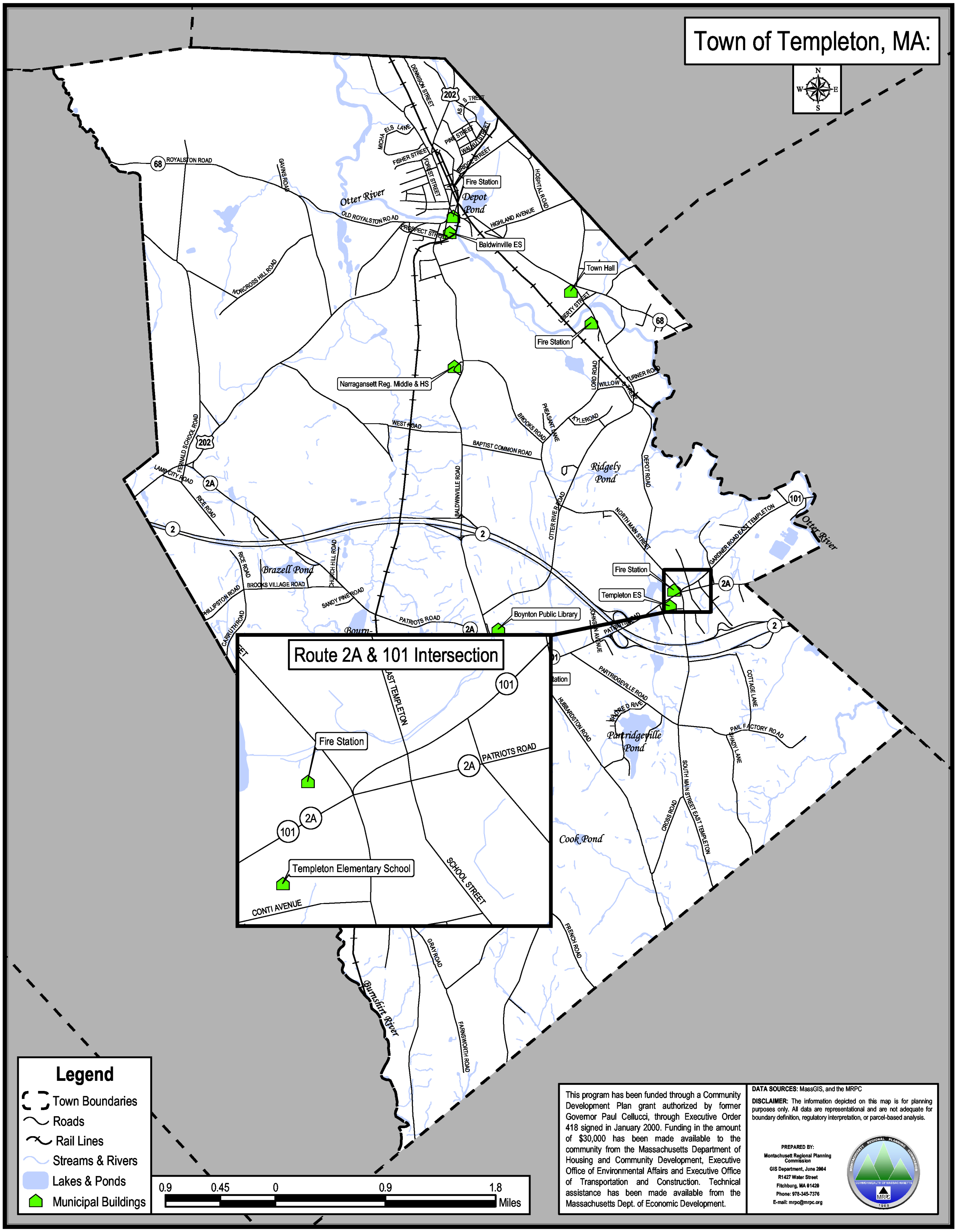
Next Steps & Project Development Process
2004 EO418 Traffic Study

VI. TRANSPORTAION ELEMENT

A. INTRODUCTION

As part of the EO418 Program, the Montachusett Regional Planning Commission (MRPC) prepared a scope of work for the Town of Templeton to conduct a comprehensive traffic engineering investigation of the operational conditions of the intersection of Patriots Road (Route 2A)/Gardner Road (Route 101)/North and South Main Streets in East Templeton . In addition, a Pavement Management System (PMS) for town roads was examined to assist local officials and a trail plan that can be utilized by the town in the development of multi-purpose trails within the community. Figure 1 outlines the study area for this report.

Figure 1 – Study Area



B. TRAFFIC ENGINEERING INVESTIGATION

1. Overview of Analyses

a) Operational Analyses

Operational conditions at each intersection were assessed based on the traffic flow that occurs during the afternoon peak (i.e., highest-volume) hour of a typical weekday. Analyses of current conditions were based on traffic data collected in 2003. For analyses of future (i.e., 2010) conditions, a regional traffic growth factor of 1.77% per year (based on trends in traffic volumes recorded in the Montachusett region) was used to predict future volumes.

The level of service (LOS) of an intersection or road segment represents the quality of traffic flow and is used to assess the operation of that facility. LOS analyses are based on the methods in the *Highway Capacity Manual (2000)*. LOS is defined differently for each type of facility, such as an unsignalized intersection, signalized intersection, two-lane road, or multi-lane road. For intersections, the LOS is defined by the average amount of delay experienced by a vehicle at the intersection due to the traffic controls (i.e., signs or signals). Usually each approach is assessed independently, since the LOS of the major and minor approaches may differ greatly. Table 1 summarizes the LOS definitions for intersections controlled by STOP signs and those controlled by traffic signals.

Table 1 - LOS Definitions for Intersections

LOS	*Average Control Delay (s per vehicle)*	
	Stop-Controlled	*Signalized*
A	<10.0	<10.0
B	10.1 – 15.0	10.1 – 20.0
C	15.1 – 25.0	20.1 – 35.0
D	25.1 – 35.0	35.1 – 55.0
E	35.1 – 50.0	55.1 – 80.0
F	>50.0	>80.0

When evaluating alternatives, LOS values and average control delay were estimated for each alternative and compared. Intersections were also evaluated for possible signalization. The *Manual of Uniform Traffic Control Devices* contains warrants for installation of traffic signals. If an intersection meets the criteria of at least one of the warrants, installation of a signal may be appropriate. These warrants, which are reprinted in the Appendix C of this report, include criteria such as minimum volumes, peak hour delay, and accidents. If recent data is available, it can be compared to the warrants to assess the appropriateness of a traffic signal under current conditions.

b) Safety Analyses

Safety of the intersection was assessed by identifying relevant records in the Massachusetts crash database and from the Ashburnham Police Department and examining them for trends, and by visiting the sites.

One of the most common safety problems at an intersection is inadequate sight distance from the minor road approaches. A driver stopped at an intersection needs to be able to see a certain distance in both directions along the major road in order to safely turn onto or cross the major road. This distance, known as the required intersection sight distance, is calculated as $d = 1.47vt_g$, where v is the design speed on the major road and t_g is the time gap, defined in Figures 2a and 2b (excerpted from *A Policy on Geometric Design of Highways and Streets*).

Figure 2a – Time Gap for Left Turns from a STOP Sign

Design Vehicle	Time gap(s) design speed of major road (tg)
Passenger Car	7.5
Single-unit truck	9.5
Combination truck	11.5

Note: Time gaps are for a stopped vehicle to turn right or left onto a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

For multilane highways:

For left turns onto two-way highways with more than two lanes, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane, from the left, in excess of one, to be crossed by the turning vehicle.

For minor road approach grades:

If the approach grade is an upgrade that exceeds 3 percent; add 0.2 seconds for each percent grade for left turns.

Figure 2a – Time Gap for Right Turns or Crossing Maneuvers from a STOP Sign

Design Vehicle	Time gap (s) at design speed of major road (t_g)
Passenger Car	6.5
Single-unit truck	8.5
Combination truck	10.5

Note: Time gaps are for a stopped vehicle to turn right onto or cross a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

For multilane highways:

For crossing a major road with more than two lanes, add 0.5 seconds for passenger cars and 0.7 seconds for trucks for each additional lane to be crossed and for narrow medians that cannot store the design vehicle.

For minor road approach grades:

If the approach grade is an upgrade that exceeds 3 percent, add 0.1 seconds for each percent grade.

2. *<u>Intersection Analysis - Patriots Road (Route 2A)/Gardner Road (Route 101)/North Main Street/South Main Street</u>*

This intersection has five approaches: Route 2A (Patriots Road) westbound and eastbound, Route 101 (Gardner Road) southbound, North Main Street, and South Main Street. Route 2A, the major road, is a four-lane arterial running east and west, and it has no traffic control devices at this intersection. The eastbound approach is divided by a narrow textured and painted median. Route 101 southbound is a one-way, two-lane road controlled by a STOP sign. North and South Main Streets are two-lane roads controlled by STOP signs. Figure 3 is a sketch of the intersection, and Figures 4 through 8 are photographs of the five approaches.

Figure 3 – Patriots Road (Route 2A)/Gardner Road (Route 101)/North Main Street/South Main Street

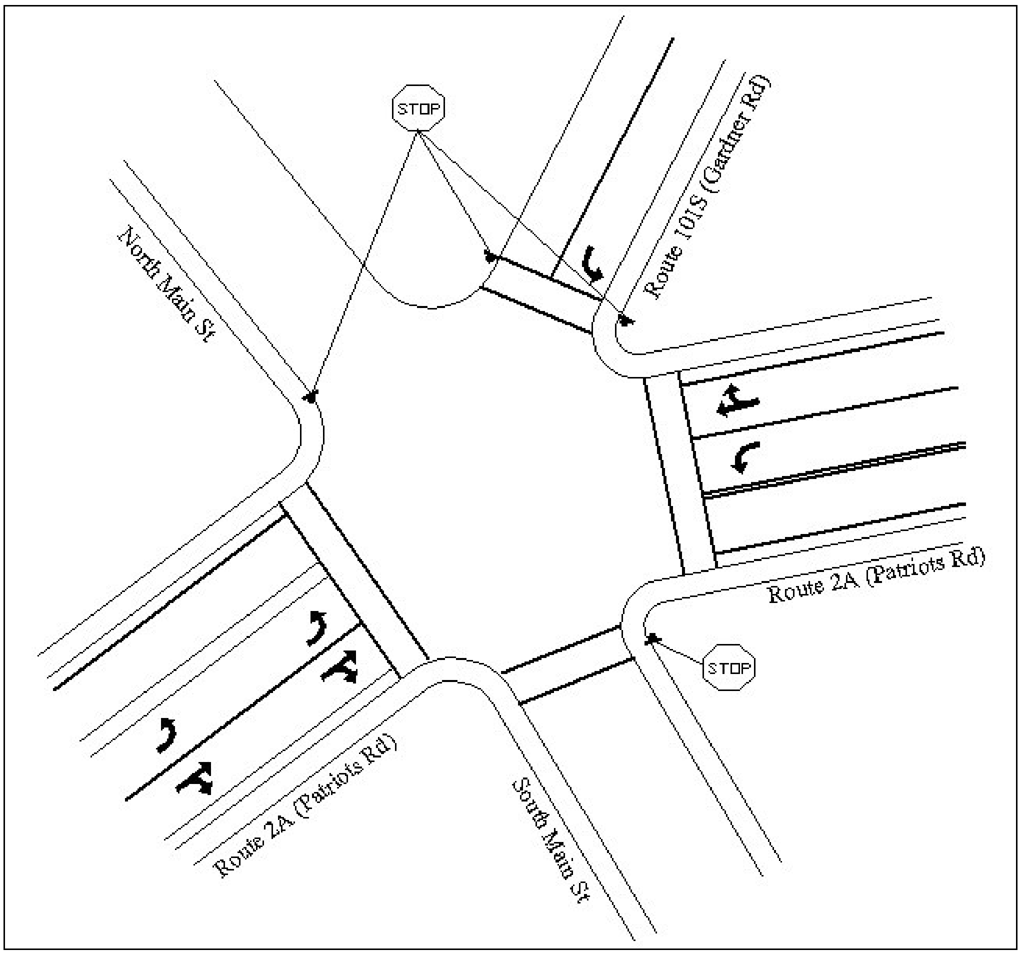


Figure 4 – Approaching the Intersection on South Main Street from the South

Figure 5 – Approaching the Intersection on North Main Street from the North

Figure 6 – Approaching the Intersection on Route 101S from the Northwest

Figure 7 – Approaching the Intersection on Route 2A from the West

Figure 8 – Approaching the Intersection on Route 2A from the East

a) Operational Conditions

Turning movement volumes collected during the afternoon peak hour (4:00-5:00 PM) in 2003 are shown in Table 2, and predicted volumes for the year 2010 in Table 3.

Table 2 - 2003 PM Peak Turning Movement Volumes

Approach	*Left Turn*	*Through*	*Right Turn*	*Total*
Northbound (South Main St)	16	15	51	82
Southbound (North Main St)	67	14	48	129
Southwest-bound (101S)	18	144	37	199
Eastbound (2A)	78	207	36	321
Westbound (2A)	37	186	71	294

Table 3 - Predicted 2010 PM Peak Turning Movement Volumes

Approach	*Left Turn*	*Through*	*Right Turn*	*Total*
Northbound (South Main St)	18	17	58	93
Southbound (North Main St)	76	16	54	146
Southwest-bound (101S)	20	163	42	225
Eastbound (2A)	88	234	41	363
Westbound (2A)	42	210	80	332

During the afternoon peak hour, given the volumes shown in Table 2, the Route 2A approaches both have an LOS of A, which is the best possible value. The South Main Street and Route 101S approaches both have an LOS of C, which indicates acceptable delays. The North Main Street approach has an LOS of E, which indicates long delays. For the predicted traffic flow in 2010, the LOS of the South Main Street and Route 101S approaches would drop to D, and the LOS of the North Main Street approach would drop to F, which indicates an unacceptably long delay.

b) Safety Conditions

In 2000-2002, five crashes were reported at this intersection. Two were rear-end collisions, and one was a collision with a parked vehicle. The other two were angle collisions, meaning crashes involving at least one turning vehicle. One of the angle collisions involved a vehicle on North Main Street and one on Route 2A westbound. The other involved a vehicle on South Main Street and one on Route 2A westbound, and resulted in two injuries.

One of the most common safety problems at intersections is inadequate sight distance from the minor road approaches. A driver stopped at an intersection needs to be able to see a certain distance in both directions along the major road in order to safely turn onto or cross the major road. The available sight distance at the intersection appears to be sufficient, except possibly looking to the right from the North Main Street approach. Vehicles using this approach seem to pull forward far enough to have an adequate view.

Some of the pavement markings are badly faded, namely the markings on Route 101S and the crosswalks on Route 2A westbound and South Main Street. North and South Main Streets do not have any pavement markings (e.g., double yellow lines). Also, the median on Route 2A eastbound is difficult to see from the other approaches because it is flat and not clearly marked.

The major problem that is apparent at this intersection is the presence of five approaches, three of which are controlled by STOP signs. Vehicles stopped on North or South Main Street or 101S have numerous conflicting flows of traffic to avoid while making a maneuver through the intersection, and there is obvious confusion about right of way among vehicles on these approaches.

c) Alternatives

Based on the predicted traffic conditions in 2010, several alternatives were examined to improve the intersection layout and traffic flow. The analysis results are summarized in Table 4.

Table 4 - 2010 PM Peak LOS and Delay

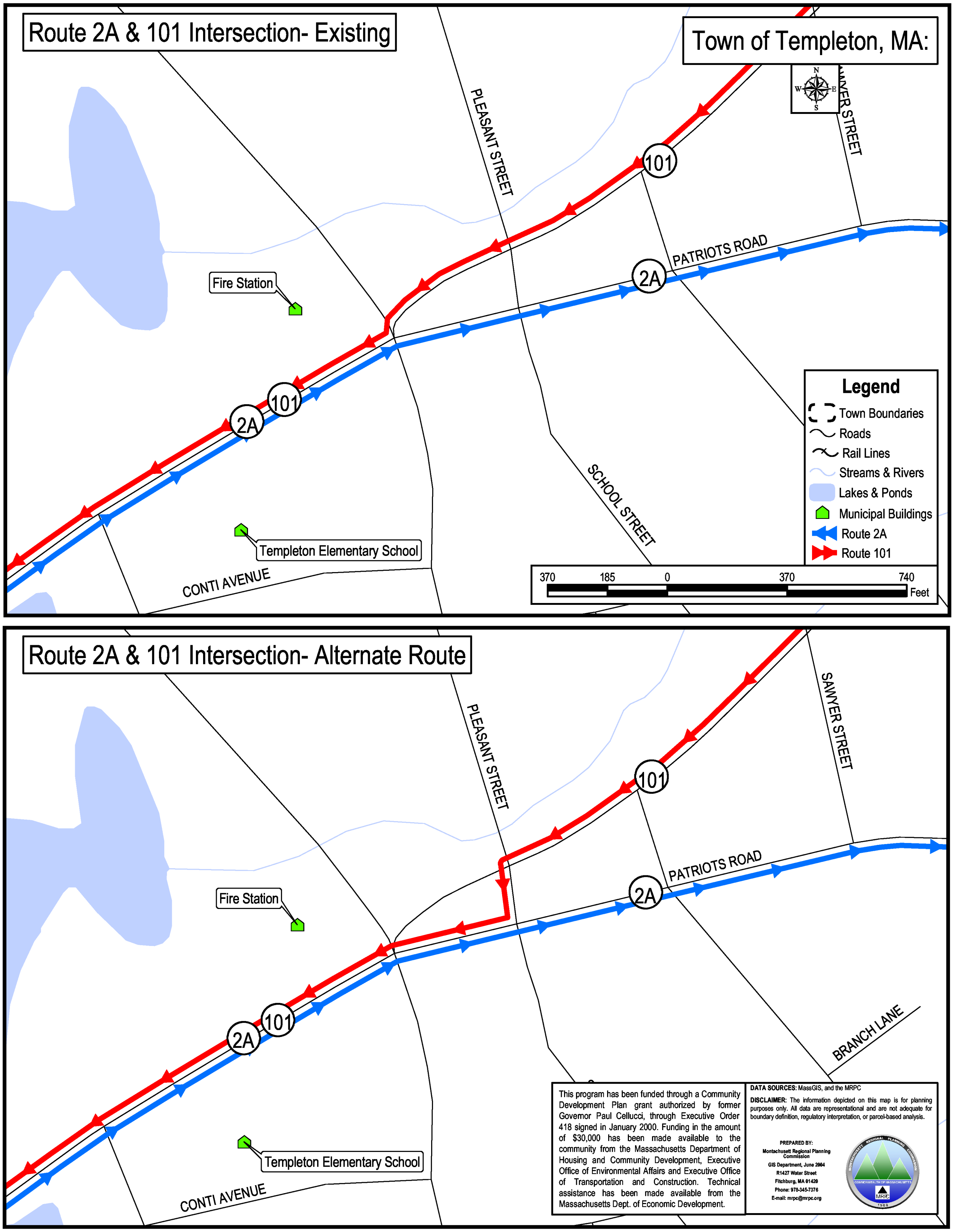
Approach	*LOS*				*Delay (s per vehicle)*			
	No change	*Alt 1*	*Alt 2*	*Alt 3*	*No change*	*Alt 1*	*Alt 2*	*Alt 3*
Northbound (South Main St)	D	C	C	n/c	32.3	32.1	24.7	n/a
Southbound (North Main St)	F	D	F	n/c	104.3	40.5	54.1	n/a
Southwest-bound (101S)	D	C	n/a	n/c	26.9	28.5	n/a	n/a
Eastbound (2A)	A	C	A	n/c	8.2	21.7	8.2	n/a
Westbound (2A)	A	C	A	n/c	8.1	21.7	8.1	n/a

1. Alternative 1 is to install a traffic signal at this intersection. A formal traffic signal warrant study was not conducted due to lack of recent traffic volume data. Installing a signal would decrease the delay to traffic on North Main Street but increase delay to traffic on Route 2A. The traffic on South Main Street and Route 101S would have approximately the same delay as without a signal, but the LOS would improve because the delay would be caused by a signal.

2. Alternative 2 is to eliminate the one-way Route 101S approach. Figure 8 shows the existing and proposed routing for Route 101. Currently, Routes 101N and 101S follow slightly different paths near the intersection under

study. Route 101N intersects Route 2A about one block to the east, following School Street. In this alternative, Route 101S traffic is directed to travel on School Street as well. The LOS of the South Main Street approach would be improved from D to C by this alternative, and the delay to traffic on North Main Street would be cut in half, although the LOS would not change. Route 2A would be basically unaffected.

Figure 8 - Existing (Left) and Alternative (Right) Routing Of Route 101



If Alternative 2 were implemented, the radius of the turns between Routes 101 and 2A should be checked to ensure they will accommodate the trucks that travel on Route 101 through Ashburnham. Table 5, excerpted from *A Policy on Geometric Design of Highways and Streets*, shows the design values for a 90-degree turn at an intersection to allow for various vehicles.

Additionally, that segment of Gardner Road between School Street and North Main Street would need to be altered to eliminate westbound traffic from utilizing it instead of the reconfigured Route 101S layout as described.

Table 5 - Curve Radii for Various Design Vehicles at a 90-Degree Turn

Design vehicle	*Simple curve radius (ft)*	*Simple curve radius with taper*		
		Radius (ft)	*Offset (ft)*	*Taper (H:V)*
Passenger car	30	20	2.5	10:1
Single-unit truck	50	40	2.0	10:1
WB-40 (46' semi)	--	45	4.0	10:1
WB-50 (55' semi)	--	60	4.0	15:1

3. Alternative 3 is to convert the five-way intersection to a roundabout. A modern roundabout consists of a central island, one or more lanes circulating around the island, and entry/exit points with triangular islands to direct the traffic. Vehicles enter and exit the roundabout by turning right at slow speeds (i.e., 25 mph or less), and entering traffic yields to circulating traffic. At this intersection, a roundabout would keep the traffic conflicts to a minimum and improve conditions on the minor approaches. Good roundabout design includes speed reduction and speed consistency, which contribute to safer merging, easier navigation of the intersection, less frequent and less severe collisions, and greater safety for pedestrians. Roundabouts also require less maintenance and longer service life than traffic signals, and they provide an opportunity for attractive landscaping. Much more information about the costs and benefits of roundabouts can be found in *Roundabouts: An Informational Guide*, a Federal Highway Administration publication (available on the internet at www.tfhrc.gov/safety/00068.htm). See also Appendix E for an abstract of this document. The Route 101S approach could also be changed to a two-way road, and Route 101N rerouted to follow the same path as 101S. That change would eliminate most of the left turns from Route 2A east of the intersection onto School Street.

   The LOS and delay values for Alternative 3 are noted as "n/c" for "not calculated" because a methodology has not yet been established in the *Highway Capacity Manual* for roundabouts. For the predicted peak hour traffic in 2010, a five-leg roundabout would be operating under capacity, as shown in Table 6.

Table 6 - 2010 PM Peak Roundabout Performance

Approach	*Volume (veh/hr)*	*Capacity (veh/hr)*	*V/C*
Northbound (South Main St)	136	750-722	0.18-0.18
Southbound (North Main St)	177	723-780	0.23-0.24
Southwest-bound (101S)	254	756-760	0.33-0.34
Eastbound (2A)	447	633-979	0.46-0.71
Westbound (2A)	408	623-999	0.41-0.66

d) Conclusions & Recommendations

To improve the traffic flow and safety conditions at this intersection, the following improvements are recommended:

- Repaint existing but faded pavement markings on the Route 2A and 101 approaches.

- Add pavement markings (e.g., longitudinal double yellow lines) on the North and South Main Street approaches.

- Delineate the existing narrow median on the Route 2A eastbound approach with paint or by installing curbing around the median.

- Modify the layout of the intersection by either rerouting Route 101S outside of the intersection (Alternative 2) or converting the intersection to a roundabout (Alternative 3).

Due to the magnitude of the recommendations, coordination with MassHighway is strongly recommended. Reconstruction of the intersection geometrics should be eligible for state or federal funding assistance, therefore requests need to go through MassHighway. A synopsis of the project request and implementation process to seek state funding assistance for a roadway project is included in Appendix F.

Project Development

Project Development is the process that takes a transportation improvement from ***concept*** through ***construction****.* There are several goals for this process:

- To ensure context sensitivity though an open, consensus-building dialog among project proponents, reviewers, the public, and other parties.
- To foster thinking beyond the roadway pavement to achieve the optimum accommodation for all modes.
- To encourage early planning, public outreach, and evaluation so that project needs, goals and objectives, issues, and impacts can be identified before significant resources are expended.
- To achieve consistent expectations and understanding between project proponents and those entities who evaluate, prioritize, and fund projects.
- To ensure allocation of resources to projects that address local, regional, and statewide priorities and needs.

Project delays and escalating costs are discouraging to everyone involved. Projects that are ultimately built but do not meet expectations in addressing needs are also frustrating. This project development framework, and the principles that it embraces, will:

- Help carry out projects effectively;
- Ensure good project planning, design, and implementation; and,
- Set the stage for long-term success.

Effective partnerships on projects are important throughout project development and require strong commitment and action from all Individuals involved, whether they be MassHighway or Federal Highway Administration (FHWA) staff, elected officials, local planning and public works professionals, citizens, or consultants. Real partnerships require ongoing relationships of trust and collaboration.

The project development process is one of a set of tools needed to achieve context-sensitive design. The process is structured to encourage public outreach throughout planning, design, environmental review, and construction so that those affected by transportation projects are in general agreement regarding the project's need, the selected approach to meet this need, and the refinements to the project that result as the process evolves. Section 2.9 of this chapter overviews public outreach approaches and tools to assist in establishing an effective project development process.

This project development process is complemented by the inclusion of the project's context as a basic design control. Flexibility for determining specific design elements that satisfy the project need, and are responsive to the context of the project, is inherent in the subsequent chapters of this Guidebook.

Applicable Projects

Project proponents are required to follow the process described in this chapter whenever MassHighway is involved in the decision-making process. The project development procedures are, therefore, applicable to any of the following situations:

- When MassHighway is the proponent; or
- When MassHighway is responsible for project funding (state or federal-aid projects); or
- When MassHighway controls the infrastructure (projects on state highways).

In addition to MassHighway, many other agencies and organizations may be involved in a project. These procedures are written to be a useful resource for projects that are locally sponsored, funded, and reviewed, as well as for those which fall under the jurisdiction of other Massachusetts authorities. Projects with local jurisdiction and local funding sources are not required to go though this review process unless the project is located on the National Highway or Federal-Aid Systems. Proponents designing projects on local roads, however, may benefit from the project development steps outlined in this chapter and the design guidance found in subsequent chapters.

Project Development Process Overview

The project development process is initiated in response to an identified need in the transportation system. It covers a range of activities extending from identification of a project need to a finished set of contract plans, and to construction.

The identified transportation need might include one or more of the following: a congestion problem, a safety concern, facility condition deterioration, a need for better multi-modal accommodation, an environmental enhancement, or an economic improvement opportunity. The development of solutions to address these needs often involves input from transportation planners, community leaders, citizens, environmental specialists, landscape architects, natural resource agencies, local public works officials, permitting agencies, design engineers, financial managers, and agency executives. Solutions might target a single mode of transportation, or address the range of road users including pedestrians, bicyclists, transit operators, automobile drivers, and truckers moving freight and goods. It is important to engage the right team of people on the project from the beginning.

The sequence of decisions made through the project development process progressively narrows the project focus and, ultimately, leads to a project that addresses the identified needs. There should be ample opportunities for public participation throughout the process.

Transportation decision-making is complex and can be influenced by legislative mandates, environmental regulations, financial limitations, agency programmatic commitments, and partnering opportunities. Decision-makers and reviewing agencies, when consulted early and often throughout the project development process, can ensure that all participants understand the potential impact these factors can have on project implementation. An eight-step project development process is defined to move a project from problem identification to completion, as illustrated in Exhibit 2-1.

Exhibit 2-1
Overview of Project Development

PROCESS	OUTCOMES
STEP I Problem/Need/Opportunity Identification	1. Project Need Form (PNF)
STEP II Planning	2. Project Planning Report (If necessary)
STEP III Project Initiation	3. Project Initiation Form (PIF) 3. Identification of Appropriate Funding 3. Definition of Appropriate Next Steps 3. Project Review Committee Action
STEP IV Environmental/Design/ROW Process	4. Plans, Specs and Estimates (PS&E) 4. Environmental Studies and Permits 4. Right-of-Way Plans 4. Permits
STEP V Programming	5. Regional and State TIP 5. Programming of Funds
STEP VI Procurement	6. Construction Bids and Contractor Selection
STEP VII Construction	7. Built Project
STEP VIII Project Assessment	

Source: MassHighway

These eight steps are described in detail in the subsequent sections of this chapter.

2.1 Step I: Problem/Need/Opportunity Identification

Projects begin with the identification of a problem, need, or opportunity. This can result from a regularly maintained asset or performance management system, such as MassHighway's bridge management system, the top 1,000 intersections safety list, or a recent corridor or area planning process. Problem, need or opportunity identification can also occur through the regional planning initiatives of a Metropolitan Planning Organization or arise from community, legislative, or citizen input. Communities and state transportation agencies are responsible for providing a wide range of transportation services. A number of on-going system management and planning processes are often where projects begin. These include:

- Long-Range Transportation Plans
- Statewide, Regional, and Metropolitan Area Plans
- Corridor Studies and Plans
- Asset Management Systems
  - Bridge
  - Pavement
- Performance Management Systems
  - Congestion Management
  - Safety Management
- Operational Plans and Initiatives
- Road Safety Audits
- Local/Community Plans
- Americans with Disabilities Act (ADA) Program Access. (These improvements must be incorporated in all transportation improvement projects or may be proposed as separate barrier removal projects.)

Road safety audits, noted above, are a relatively new activity in the United States with more emphasis on crash prevention—designing safer new roads and modifying existing roads before crash statistics reveal a problem. Road safety audits foster safer road projects by promoting elimination or mitigation of safety hazards (such as dangerous intersection layouts) and encouraging incorporation of crash-reducing features (such as traffic control devices, delineation, etc.) during the planning and design stages of project development.

2.1.1 Problem/Need/Opportunity Definition

As problems, needs, or opportunities for improvements arise they can be simple and straightforward, or complex in nature without an obvious solution at the start.

Most issues are addressed through the development of a discrete project, specifically tailored to solve the identified need or problem. These projects could include, as examples: geometric improvements at an intersection, or increased parking and improved bicycle and pedestrian access at a transit station where parking demand clearly exceeds supply, or traffic control enhancements. These types of projects often proceed relatively quickly from issue identification into actual design.

Other more significant needs require a robust multi-modal planning effort to identify possible solutions and analyze various alternatives. For example, with a corridor whose roadway network is overly congested, or whose transit service is overcrowded, there may be a need for a corridor- or location-specific planning study. These studies may require an extensive public participation process to identify the problems and examine a wide range of possible solutions through an alternatives analysis.

As a first step in the project development process, the proponent would lead an effort to:

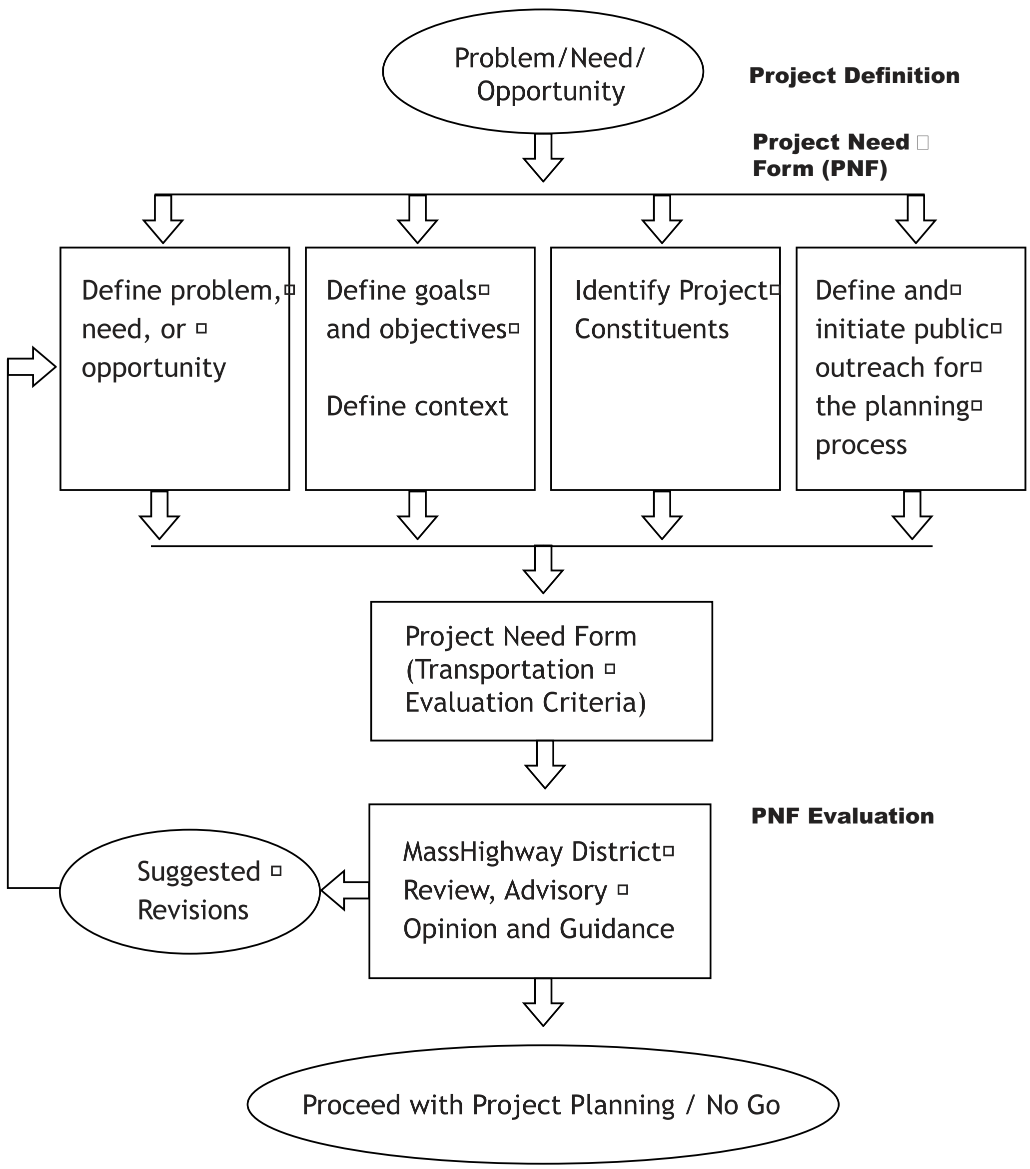
- Define the problem, need, or opportunity based on objective criteria;
- Establish preliminary project goals and objectives; and,
- Define the scope of planning and public outreach needed.

2.1.2 Project Need Form

This step in the project development process leads to completion of a **Project Need Form** (PNF). The problem/need/opportunity identification and PNF process is illustrated in Exhibit 2-2. The PNF provides sufficient material to understand the transportation need(s), and results in one of the following three outcomes:

- Verification of the problem, need, or opportunity to enable it to move forward into design;
- Determination of the level of further project planning warranted; or,
- Dismissal of a project from further consideration.

Exhibit 2-2
Step I: Problem/Need/Opportunity Identification



Source: MassHighway

A copy of the Project Need Form is provided in Appendix 2-A-1 of this chapter. Electronic versions of this form and instructions for completion can be found on MassHighway's website (www.mass.gov/mhd).

At the beginning of this process, the proponent should meet with potential participants, such as MassHighway District staff, the MPO, regional planning agencies, environmental agencies, local boards and officials, and community members. This proactive, informal review and consultation can help ensure the project will develop with fewer problems in future phases.

The Project Need Form is important to define the condition, deficiency, or situation that indicates the need for action — the ***project need***. The statement should be supported by facts, statistics, or even by plans or photographs to the extent that information is available.

The project need is not a project description (such as "replace a bridge" or "reconstruct a road"). That approach "decides" the project outcome too early in the process. A goal of the PNF is to state, in general terms, the deficiencies or needs related to the transportation facility (such as "the bridge is structurally deficient" or "the pavement is in poor condition"). The Project Need Form should document the problems and explain why corrective action is needed. An example of a need could be:

> *The intersection is hazardous. The high-crash rate at the intersection illustrates this problem.*

Other examples might be:

> *There is significant congestion at the intersection. During peak periods, traffic from the side street has difficulty exiting onto the main street and long queues develop.*

Or:

> *There is no formal accommodation for bicycles or pedestrians between the elementary school and the large residential neighborhood to the north where a significant portion of the student body live.*

The purpose of a project is driven by these needs. As examples, the purpose might be to improve safety, to enhance mobility, to enhance commercial development, to improve structural capacity, to enhance pedestrian and bicycle movement, etc., or some combination of these.

2.1.3 Transportation Evaluation Criteria

The MPOs and MassHighway use transportation evaluation criteria (TEC) to assess whether proposed transportation projects should be supported with state or federal funding. The criteria are organized by two basic project purposes: preserving the current transportation system; and improving or expanding the transportation system. A discussion of these criteria are provided as Appendix 2-A-2 to this chapter. These are useful in the preparation of a Project Need Form and should be submitted as an attachment, if available.

2.1.4 Identify Project Constituents and Public Outreach Plan

When defining the project need, the proponent should also think about public support of the project. To achieve this, the Project Need Form should:

- Identify interested parties;
- Document public outreach and feedback to date (if any); and
- Outline a public participation process for moving forward.

More information on the types of project constituents and elements of an outreach plan are found in Section 2.9.

2.1.5 Project Planning Scope

With the preliminary elements of a project defined (need, goals and objectives, project constituents, etc.) in the Project Need Form, the planning scope necessary to move the project forward requires definition.

The proponent may need to conduct planning activities appropriate to the extent and complexity of the type of project under consideration to ensure that all project benefits, impacts, and costs are objectively estimated:

- For a straightforward project (examples might include a sidewalk project, roadway resurfacing, or a traffic signal equipment upgrade), the proponent can seek approval to advance the project to design from the ***Project Need Form***. In this case, the proponent defines the actions proposed to address the project need(s), describes the alternatives considered (if necessary), and documents any anticipated impacts as part of the Project Need Form. (This may also be the best approach where detailed planning for the project has already occurred and is documented).
- For more complex projects (as examples, if there are several alternatives to consider, if there are contextual constraints which add complexity to the solution, or if there is keen public interest), the project proponent should define the range of actions to be

considered and suggest a planning scope for a ***Project Planning Report***. Guidance on the scope of this effort is provided in the next section of this chapter.

2.1.6 Project Need Form Review

Once the Project Need Form is prepared, it is submitted to the MassHighway District Office and Metropolitan Planning Organization staff for initial review. MassHighway typically develops a multi-disciplinary team to review project requests.

The intent of the Project Need Form review process is to allow the proponent to propose a project at its most basic level to the MassHighway District Office and MPO staff. Through this process, MassHighway and MPO staff can provide guidance for project scoping and planning considerations, in addition to suggestions for likely steps needed for project approvals. This guidance can be very valuable, especially if given before the proponent invests significant time and resources in the project design. The MassHighway and MPO staff suggestions at this stage can go a long way in ensuring the project's success.

Through this review, the proponent may be asked to answer questions that arise from the PNF review, to provide further documentation on the alternatives considered, and/or to complete (additional) public outreach.

After the Project Need Form has been reviewed and evaluated by the MassHighway District Office, a project requiring further planning would move into Planning (Step II). Some projects that are straightforward, or are supported by prior planning studies, are expected to move directly to Project Initiation (Step III).

Massachusetts Highway Department – District ___
Project Need Form (PNF)

This form is intended to provide preliminary information about the proposed project. It is not expected that all information that is asked for is available or known but applicants are encouraged to complete the form as fully as possible.

From: ______________________________ **Title**:________________________________

Municipality/Organization: ____________________________________

Phone: _______________________ **Fax:** ________________________________

Date: ________________________ **Email:**________________________________

Project Reference No. (to be filled out by MassHighway): ________________

PART I – LOCATION IDENTIFICATION AND DESCRIPTION OF NEED

Municipality: ____

Route and/or Street(s): ____

Bridge ID Number (if applicable): ____

Who owns the roadway/facility? ____

Estimated project limits by mile marker and station from MassHighway's roadway database or other distinguishing landmarks such as cross street(s). Include a locus map of the project and photos illustrating project need:

Start: ____

End:____

Total Mileage:____

Please provide a brief description of the project need:

____

____

____

Estimated Construction Cost: ____________________________

Does the project have Federal Funding? ❑**Yes** ❑**No**

-- A copy of the PNF should be sent to local MPO staff --

If yes, legislation:______________________________ **Amount: $**________________

Is the project authorized in a state transportation bond bill? ❑**Yes** ❑**No**

If yes, bill:____________________________________ **Amount: $**________________

PART II – PROJECT BACKGROUND

In what type of area is the project located? *Project limits may include more than one type of area. For a definition of areas, please refer to Chapter 3 of the Guidebook.*

- ❑ Rural Natural
- ❑ Rural Village
- ❑ Rural Developed
- ❑ Suburban Low Density
- ❑ Suburban High Density
- ❑ Suburban Village/Town Center
- ❑ Urban Residential or CBD

How does the roadway/facility function in the community?

- ❑ High-speed, primary corridor with limited access
- ❑ Moderate speed, major corridor between towns/regions
- ❑ Low to moderate speed corridor between towns/regions
- ❑ Moderate speed, major street connecting residential areas to a town center or major connector
- ❑ Low to moderate speed street connecting residential areas with other streets
- ❑ Primarily or exclusively a residential street

What is the federal functional classification of the road?

- ❑ Interstate
- ❑ Urban Principal Arterial
- ❑ Urban Minor Arterial
- ❑ Urban Collector
- ❑ Rural Principal Arterial
- ❑ Rural Minor Arterial
- ❑ Rural Major Collector
- ❑ Rural Minor Collector

Is the proposed project on the National Highway System? ❑ Yes ❑ No

Does the project have any Intelligent Transportation System Components?
❑ **Yes** ❑ **No** **If yes, describe**:____

Is the project a footprint road project? ❑ **Yes** ❑ **No**

Is the project a footprint bridge project? ❑ **Yes** ❑ **No**

Provide whatever information is available to characterize the current, general use of the facility (attach traffic counts).

CHARACTERISTIC	**USE/DATA**	**DATA SOURCE**	**NOT AVAILABLE/ Comments**
Number of Lanes			
Lane Width			
Shoulder Width			
Sidewalk Availability/Width			
Bicycle Facility Availability/Width			
Existing Right of Way			
Current Average Annual Daily Traffic (AADT)			
Current Peak Hour Vehicular Volume			
Current Peak Hour Bicycle Traffic			
Current Peak Hour Pedestrian Traffic			
Percent Truck Traffic			
Current Transit Operations/Facilities			
Traffic Control (signal, flash, signs, etc.)			
Roadway Lighting			
Pavement Condition an d Markings			
Posted Speed Limit			
85^{th} Percentile Speed			

PART III – TRANSPORTATION NEEDS ASSESSMENT

Choose a project type – Roadway, Sidewalk or Multiuse Path; Bridge or Other. Answer the questions that apply to the proposed project. Depending on the nature of the project, not all questions need to be answered. For all projects, answer **For All Projects.**

Roadway, Sidewalk, Multiuse Path

- ❑ **Preventive Maintenance**
- ❑ **Rehabilitation/Resurfacing**
- ❑ **Reconstruction**
- ❑ **Widening**
- ❑ **New Facility**
- ❑ **Intersection, Roundabout or Traffic Signal Improvements**
- ❑ **New Interchange or Interchange Reconfiguration**
- ❑ **Safety**

What is the condition of the facility, e.g. extent of cracking, deterioration, rideabiltiy/walkability, surface condition, structural adequacy, etc.? Include a pavement management system (PMS) condition rating from a MassHighway approved PMS, as appropriate, and attach photo documentation with this submittal showing typical facility surface or site conditions.

____

____

What year was the last repair made to the facility (at minimum a preventative maintenance treatment)?

____

What repair was made to the facility? (Use repair typed above and describe)

____

What is the crash history or other safety concerns of the facility? (For safety projects, consult MassHighway's Traffic Division for more detailed analysis requirements).

____

____

Are there mobility issues for motorists, bicyclists or pedestrians? (As an alternate to this question, attach Transportation Evaluation Criteria Form.)

____

____

Are there congestion issues? Provide level of service analysis results if necessary. (As an alternate to this question, attach Transportation Evaluation Criteria Form.)

____

____

What other conditions exist that warrant this project? (As an alternate to this question, attach Transportation Evaluation Criteria Form.)

____

Evaluate the impact of the project on the following resources/environmental conditions. If major impact", " minor impact", or "will improve" are selected, describe below. (As an alternate to this question, attach Transportation Evaluation Criteria Form.)

RESOURCE/ CONDITION	MAJOR IMPACT	MINOR IMPACT	NO IMPACT	WILL IMPROVE	UNKNOWN
Cultural Resources					
Wetlands					
Hazardous Materials					
Air Quality					
Noise					
Other					

Bridge

- ❑ **Maintenance**
- ❑ **Rehabilitation**
- ❑ **Replacement**
- ❑ **New or Widening**

What is the bridge rating and date of inspection?

- ❑ **Structurally Deficient?**
- ❑ **Functionally Obsolete?**
- ❑ **Posted?**
- ❑ **Unknown?**

What is the condition of the bridge elements?

What is the condition of other infrastructure elements?

What is the schedule of preventative maintenance?

____

____

If a new bridge or a bridge that does not meet current eligibility requirements, describe why the project is proposed.

____

____

<u>Other</u>

- ❑ **New or Expanded TDM/Park and Ride Lot**
- ❑ **New or Expanded Traffic Management System**
- ❑ **Traffic Calming, Streetscape, Lighting, or Transit Improvements**
- ❑ **Intelligent Transportation Systems**
- ❑ **Other**

Describe the conditions that warrant the project.

____

____

<u>For All Projects</u>

Describe Right of Way Issues

- ❑ **Probably adequate**
- ❑ **Probably will require takings**
- ❑ **Probably will require easements and/or rights of entry**
- ❑ **Unknown**

Describe known project area concerns or constraints.

____

____

Describe the project's effect on multimodal accommodation.

____

____

PART IV – PUBLIC PROCESS

Please describe the public process associated with the project to date.

- ❑ **None to Date**

____

____

What is the expected level of community interest in the project?

❑ **High** ❑ **Medium** ❑ **Low** ❑ **Unknown**

Describe issues of concern raised by the public during the public process to date.

____

____

____