Re-Design of the Intersections of Burncoat and East Mountain Streets and West Boylston and West Mountain Streets

Final Report

A Major Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science.

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Abstract

This project studied the junctions of West Boylston, Mountain, and Burncoat Streets, observing traffic trends, collision histories, and signal timings. The information collected through field testing and observations was then organized and analyzed using procedures outlined in the MUTCD and software to analyze the existing conditions. The analysis led to the development of possible design alternatives, which were evaluated in order to determine which would be recommended. This set of recommendations has been sent to the Worcester DPW and intends to improve the overall safety and flow of the intersection.

Acknowledgements

This project could not have been done without the help of a few people. James Kempton from the Worcester Department of Public Works assisted the group extensively over the course of the project, at first providing guidance and some important reference materials. He then helped with a portion of the data collection procedure, providing access to DPW resources, and was often there to help with any additional clarification. Don Pellegrino, Lab Manager of the WPI Civil Engineering department, gave a significant portion of his time and expertise to the project in providing access to important testing equipment and software, and additionally by helping the team to physically set up equipment in the field on various occasions. Christine Conron of the Civil Engineering department also provided guidance in the team's usage of software applications for the purpose of analysis. Finally, Professor Malcolm Ray provided advising duties for the team, making sure the project was on going in the right direction and providing feedback on periodical project submittals. With the help of these individuals, it was possible for this project to go be a success

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Chapter 1: Introduction

The Traffic Engineering Division of the Worcester Department of Public Works (DPW) has called on WPI students to conduct a study on the possible redesign of the intersections of West Boylston, Burncoat, and Mountain Streets in the northern region of Worcester (Figure 1). These streets meet in multiple intersections:

- West Boylston and West Mountain
- Burncoat and East Mountain
- Triangle and East Mountain (un-signalized)

Figure 1: The Intersection (courtesy of Google Maps)

The DPW has received complaints concerning the traffic flow patterns in the intersection of West Boylston Street and West Mountain Street. (Complaint Letter, May 10, 2008) This complaint is part of why a re-design of this particular intersection needs to be explored. The other major intersection, Burncoat Street and East Mountain Street, is complicated and also has caused problems with the traffic flow through West Boylston Street along West Mountain Street. Triangle Street is another element in this site. More specific information about these intersections can be found in the Literature Review chapter.

The purpose of this project is the evaluation, analysis, and re-design of the intersections of Burncoat and East Mountain as well as West Mountain and West Boylston. The DPW would like to improve the flow of traffic through these intersections as well as their interaction with each other. The solutions could be as simple as changing the traffic signal timing, or maybe as complex as re-designing the geometry of the entire intersection. One of the current problems with the intersection of West Boylston and West Mountain is the traffic backup on surrounding roads during peak hours. The increased queue lengths at these high-traffic times decrease the level of service in the intersection. Also, Mountain St. eastbound has two lanes that merge within ten feet past the West Boylston intersection. At the intersection of East Mountain and Burncoat, East Mountain unofficially splits from one sixteen foot wide lane to two eight foot wide lanes during peak hours. Another unusual characteristic of Burncoat St. is that it was to be a two-way street in the 1996 design. This lasted for approximately one week before it was changed to the current one way setup. More discussion of this can be found in the Literature Review chapter of this proposal. The objective of this study is to analyze and re-design the intersection to increase its safety and efficiency. (J. Kempton, personal communication, August 27 2008)

The Traffic Engineering Division of Public Works would like to find solutions to all of the flow and safety problems experienced at these intersections. If the city is able to control these issues, the traffic would flow through these intersections with relative ease. To accomplish the project objective, traffic data must be collected, the data must be analyzed, a new design formulated, and a cost-benefit analysis for each of the recommendations will be performed. This analysis will show which of the recommendations are the most realistic and the most cost-effective with the materials and tools that are at the city's disposal.

This study will also be looking at how each of our recommended solutions will affect the community. For example, the drivers in the surrounding area would be affected by a reconstruction of the intersection because detours during the construction will make their commute longer. Businesses might also be affected. If detours cut off the traffic flow to their businesses, they could lose money due to a decrease in drive-by business.

The goal of the following chapters will be to understand all of the intersections' deficiencies that are greater issues now than in previous years. This will include both of the intersections for the best results. The next chapter will be discussing the history of the intersections in question as well as the sources that have been and will be used for this project.

Chapter 2: Background

In order to gain perspective into the intersection being studied, it is important to examine background texts and refer to materials that outline industry standards relating to intersection design. This Chapter reviews past studies and reports about the intersections, focusing primarily on the projected effects that businesses introduced in the mid 1990s had on the traffic volumes of the intersections, and what had been done about it in the past. It also provides this context by describing the existing conditions of the intersection and detailing the necessary guidebooks that will be used to assure the proposed design of this intersection meets industry standards. Overall, the chapter is divided into:

- Existing Conditions
- History of the Intersection
- Intersection Design Procedure
- Sources Used

2.1 Existing Conditions

The region of West Boylston St., Mountain St., and Burncoat St. in northern Worcester is being examined in this project. It consists of two major intersections and one minor one. The basic existing conditions of the intersection are described below.

West Boylston and West Mountain

This is a four way signalized intersection and West Boylston is the major street for signal purposes. (Figure 2 and Figure 3) The West Mountain Street westbound approach has two lanes, a shared left and through lane and a shared through and right lane. West Mountain St. from the other direction is similar except there is an island separating the right turning lane from the others just before the intersection. West Boylston St. is the same in both directions. It has a separate left turning lane and two through lanes, with one of them shared right. (Vanasse Hangen Brustlin, Inc., 1996)

Figure 2: West Boylston and West Mountain Streets facing eastward

Figure 3: West Boylston St. and West Mountain St. facing south

Burncoat and East Mountain East

This is a four way intersection with two stacked lanes of one-way northbound traffic on the southern approach of Burncoat Street. Southbound traffic approaching the intersection on Burncoat St. must turn right on East Mountain and make a quick left to Triangle Street before merging back with Burncoat St Along the north side of East Mountain St. is a residential zone and a small strip mall. Between the strip mall and East Mountain St. is a lane (see Figure 4) used for bus staging. (Vanasse Hangen Brustlin, Inc., 1996)

Figure 4: Bus Staging Lane off East Mountain St.

Triangle and East Mountain Streets

This is a minor un-signalized intersection that carries all traffic intending to travel on Burncoat St. southbound past East Mountain St. It is one way southbound and has a single lane. Triangle St. can be seen in the middle of Figure 5 to the right.

Figure 5: East Mountain St and Triangle St. on the Right

2.2 History of the Intersection

The region of West Boylston St., Mountain St., and Burncoat St. in northern Worcester has changed over the years, and this section discusses important actions that have taken place in these intersections. According to James Kempton of the Worcester DPW, this intersection was re-designed in 1984 and has retained the same geometry ever since.

2.2.1 VHB Functional Design Report

In 1992, a Super Stop & Shop supermarket business proposed to move into the area, and this meant the intersections would be receiving increased usage. It also meant that a new access driveway needed to be installed off West Boylston Street north of the intersection with West Mountain Street. Before this could take place, a study needed to be done of the surrounding intersections. A study called Traffic Impact and Access Study was conducted by Vanasse Hangen Brustlin, Inc. for Super Stop & Shop in order to determine if signalization would be necessary. (Vanasse Hangen Brustlin, 1992) The focus of this study was on the potential traffic impact the Super Stop & Shop driveway would have on the intersection, as well as the access requirements. The study produced recommendations outlining specific site access requirements and brought attention to existing roadway deficiencies. The result of this traffic impact and access study was a roadway with adequate capacity for site-generated traffic and for future growth. The study was completed in May of 1996, and then updated in August of 1996. (Functional Design Report Oct 1996)

The 1996 design report focused mainly on designing the intersection of West Mountain and West Boylston streets, including a re-design of the alignment, reconstruction of the pavement, and improving signal timing. While the design focus was mainly on that intersection, the intersection of East Mountain and Burncoat Streets was also studied. The 1996 report analyzed existing, projected, and proposed traffic and geometry situations. The studies in geometry included physical design and traffic signals, while the traffic analysis included turning movement counts (TMCs) done at peak hours on weekday mornings, weekday evenings, and Saturday at midday. During these times, TMCs and Automatic Traffic Recorder (ATR) counts were completed to determine volumes for the signal timing plan. The 1996 report projected traffic volumes by assuming a one percent annual growth rate. This is a major reason why we plan to update the figures with current traffic volume counts. It seems that no counts have been done since the 1996 report so verifying the growth assumptions will be one aspect of this project. (J. Kempton, personal communication, August 27 2008)

The 1996 report found that both of the intersections on Mountain Street, with Burncoat Street and with West Boylston Street, were performing at a very low level of service rating during peak traffic volume hours. Between 1990 and 1992, the intersection with Burncoat averaged two accidents per year while the intersection with West Boylston averaged almost ten. In order to improve the intersections, it was recommended to allow two-way traffic on Burncoat St. and to create a standard, four-way, signalized intersection that is coordinated with the West Boylston St. signal, install a fully actuated, eight-phase traffic signal at the Burncoat St. intersection, allow two-way traffic on Triangle St. at the intersection with East Mountain St., and to upgrade the pavement markings and signage in both intersections. (VHB Oct. 1996)

2.2.2 Traffic Study of West Mountain Street

Another report that gives insight into the past traffic patterns of the region is a traffic study of West Mountain Street from November of 1996. (Petruzzi, 1996) This report studied the Mountain Street corridor which runs from the Holden town line west of Interstate 190 through to West Boylston Street. It briefly described the existing conditions and a projection of traffic after the opening of a large movie theater owned by National Amusements, a Shaw's supermarket, and the Stop & Shop discussed in the previous section of this chapter. Following these descriptions is a detailed report of projected level of service grades post construction and also projected trip distributions to certain businesses, basically an analysis of the traffic flow. An interesting fact to note about this report is that it did not include 24 hour traffic counts. National Amusements funded a number of improvements in the surrounding area upon its arrival. In relation to the scope of this project, the cinema updated the intersection of West Mountain St. and West Boylston by installing a new traffic signal controller and new signal timing and sequencing for the left turn movements off West Boylston Street in both directions. Super Stop & Shop also contributed to the improvement of this intersection. It financed and implemented the addition of a traffic signal at East Mountain and Burncoat that was to be synchronized with West Mountain and West Boylston. It also called for two way traffic and geometry improvements on Burncoat St. (Petruzzi, 1996)

2.2.3 Leading Left Turns

In 1997 the city of Worcester took action at the West Boylston and West Mountain St. intersection regarding the left turn situations from West Mountain St. It introduced a leading left turn for eastbound traffic from 6:30 AM to 9:30 AM, and for westbound traffic from 3:30 PM to 6:30 PM. This was implemented on July 23, 1997 and was part of the Stop & Shop plan. (Letter, Hoover, Thomas A., 1997) This leading left turn situation was criticized this year by an unhappy commuter in an email to the DPW from a citizen. (Letter May 10, 2008) This citizen travels west from East Mountain to West Boylston to travel towards Worcester. He noted the difficulties facing a commuter who does not travel through this intersection during commuter hours.

2.3 Intersection Design Procedure

In order to analyze intersections to find out ways to re-design them, certain procedures are followed and carried out. The amount of traffic going through an intersection is the most important aspect of this and is determined through collecting various types of data. These data are then analyzed in certain ways to determine what can be done to ensure clean operation.

2.3.1 Counts

ATR counts are used to find the amount of traffic going through the intersections over the course of an average week. These are done with electronic ATRs. These find information about the roadways such as volume, speed and number of trucks. The ATR counts that were performed for this report dealt with only volume, because the area is very small and is on city streets that have the standard speed limit of 30 miles per hour. The results of these are used towards analyzing different pieces of information including Average Daily Traffic, Average Annual Daily Traffic, accident rates, and peak hours. In a similar fashion to ATR counts, TMCs are done to determine the trends of traffic flow in intersections. These are done according to procedure and are during times of the day when traffic is at its highest, known as peak hours. With the use of ATR and TMC counts, numbers are made available for the purpose of designs.

2.3.2 Queue

In addition to major data collection procedures such as ATRs and TMCs, Other important things must be observed at intersections. A queue analysis is an important aspect of this, and understanding queue theory is most important in this intersection due to the finite queue lengths that exist due to the close proximity of the two intersections. Before queue analysis, specific data about queue is also collected. This includes channelization, saturation levels, arrival distribution, and of course queue length. The further analysis could be done with either a deterministic method or a stochastic method. The deterministic method is used in higher volume intersections, so is most relevant for this report. It determines maximum queue length, time duration of the queue, average queue length, and finally the total delay of the queue. (Garber & Hoel, 2008)

2.3.3 Signal Timing

The signal timing of an intersection is of great importance to an intersection study. This is the amount of time the intersection controller sets aside for each approach at an intersection. Signal timing is divided into phases. A phase is the amount of time given for a certain approach to be given clearance to proceed through the intersection, via a green (and eventually yellow) light. The phasing and timing of an intersection can be determined by visiting the intersection firsthand and measuring time intervals. In the situation of the current intersection, intervals have a minimum and maximum time for each phase, and also operate differently at certain times of day. Also relevant in the intersections studied is actuated signal timing between intersections. West Boylston and West Mountain Streets are in coordination with Burncoat and East Mountain streets, to maximize efficient traffic flow between the two points. The West Boylston Street intersection takes precedence in the coordination over the Burncoat St. intersection.

2.3.4 Level of Service

For proper design, signal timing at an intersection is analyzed to determine what changes can be made to decrease overall delays in the intersection. The way this is done is by performing a level of service analysis on each part of the intersection. This entails entering peak hour values into software to determine what the level of service of the intersection is. This is a letter grade, ranging from "A" (optimum) to" F" (failure to operate). Different types of software are used by professionals, but it seems that the leading types are Synchro® and HCS 2000®.

2.3.5 Crash Data

Another important aspect of designing an intersection is the collection of crash data. This is the basis for safety analyses. Collision diagrams are made with accident reports that show which types of intersection occur, what the problem regions of an intersection are, and the overall frequency of crashes that occur. These are then referred to in an analysis of the data that includes calculations of crash rates and other similar statistics.

2.3.6 Warrant Analysis

One important analysis that is performed on intersections is a warrant analysis, which is basically a checklist of characteristics exhibited at an intersection. There are eight different warrants that may be met to officially "warrant" a signalization there. While there already are signals at the studied intersection, it is still important to do the warrant analysis to determine how many warrants are actually met.

2.4 Sources used

Through the Course of this project, there are a series of important resources that have been referenced. All procedures and designs outlined in this report conform to the standards set by transportation organizations. Regulations set forth by AASHTO publications are referenced, (AASHTO, 2008) in addition to the MUTCD, which describes specific standards of signage and signalization. (MUTCD, 2007) In addition to these references, the textbook used from the course CE 3050 is of use.(Garber & Hoel, 2002)

Also, a series of relevant documents received by the team in an interview with the Worcester DPW's James Kempton are the main basis of information on this particular intersection. These include:

- Two reports done for the Stop & Shop Supermarket Company, (Vanasse Hangen Brustlin 1996 & 1997)
- Traffic study of the West Mountain St. corridor, (Petruzzi, 1996)
- Traffic Control Signal Permits for the two major intersections, (Massachusetts Highway Department, 1997)
- Map of the region detailing land use designations from the City of Worcester GIS Technical Services Division, (Worcester, 2008)
- Complaint letter from a Worcester citizen regarding signal timing and phasing at West Boylston and West Mountain St., (Complaint Letter, May 10, 2008) and
- Map three of five of West Boylston and West Mountain intersection from 1984 re-design. (Worcester, 1984)

Chapter 3: Methodology

The aim of this project is to improve the overall efficiency and safety of the intersections between West Boylston, Mountain, and Burncoat streets by proposing a series of possible new designs. This has been accomplished by completing the following objectives:

- Data Collection
- Data Analysis
- Re-Design
- Final Recommendations

This chapter outlines the tasks that have been completed in order to accomplish these greater objectives.

3.1 Data Collection

The data collection aspect of this project involved the procurement of a series of records and instrumentation from the DPW. These were then utilized during a series of tests conducted by the project team in order to gain insight into the current condition of the intersection. The data collection section is of this report discusses the following tasks:

- Traffic Volume counts
- Turning Movement Counts
- Other Observations

3.1.1 Procuring Records and Equipment

The first step in data collection was to meet with the Traffic Engineering department of the DPW representative, James Kempton. This meeting took place on August 27, and was how the team was introduced to the intersection. The objective of this first meeting was to find out what has been occurring with the intersections of West Boylston, Mountain, and Burncoat streets. Once it was determined what sort of steps would need to be made to complete the project, it was clear what sort of resources were needed. The information and equipment that were needed to complete the tasks included:

- Various reference reports and documentation with background information (see Section 2.3),
- JAMAR® Automatic Traffic Recorders (ATR) and corresponding TraxPro® software,
- JAMAR® Turning Counters and corresponding PETRA® software,
- Accident Reports and Summaries for both intersections and,
- The current timing of the signals for analyzing the intersections.

3.1.2 ATR Data Collection

ATRs were used for volume counts over the course of one week, and certain regions had speed measurements done. The DPW allowed the use of four of their ATRs, in conjunction with both of the WPI owned ATRs. The ATRs were used in conjunction with TraxPro software, which was provided by Don Pellegrino, the manager of the WPI pavement lab. Some of the tubing that was used was owned by the city of Worcester, while a number of tubes were ordered by Mr. Pellegrino on September 19th. The tubes ordered by Mr. Pellegrino were mini-tubing, which are smaller diameter tubes that come in convenient pairs of equal lengths.

Before the ATRs were placed, the team gathered advice from Professor Ray and also Christine Conron of the Civil Engineering department. Professor Ray advised that ATRs should be placed at all six approaches to the intersection system. With this information, the team went to the site and determined the best locations to install the ATRs. This was a precautionary measure to ensure that there were telephone poles, anchored traffic signs or trees available to secure the ATRs in place and what places would generally be best for setting up the ATRs. In a meeting with Ms. Conron, she advised that the ATRs be put in the places Professor Ray recommended, however she recommended placing the ATR for the southern end of Burncoat at the end of the grassy triangle with one tube running in each direction so the losses from Ventura Street would not affect the count. She also recommended placing the ATRs at the north and west of the West Boylston and West Mountain intersection past Malden St. and the Malden St. Connector, respectively. This would include Malden as part of the system, accounting for cars that use it to bypass the intersection.

How to Set up an ATR

In order to set up an ATR, there is some equipment that is necessary. This includes the following:

- ATR,

- Tubing,
- Chains,
- Locks,
- Hammer,
- Nails,
- Pry Bar and
- Mastic.

The ATR is to be placed on the ground and should be turned on. A number of options exist that register values in certain ways. The positioning of the tubing, whether or not speed is to be registered, and many other things are entered into an ATR. The tubing must also be laid out across the street as to form a 90 degree angle with the traffic. Once the tubing is laid out, it must be pulled one foot per ten feet of length to make it taut; however, this is usually estimated. The end of the tube, which has to have a hook on it, is then nailed into the pavement with a hammer. This needs to be done at both ends of the road. Once the tubing is secured, an adhesive tape called Mastic can then be put over the tubing and hammered down creating a bond with the pavement. While Mr. Pelligrino insisted on using this method of security every time, Mr. Kempton never used the mastic. Once the tubing is all secure, the ATR is chained to a pole, tree, or sign and a lock is put through to make sure it is safe. The pry bar is used after the count is done to remove the nails from the pavement.

Setting up the ATRs at West Boylston, Burncoat, and Mountain Streets

The setting up of the six ATRs took place on September 24, 2008 with the help of Mr. Pellegrino and Mr. Kempton. During the set up, it was found that most of the ATRs would not be able to get speed readings due to their positioning, however it was decided that the count was more important than the speed for this particular set of intersections. There was one major problem during the set up, though, with the ATR to be placed at the junction of Burncoat St. and Triangle St. When it was turned on, it would turn off after a few seconds. It was determined that this ATR would need a new battery, so it had to be brought back to the laboratory at WPI. This is why only five ATR counts were done during the first week. Once the new battery arrived, it was already late enough in the week that setting it up on the following Wednesday was the most viable option, since it would give it the most similar results to the first count.

On this second Wednesday, October 1, four of the ATRs were removed and the new ATR at Triangle St. was installed. The ATR on East Mountain St., east of Burncoat St. remained as a reference counter so the counts from the two different weeks could be calibrated. The four ATRs that were removed were returned to Mr. Kempton at the DPW office along with tubes, locks, and chains. At the end of the week, the Triangle Street ATR counts were collected. These counts, however, turned out to be inaccurate because the placement of the tubing was such that a large number of cars approached it at an angle and were counted as two cars although the mis-count was not consistent. This meant a third week of counts was necessary. During the third week (i.e., the week of October 8) the ATR was set up further back, south of Ventura St. and in close proximity to the local school. The ATR counts were finally completed on October 15.

3.1.3 Turning Movement Counts

In addition to volume counts, TMCs were done at each of the two intersections. These were performed with the use of JAMAR® counters provided by the WPI impact lab. They required the use of PETRA® software for uploading the data.

The TMCs for the two intersections were done according to the following typical procedure. Two group members at a time went to the intersection with hand-held counters and counted every single car that went through the intersection and the turning movement they executed while going through the intersections. The TMCs were done during peak hours, 7:00 AM to 9:00 AM in the morning; and 4:00 PM to 6:00 PM in the afternoon.

The first set of TMCs focused on the intersection of West Boylston and Mountain Streets. Afternoon counts were performed on Wednesday September 24 and morning counts the following Thursday morning. Counts the following week focused on Burncoat St., Mountain St., and Triangle St. The afternoon counts were done on Tuesday, September 30, and the morning counts on Wednesday October 1st. These were more challenging because they were done as if Triangle St. southbound was part of Burncoat Street. For example, cars traveling south on Burncoat that approached East Mountain St., turned right, and then made subsequent left turns onto Triangle St., were entered into the counter as going straight through on Burncoat. This made for a more challenging count because two separate regions had to be watched by the team members but, it was a much more accurate and efficient method than only counting what happened at the Burncoat intersection, disregarding what happened at Triangle, and then doing separate counts on another day of just the Triangle Street intersection. Once the counts were completed, the data was uploaded onto the team members' computers and viewed using PETRA® software.

3.1.4 Signal Timing

To collect the signal timings, the site was visited and notes were taken on the amount of time it took to for a green light to turn auburn, then to red for each movement. If there were automations made for specific times, the site was visited during those times to discover the correct automated timings. By completing this, correct signal timings have been obtained and the team is no longer relying on the timings that were provided (i.e., the planned DPW timings). If the incorrect signal timings were used in the analysis there could possibly be an attempt to correct a problem that is not there anymore.

3.1.5 Queue Lengths

For the queue lengths the pertinent information for the project involved whether the length of the queue on West Mountain at West Boylston extended into the intersection of Burncoat and East Mountain. The length of the queue is an indicator of how much trouble the intersection is having with the amount of flow. The right turns on red were also taken down in an attempt to see how many cars did not use the signals.

3.1.6 Accident Reports

The team went to the DPW to collect accident reports related to the intersections being studied. After the reports were collected, copies were made and then sorted into piles for the three intersections: West Boylston, Triangle, and Burncoat. These reports were then skimmed through for information to put on the collision diagrams, which will be discussed in the findings chapter. For the remaining accident reports that could not be found at the DPW, Mr. Kempton was emailed the list and was asked if he could get in contact with the Police Department to attempt to find the missing reports. These missing reports were provided to the team on January 23, 2009.

3.1.7 Other Observations

During the many visits to the intersection, other observations were made besides basic volume and turning movement information. Some of the other miscellaneous pieces of information collected for the intersections were:

- Traffic speed counts,
- Pedestrian traffic volume,
- The condition of pavement and its markings,
- Aesthetics and
- The geometry of the intersections

These observations were made during various appearances at the intersection and are important in the Analysis and Findings chapters of this report.

3.2 Analysis

Once the data was collected, the following analyses were conducted:

- Compiled all counts and examined for trends and inconsistencies,
- Review accident summaries and reports,
- Perform traffic signal warrant analysis,
- Perform signal timing analysis and
- Perform a level of service analysis.

All of the data from both the ATR counts and the TMCs were compiled and compared to check for any trends and inconsistencies. The signal timing plan was analyzed to determine whether the documentation provided corresponded with field observations that were made. Also, further analysis was done regarding accidents occurring in the intersections to check for correlation with other observed issues.

Both accident reports and summaries were examined, and conclusions have been drawn about which parts of the intersections were more dangerous and which components of the intersection required the most work. Our analysis also involved trying to determine if the collision was caused by a driver, a pedestrian, or problems with the intersection. The next task, a warrant analysis, is a method of determining whether there is a need for a traffic signal. A major factor in this was the intersection's approaching traffic volume. ATR data was referred to while conducting this analysis and compared with the eight warrants detailed in the MUTCD. (MUTCD, 2003)

Another part of the analysis was to address the issue of signal timing and phasing. The current timing was analyzed for its level of service. This involved the use of a software program called Highway Capacity Software (HCS) 2000. The application used was HCS Signals. For this analysis, TMC data was entered into the program along with signal timing data and intersection geometry procured from field observations and documentation provided by the city of Worcester. For the purpose of analyzing the worst case scenario of the intersection, the maximum timings for each phase were used for the LOS analysis to simulate the worst case scenario.

The other major software that was utilized in the analysis of this intersection was HCS Arterials, another application of HCS 2000. This computed the through level of service of Mountain St. between West Boylston and Burncoat streets. This application is use to give a level of service rating for the whole system.

3.3 Design Alternatives

In order to discover alternative designs, the program HCS2000 was used to determine the level of service improvement for different alternatives. Different kinds of changes in the intersections were examined, including:

- Signal Timing,
- Number of lanes and
- Geometry of the intersections.

In this section, each alternative was examined individually according to level of service improvement, side-effects and cost. Other design changes that were examined included:

- Pavement Markings,
- Pavement rehabilitation and
- Intersection alignment.

3.4 Recommendations

In this section of the report, different alternatives are examined in conjunction with one another, and final recommendations are given based on effectiveness and cost.

Chapter 4: Findings

The data that was collected for this report is presented in this chapter. Much of the data was gathered in visits to the intersection while some was provided by the Worcester DPW. The following data are discussed in the following sections in this chapter.

- ATR counts and TMCs,
- Crash data,
- General observations and
- Issues that affect re-design.

4.1 Counts

The most important data collected on-site were the ATR counts and TMCs. This data presents a complete picture of the trends and patterns in the current intersections and are used in the re-design process.

4.1.1 ATRs

The entire set of volume data collected can be found in Appendix A: ATR Data, but it is summarized in this section. This data was collected in hourly intervals. The intersection of West Boylston and West Mountain Street has much more volume over a given time than the intersection of Burncoat and Mountain Street. Table 1 and Table 2: Maximum Hourly Volumes show the average hourly volumes and maximum hourly volumes of each of the ATR site taken over the course of the week.

Table 1: Average Hourly Volumes

Average Volumes Arranged by Hour

Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT			MT East of Burn.			Burn./Triangle		
	EB	WB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	EB	WB	Total	SB	NB	Total
12:00:00 AM	30.6	48.7	79.3	4.29	60.3	64.6	48.4	42.1	90.6	48.4	55.6	104	8.71	5	13.7	31.4	47.1	78.6	25.1	20.7	45.9
1:00:00 AM	16.1	24.3	40.4	1.57	32.6	34.1	29.1	23.1	42.7	25.3	31.9	57.1	6.86	3.86	10.7	19.6	28.3	47.9	12.3	13.7	26
2:00:00 AM	15.3	16	31.3	2.43	27.3	29.7	20.4	14.3	31.4	21.9	21.1	43	6.14	3.57	9.71	13.4	13	26.4	9.57	9.43	19
3:00:00 AM	16.3	14.3	30.6	1	26	27	17.4	18.4	35.9	25	21.4	46.4	10.4	5.43	15.9	16	16	32	7	8.14	15.1
4:00:00 AM	30.3	23.4	53.7	1.71	45.7	47.4	29.7	28.6	49.3	37.3	31.9	69.1	12.9	5.43	18.3	29.9	24.7	54.6	5.43	12.6	18
5:00:00 AM	117	60.1	177	3.43	109	113	68.7	73.3	119	96.3	66.9	163	16.3	13.9	30.1	103	56.1	159	17.1	29.7	46.9
6:00:00 AM	280	154	434	11.9	266	278	153	183	336	258	151	409	33.6	45.1	78.7	282	151	433	74.4	81.3	156
7:00:00 AM	430	308	738	55	562	617	254	364	480	414	251	665	64.3	64.9	129	421	320	741	168	130	298
8:00:00 AM	448	281	729	33	616	649	295	349	522	433	299	731	79.3	77.1	156	447	289	736	150	140	290
9:00:00 AM	367	334	701	65.7	736	802	353	345	698	374	328	702	69.1	74.9	144	364	341	705	155	162	316
10:00:00 AM	378	367	744	108	839	947	421	326	459	380	386	766	76.1	73.8	150	375	355	730	168	185	354
11:00:00 AM	390	458	849	127	937	1065	469	396	701	391	439	830	87.4	81.9	169	407	449	856	190	229	419
12:00:00 PM	463	461	924	201	948	1149	488	411	899	406	448	854	103	91	194	474	492	966	208	226	434
1:00:00 PM	437	487	924	181	941	1123	489	397	547	417	490	907	103	86.7	190	471	482	953	197	225	421
2:00:00 PM	481	543	1024	189	941	1130	477	371	723	398	529	927	120	89.9	210	475	529	1005	214	228	443
3:00:00 PM	431	604	1034	178	967	1146	412	355	767	408	536	944	119	115	234	445	593	1038	243	226	469
4:00:00 PM	420	609	1029	178	981	1159	427	341	466	416	523	940	120	95.6	215	438	610	1048	240	278	518
5:00:00 PM	401	610	1011	189	942	1131	436	342	664	409	501	910	132	91.6	224	425	646	1071	237	264	501
6:00:00 PM	328	441	769	182	767	949	394	335	729	373	430	803	95.1	74.1	169	326	459	785	222	213	434
7:00:00 PM	229	349	578	143	591	735	310	265	394	255	348	603	66.1	64.3	130	245	334	579	158	145	303
8:00:00 PM	171	244	415	89.3	421	510	223	202	340	198	251	448	48.6	37.1	85.7	181	247	428	112	95	207
9:00:00 PM	145	176	321	52.6	315	367	207	172	379	177	218	395	34.7	26.7	61.4	139	173	312	91.4	71	162
10:00:00 PM	108	129	237	28.9	192	221	131	121	183	115	145	260	24.9	19.4	44.3	104	123	227	56.1	53.6	110
11:00:00 PM	56.4	117	174	12.6	124	137	78.3	89	142	77.7	112	190	17.4	10.7	28.1	64	111	175	40.9	34.7	75.6

Table 2: Maximum Hourly Volumes

Maximum Volumes Arranged by Hour

Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT			MT East of Burn.			Burn./Triangle		
	EB	WB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	EB	WB	Total	SB	NB	Total
12:00:00 AM	56	77	133	8	112	120	81	74	155	90	88	178	16	10	21	42	63	105	41	36	77
1:00:00 AM	39	42	81	3	59	60	56	38	75	43	50	93	18	5	23	31	52	80	28	26	49
2:00:00 AM	27	36	63	6	41	44	42	26	56	39	36	71	10	6	15	20	23	41	20	18	36
3:00:00 AM	19	24	37	3	34	34	24	25	43	29	28	55	14	8	22	21	25	37	12	14	26
4:00:00 AM	38	30	65	4	56	59	38	40	70	47	42	85	17	9	24	41	36	71	8	17	25
5:00:00 AM	149	85	234	7	147	154	90	95	185	123	86	205	26	18	43	133	80	213	33	48	79
6:00:00 AM	372	196	568	27	332	354	188	271	448	360	201	538	49	67	107	378	201	554	124	130	254
7:00:00 AM	593	403	996	98	749	806	317	475	792	541	382	880	86	85	169	551	411	962	259	193	425
8:00:00 AM	640	348	962	63	731	762	335	422	736	540	394	895	103	99	196	567	346	913	212	175	371
9:00:00 AM	435	374	802	111	869	980	395	389	784	446	388	805	84	98	182	423	379	787	179	178	349
10:00:00 AM	418	445	821	146	1065	1188	480	392	871	421	431	835	92	93	175	423	441	852	186	229	415
11:00:00 AM	431	515	902	202	1280	1387	508	466	892	460	506	941	110	102	206	479	526	996	252	274	526
12:00:00 PM	522	525	999	329	1182	1351	523	433	944	461	526	945	120	100	212	562	546	1108	229	288	490
1:00:00 PM	491	527	999	352	1113	1239	512	412	921	443	547	988	112	105	211	563	598	1161	237	270	467
2:00:00 PM	533	582	1079	303	1138	1224	528	413	879	433	566	969	131	95	226	545	568	1102	262	251	508
3:00:00 PM	497	672	1169	286	1119	1215	436	402	815	458	592	1034	135	143	266	486	691	1132	301	271	572
4:00:00 PM	470	704	1169	265	1213	1298	474	359	789	471	570	1038	148	105	252	518	704	1217	311	321	625
5:00:00 PM	464	758	1222	252	1243	1360	470	373	834	447	580	1002	174	117	281	503	808	1267	281	335	616
6:00:00 PM	374	516	890	310	1037	1116	432	387	801	402	485	874	114	88	202	369	529	897	252	257	498
7:00:00 PM	266	410	651	279	809	907	363	316	642	290	380	669	87	74	161	334	394	728	201	166	358
8:00:00 PM	199	311	510	147	506	590	285	247	516	225	302	527	71	45	116	208	307	515	131	117	248
9:00:00 PM	167	223	385	77	405	472	270	227	472	252	258	492	38	37	74	180	233	400	120	84	204
10:00:00 PM	142	178	311	38	303	332	172	157	327	157	199	347	30	25	53	155	193	327	74	79	153
11:00:00 PM	83	148	216	21	183	202	114	127	241	125	149	274	26	16	39	88	144	232	60	61	112

From Table 1 and Table 2 above, it can be determined that the heaviest volume area is West Boylston Street over the entire afternoon. Afternoon TMCs are performed 4:00pm to 6:00pm, so it is beneficial to note that these high volumes are not only during those two hours, but for the entire afternoon. This is why the ATR results are so important. In the level of service analysis, for example, even though only one peak hour was analyzed for the intersections, the highest volume during the peak hour is applicable for the entire afternoon, not just the one hour; therefore, these over-capacity volumes are not just a problem for one hour in a day, but for approximately six hours. This emphasizes the importance of the re-design of these intersections.

There were some discrepancies in the data that were noticed during the organization of the ATR data. It should be noted that the count on West Boylston St. north of West Mountain Street was defective. While the northbound volumes are unrealistically greater than the southbound volumes, the total volume would have been realistic. Thus, the directional split was determined to be incorrect. This was attributed to mistakes during the initial programming and installation of the ATR. Also, from comparing this information with the results from the TMCs, it is further demonstrated that the directional split was inaccurate.

4.1.2 Turning Movement Counts

The TMCs are the primary data used in the level of service analyses of these intersections. Including that they are the data used to find the peak hours. The calculations for this can be found in Appendix B: Peak Hour and Peak Hour Factor Calculations. The TMCs show a pattern of morning traffic moving from West to East along Mountain Street in the morning, and from East to West in the evening. This is illustrated in Figure 6, Figure 7, Figure 8, and Figure 9 below.

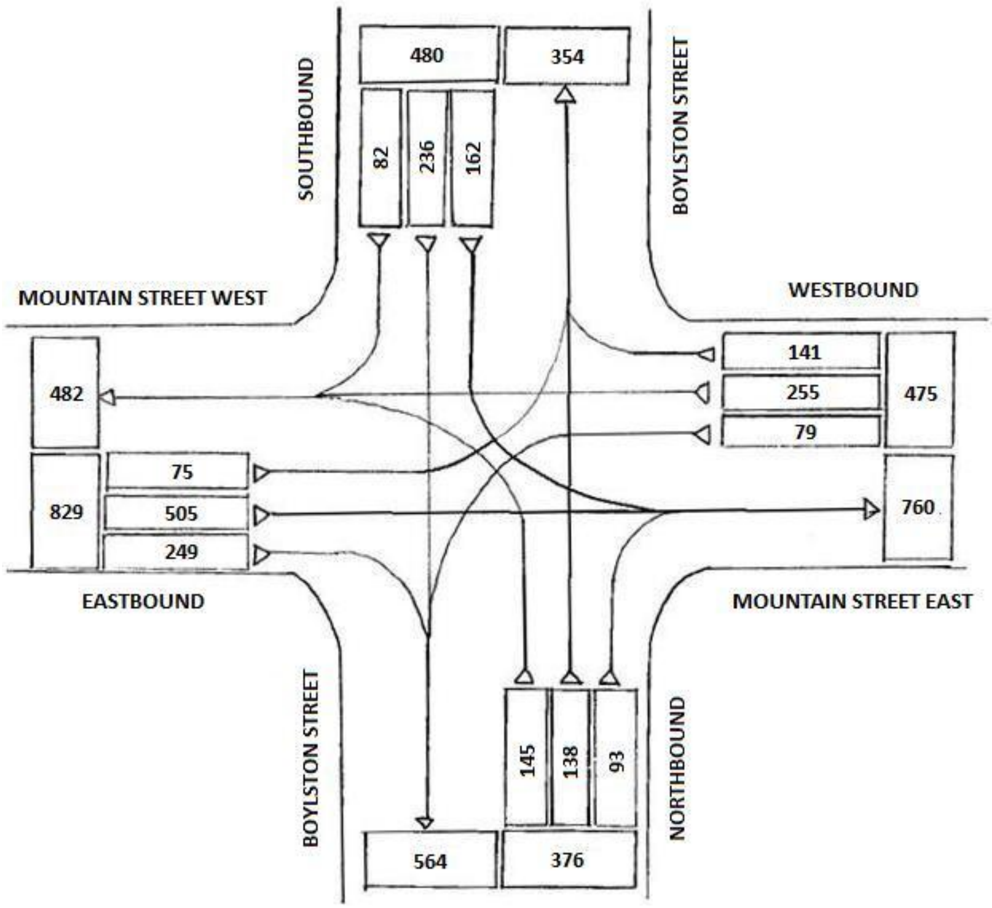


Figure 6: Turning Movement Count at West Boylston and West Mountain, Morning.

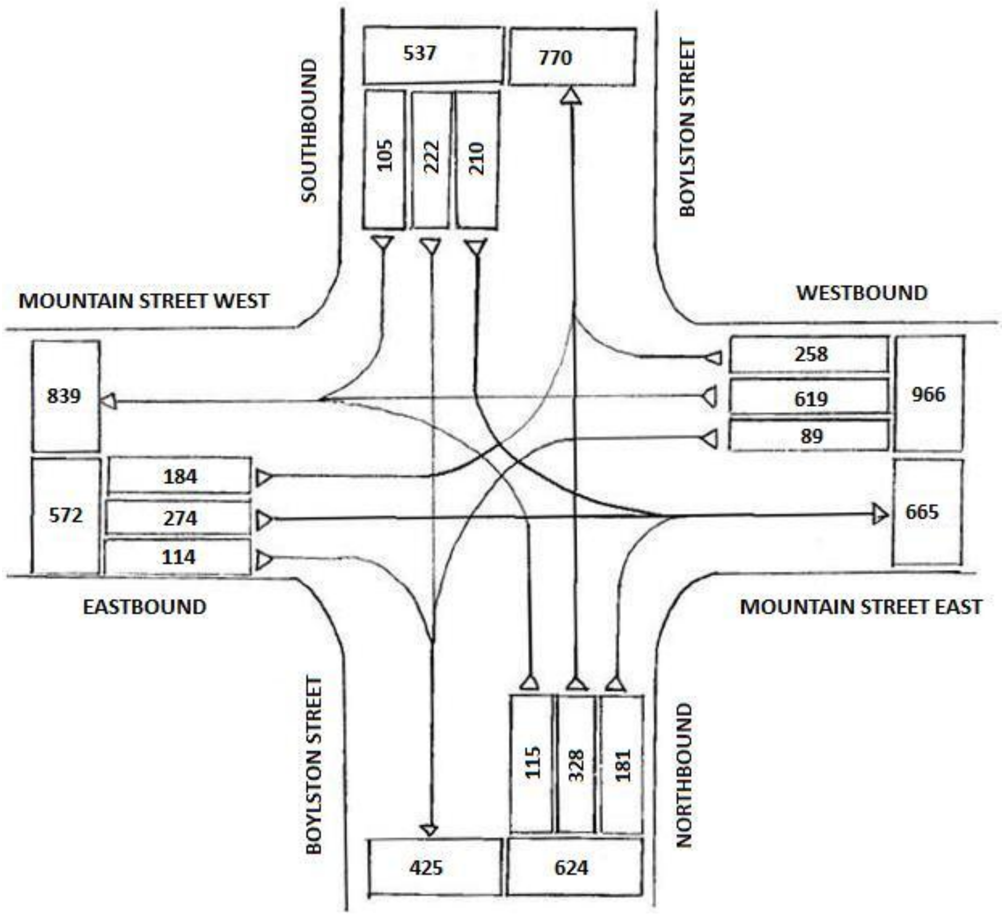


Figure 7: Turning Movement Count at West Boylston and West Mountain, Evening.

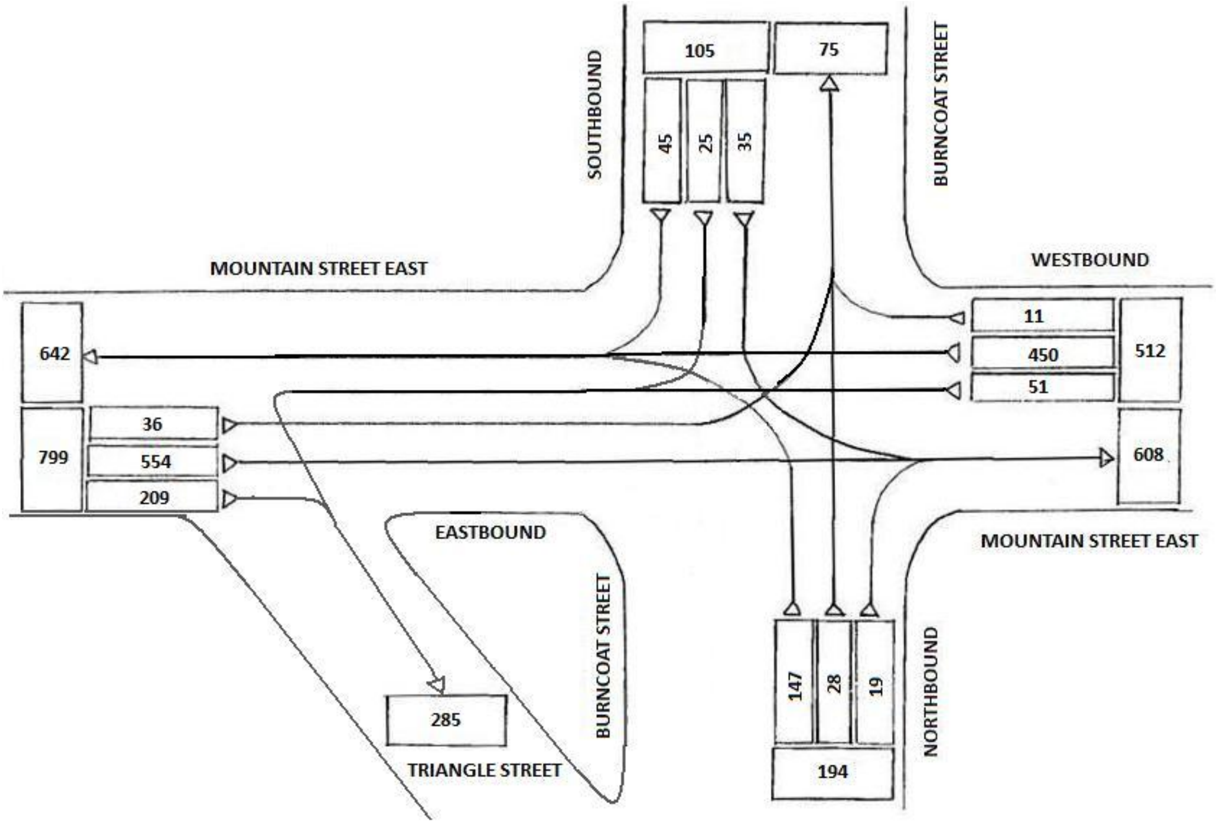


Figure 8: Turning Movement Count at Burncoat and East Mountain, Morning.

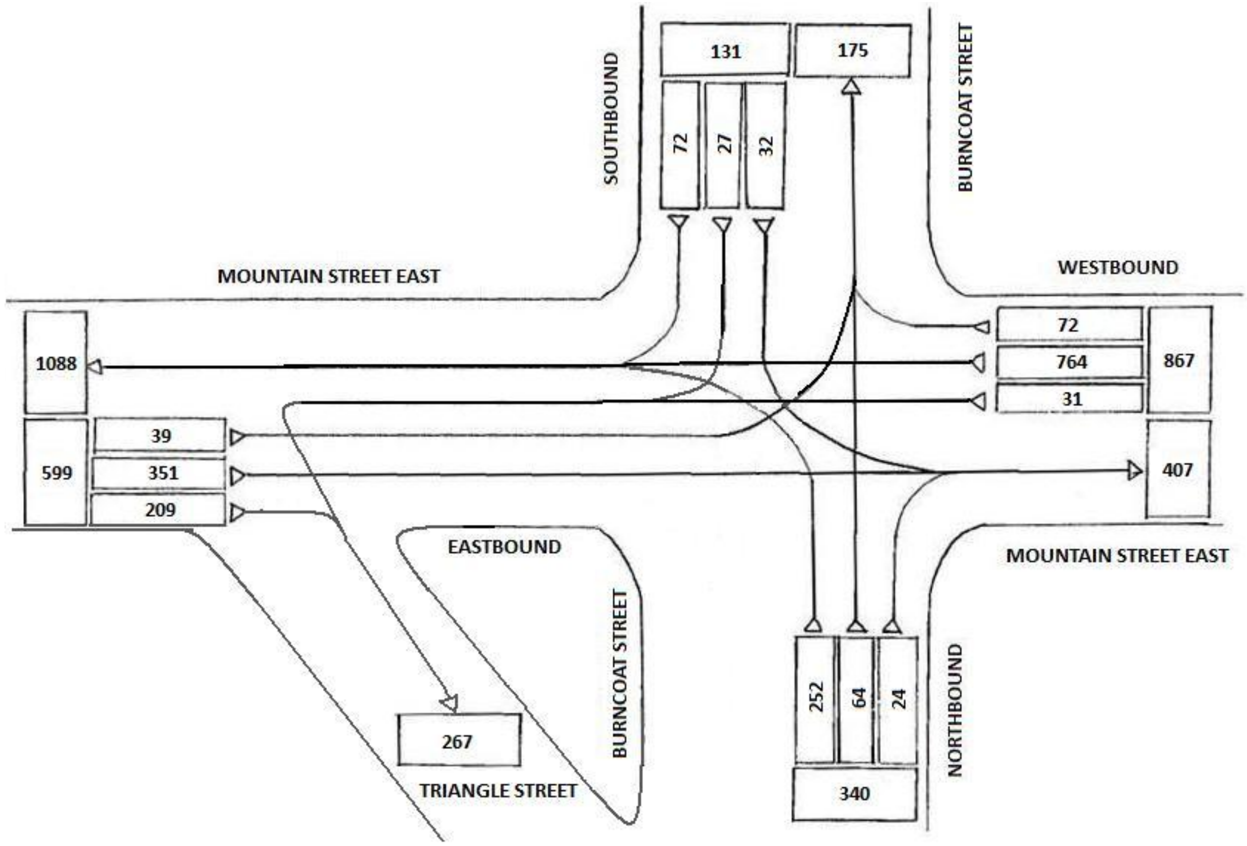


Figure 9: Turning Movement Count at Burncoat and East Mountain, Evening.

As an example of how to read the figures above, in Figure 8, a total of 799 vehicles entered the Burncoat-East Mountain intersection traveling eastbound during the Wednesday morning peak hour. Of them, 36 (4.5 percent) turned left on Burncoat Street, 554 (69.3 percent) went straight through the intersection, and 209 (26.2 percent) turned right onto Triangle Street. Also, 642 vehicles exited the intersection going west towards West Boylston Street. Of the 642 through-vehicles, 45 (7.0 percent) came from Burncoat Street southbound (taking a right turn), 450 (70.1 percent) came from the westbound side of East Mountain Street (going straight through the intersection), and 147 (22.9 percent) came from the northbound side of Burncoat (taking a left turn). All four figures read similarly.

As mentioned before, the ATR count on West Boylston Street, north of West Mountain Street was faulty. This is further demonstrated with the ATR counts shown in Figure 6 and Figure 7. In the afternoon, the ATRs gave a northbound count of approximately 1000 and a southbound count of approximately 200. The TMC, though, gave a northbound count of approximately 700 and a southbound count of approximately 500. For the morning, instead of a northbound count of approximately 750 and a southbound count of less than 100, the TMC gave a northbound count of approximately 350 and a southbound count of 500.

As for general trends shown by these counts, it was noticed that in the morning, the general direction of the traffic flow was entering from all of the roads of the system, and exiting westward via West Mountain Street, towards Interstate 190. In the evening, the exact opposite happens. There is a high flow coming in from the west side of the West Mountain Street/West Boylston intersection, presumably from Interstate 190, and the flow is distributed out through the other five roads connecting in this area.

Another trend was that overall, the peak hour volumes were greater for the evening peak hours than the morning peak hours in a given day. Thus, the afternoon values were used in the analysis and design processes.

4.2 Crash Data

The crash data of this intersection is compiled in Police Reports that were made available to the team by the Worcester DPW. The information on crashes is important because it confirms problems identified by the level of service analysis by revealing the real-life safety issues that go along with the parts of the intersection that have a poor level of service. There were three years of crash data available: from 2005 to 2007. The city's database of accident summaries showed a total of 52 crashes that occurred near the two intersections; this included 15 crashes in 2005, 22 in 2006, and 15 in 2007.

Some of the accidents were not due to any fault of the intersection itself, but simply environmental conditions that made it difficult for drivers to maneuver on the road. It cannot be determined for certain which accidents these were, but these factors were taken into account when considering possible redesigns of the intersection to be recommended to the City of Worcester.

Collision diagrams are used to represent the accidents that have occurred near this intersection in a concise graphical representation. The diagram helps visualize any correlations that might be depicted by the amount of accidents occurring in the intersections.

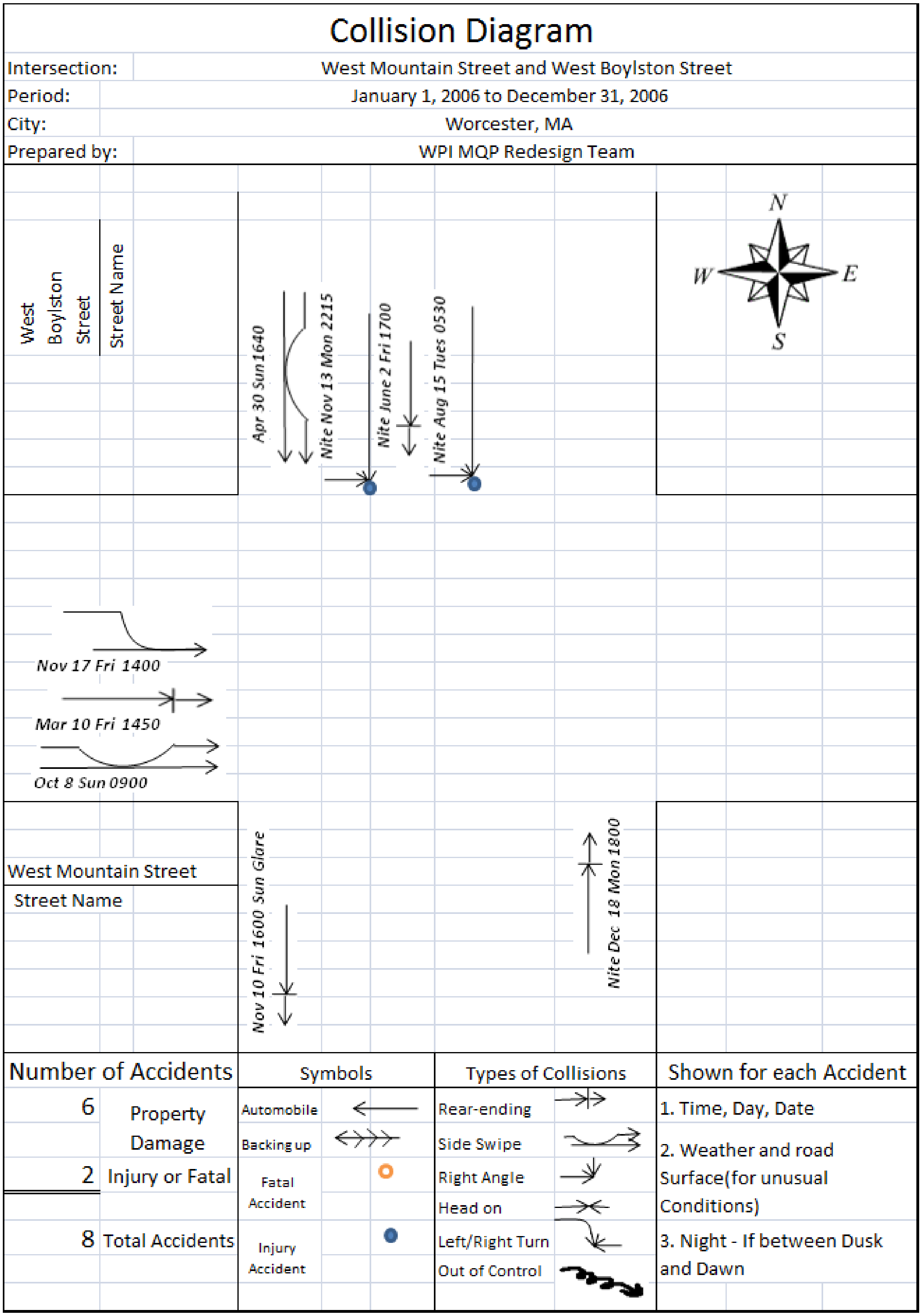


Figure 10: West Mountain and West Boylston Street Collisions in 2006.

Collision diagrams, like Figure 10 above, show what types of accidents have occurred in this intersection with all the information that is pertinent to the accident. This information includes: whether it was day or night, the month, date, day of the week and time, as well as the weather and road surface conditions at the time of the collision. There are collision diagrams of all relevant recorded accidents that have occurred in the past three years in these two intersections in Appendix C: Collision Diagrams. There is also a CAD drawing describing all of the accidents that have been documented in the list.

4.3 General Observations

The general observations that were noted during visits to the intersection include:

- Types of traffic using the intersection,
- Queue related issues and
- Signal Timing.

4.3.1 Types of Traffic

As mentioned before, the majority of the traffic traveling through the intersections during the morning peak hours was going west towards Interstate 190 and the opposite during the evening peak hours. This is why many of the drivers who use this series of intersections are assumed to be commuters going to and from their workplaces. School buses were another common type of vehicle which uses this intersection, as were students commuting to the schools of the region (i.e., Burncoat Preparatory School and Quinsigamond Community College). Other types of vehicles seen using these intersections included dump trucks, 18 wheelers, trailers, and general heavy trucks, but they were not overly prevalent. In addition, there were a number of businesses in the area including a Honey Farms convenience store, the Hong Kong Island Chinese Cuisine restaurant, a Veterinary Hospital, a New England Backpacker sporting goods store, a Mobil gas station, a Price Chopper grocery store, a Cinema, and a Super Stop and Shop grocery store. These businesses were also common destinations for passenger vehicles travelling in the area. The majority of the vehicles at these intersections were cars, light trucks, and vans.

During the TMCs, the use of the crosswalks by the pedestrians was also observed. The walking signals at both intersections were used on a regular basis by pedestrians. The number of pedestrians during observation, however, was never more than five per hour. Also, there was greater pedestrian traffic in the morning than in the evening peak hours. The pedestrian traffic was neglected during the analysis of the intersections.

4.3.2 Queue

Information on the queue lengths was observed at approximately 3:30pm on Thursday December 4, 2008. The results are shown in Table 3 below.

Table 3: Observed Queue Lengths (number of cars)

Approach	Maximum Number of Cars in the Queue				# of Lanes
West Boylston/West Mountain					
W Mountain Eastbound	6	8	7	9	2
E Mountain Westbound	14	11	5	13	2
West Boylston Southbound	8L*	6	5	8	3
West Boylston Northbound	6	9L*	7	5	3
Burncoat/East Mountain					
E Mountain Westbound	3	10	10	7	1
E Mountain Eastbound	13	6	11	12	2
Burncoat St. Northbound	3L*	3	9	5	2
Burncoat St. Southbound	3	0	1	2	1

*** "L" denotes when the largest queue length occurs in the left turn bay**

Queue lengths at this series of intersections are a significant and noticeable problem. During peak hours, the most prominent problem area is the length of East Mountain St. between West Boylston and Burncoat. An important indicator that there is a problem with this set of intersections is that during peak hours, the short length of road between the two intersections unofficially changes from a two lane road to four lanes. Even for the two hours observed during the peak hour window it could be seen that some drivers were not expecting this change, and there were some instances that this nearly led to a collision.

Due to the finite capacity of queue length available in this section of East Mountain Street, defined by the close proximity between Burncoat and West Boylston Streets, the two intersections' queues back up into each other causing gridlock, especially at Burncoat. It is because this region is filled with so much backup that the cars form illegal second lanes in both directions. As can be seen in the Figure 11 below, the westbound portion of East Mountain Street between the two intersections technically only forms a second lane after it intersects with Triangle St., and the length of this is approximately nine car lengths. Drivers at this intersection, however, unofficially form a multi-channel approach to West Boylston St. around Burncoat St. during peak hours. This means during peak hours, the one lane splits into two, causing safety issues and confusion at Burncoat, Triangle, and the entrances/exits of the plazas. The creation of a second lane of traffic and its effects is illustrated in a sketch in Figure 11 below.

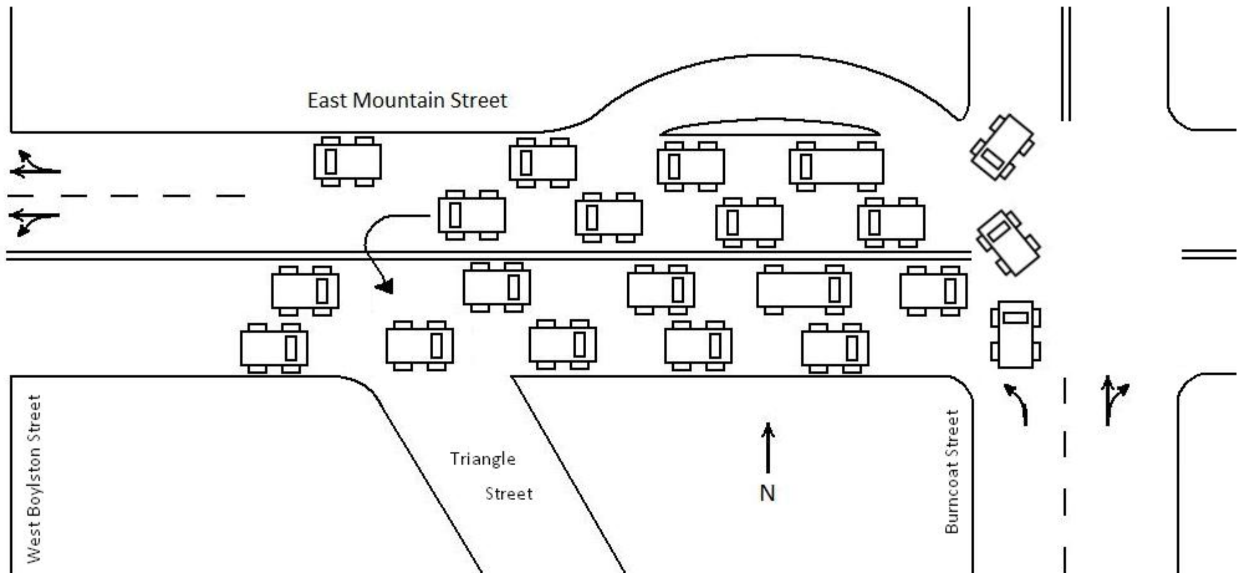


Figure 11: Sketch of lane confusion along East Mountain St.

This practice leads to many problems. First, the length of road between the intersections was not built to hold four lanes of vehicles; it is not marked as such, and this makes a very dangerous situation especially for drivers who are not familiar with the intersection. Also, for the vehicles who are attempting to take a left onto Triangle Street, first they must merge to the left (unofficial) lane, and then they must turn left crossing two lanes of traffic. This usually means waiting until the East Mountain/Burncoat intersection gives the East/West direction a green light and, until then, backing up traffic on the left side of the lane into the Burncoat intersection, where northbound vehicles are trying to turn left, creating gridlock.

This problem exists on both sides of East Mountain St. In the eastbound direction, the entire length is supposed to be a single lane, but is illegally split into two lanes. This is even worse because either during or immediately after going through the Burncoat intersection, the two lanes must merge together because the receiving lane there is a single lane. In addition, the left of these two lanes will get backed up if there are any vehicles turning left.

The arrival distribution is similar at all approaches. The queue length continues to extend steadily until the green phase begins. Then the approach empties, but not completely, especially in the case of the higher-volume approaches during peak hours and most of the afternoon. It is during these times that the negative effects of the queue limitation are the most apparent. For example, during a visit to the intersection around 5:00 PM one afternoon, it was observed that when the westbound green phase at the West Mountain/West Boylston intersection began and started alleviating the queue length, there was approximately seven seconds before the green phase began at the westbound approach at the East Mountain/Burncoat intersection. The major issue with this delay is that some of the vehicles waiting at the Burncoat intersection did not get to the West Boylston intersection in time to go through, meaning the queue length is not entirely alleviated when the traffic turning left from northbound Burncoat St. gets involved in the backup. Thus, while the intersections operate in a master/slave system (i.e., West Boylston-West Mountain is the master and Burncoat-East Mountain is the slave), this system does not account for the oversaturation that occurs on East Mountain Street between the intersections.

4.3.3 Signal Timing

The signal timing was the most important aspect of the intersections that was studied, and was the main design aspect of the possible re-designs. Signal timing is significant because it dictates how traffic flows through intersections. Some information concerning the signal timing was provided by the DPW, but this most recent record is from 1997. Since then there has been at least one change. There was a re-design in 1997 which created the one-way portion of Burncoat and Triangle Street. Before then, Burncoat Street had been two-way throughout. Since this change was made, it cannot be certain if any signal timings were also changed; therefore, the signals were timed by hand to make sure they were consistent with the 1997 signal timing plan.

Observed Signal Timing

Some notable qualitative observations that were made are that the East Mountain and Burncoat intersection operates as a “slave” intersection with the West Boylston-Mountain controller as the “master.” Also, both intersections had pedestrian phases actuated by the pedestrian button. Eventually, the pedestrian phase was dropped from the analysis because it is not included as a part of the regular timing of the intersection. More specific signal timing observations were made at around 4:00 P.M. on a Thursday evening and are summarized in Table 4 below. The multiple rows for each direction signify timings of separate cycles.

Table 4: Signal Timing Observations

West Boylston			
Phase		Green (s)	Yellow (s)
1	West Mountain (EB&WB)	50	2
		50	3
2	West Boylston Left Turns	10	2
		15	2
3	West Boylston (NB&SB)	25	4
		25	3
Burncoat			
Phase		Green (s)	Yellow (s)
1	East Mountain (EB&WB)	40	2
		35	3
		45	3
2	Burncoat (NB&SB)	10	3
		10	2

These observations were then compared to the documents provided by the DPW dated from 1997, the details of which are described in the next section (Massachusetts Highway Department, 1997).

Documented Signal Timing Plans

These two intersection signals are operated based on signal timing "plans". These plans are programmed to have different overall cycle lengths. The plans are mainly different in the length of green times for each phase, and differ in the balance between phases. Also, there are periods of time when the intersections are in free operation. This means there is a control street that remains green for a maximum amount of time or until a car arrives at the other street in the intersection, as noted before in the observations section. Free, or automatic operation is in effect at times of the day when volumes are known to be low; at night from 8:00 PM to midnight, weekend mornings from 6:00 AM to 8:00 AM, and from midnight to 6:00 AM at West Mountain and West Boylston. At Burncoat and East Mountain streets, the signals flash between 12:00 AM and 6:00 AM, with East Mountain St. flashing yellow and with Burncoat St. flashing red.

The sequencing of the intersection of West Mountain Street and West Boylston Street is described in detail in Table 5. The sequencing at East Mountain Street and Burncoat Street is described in Table 6.

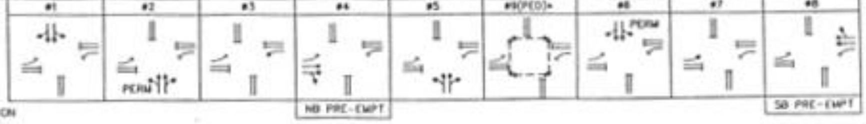
Table 5: Signal Timing plan at West Boylston and West Mountain. (Massachusetts Highway Department, 1997)

WEST BOYLSTON ST ˈET AT MOUNTAIN STREET EAST

PROPOSED

SEQUENCE AND TIMING

APPROACH	DIRECTION	HOUSING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	FLASHING OPERATION
MINIMUM INTERVAL			8			10			8			10			6			-			10			6			10			
VEHICLE EXTENSION			3			3			3			3			3			-			3			3			3			
MAXIMUM 1			10			35			20			25			10			-			35			20			25			
MAXIMUM 2			15			50			20			25			15			-			50			20			25			
YELLOW CLEARANCE				3			3			3			4			3			-			3			3			4		
RED CLEARANCE					2			2			2			1			2			-			2			2			1	
PEDESTRIAN																		5	17	1										
WEST BOYLSTON ST	NB	A	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{G-	{Y-	{R-	{R-	{R-	{R-	F{R-
WEST BOYLSTON ST	NB	B,C	R	R	R	R	R	R	R	R	R	G	Y	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	FY
WEST BOYLSTON ST	SB	D	{R-	{R-	{R-	{R-	{R-	{R-	{G-	{Y-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	{R-	F{R-
WEST BOYLSTON ST	SB	E,F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	G	Y	R	FY
MOUNTAIN ST EAST	WB	G,H	R	R	R	G	Y	R	R	R	R	R	R	R	G	Y	R	R	R	R	R	R	R	R	R	R	R	R	R	FR
MOUNTAIN ST EAST	WB	K	R	R	R	G	Y	R	R	R	R	R	R	R	G{G-	Y{Y-	R	R	R	R	R	R	R	R	R	R	R	R	R	FR
MOUNTAIN ST WEST	EB	I,J	G	Y	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	G	Y	R	R	R	R	R	R	R	FR
MOUNTAIN ST WEST	EB	L	G{G-	Y{Y-	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	G	Y	R	R	R	R	R	R	R	FR
PEDESTRIAN		P1-P8	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	W	FDW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	OUT
DETECTOR			NON-LOCK			NON-LOCK			NON-LOCK			NON-LOCK			NON-LOCK			-			NON-LOCK			NON-LOCK			NON-LOCK			
RECALL			OFF			OFF			OFF			SOFT			OFF			-			OFF			OFF			SOFT			
			#1			#2			#3			#4			#5			#9(PED)*			#6			#7			#8			



NOTES:
1. FLASHING OPERATION PER M.U.T.C.D. SECTION 4B-18.
2. * UPON PUSH BUTTON ACTUATION
3. #4 & #8 DUAL ENTRY
4. MAXIMUM 1 = NORMAL OPERATION
5. MAXIMUM 2 = 3PM-7PM MON-FRI
6. PERM = PERMISSIVE
7. RETAIN EXISTING PRE-EMPT OPERATION
8. #2&#6 OMIT #1 OR #5

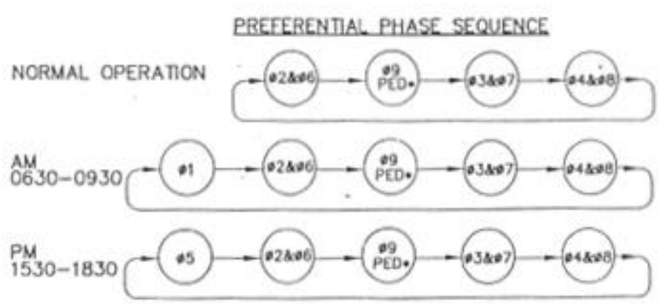


Table 6: Signal Timing at Burncoat and East Mountain Streets

AB-348-2447

BURNCOAT STREET AT MOUNTAIN STREET EAST

			SEQUENCE AND TIMING																		
APPROACH	DIRECTION	HOUSING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	FLASHING OPERATION
MINIMUM INTERVAL			10						10			10			10						
VEHICLE EXTENSION			3						3			3			3						
MAXIMUM 1			40						25			40			25						
MAXIMUM 2			40						25			40			25						
YELLOW CLEARANCE				3						3			3			3					
RED CLEARANCE					2						2			2			2				
PEDESTRIAN INTERVAL						5	12	1													
BURNCOAT STREET	NB	A,B	R	R	R	R	R	R	G	Y	R	R	R	R	R	R	R				FR
BURNCOAT STREET	SB	C,D	R	R	R	R	R	R	R	R	R	R	R	R	G	Y	R				FR
MOUNTAIN ST EAST	WB	E,F	G	Y	R	R	R	R	R	R	R	R	R	R	R	R	R				FY
MOUNTAIN ST EAST	EB	G,H,J	R	R	R	R	R	R	R	R	R	G	Y	R	R	R	R				FY
PEDESTRIAN X-ING	ALL	P1-P4	DW	DW	DW	W	FDW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW				OUT

	#2	#3(PED)*	#4	#6	#8	#1,#3,#5 & #7
DETECTOR	NON-LOCK	-	NON-LOCK	NON-LOCK	NON-LOCK	
RECALL	SOFT	-	OFF	SOFT	OFF	
						NOT USED

NOTES:

1. FLASHING OPERATION PER M.U.T.C.D. SECTION 4B-18.
2. * UPON PUSH BUTTON ACTUATION
3. #4 & #8 DUAL ENTRY
4. MAXIMUM 1 = NORMAL OPERATION
5. MAXIMUM 2 = NOT USED
6. FLASH OPERATION = 12 MIDNIGHT TO 6AM

SEQUENCE & TIMING NOTES:

1. IF THE ASSIGNED RIGHT OF WAY FOR ANY TRAFFIC MOVEMENT IS TO REMAIN IN EFFECT DURING THE NEXT CALLED PHASE, THE SIGNAL INDICATIONS FOR THAT TRAFFIC MOVEMENT WILL NOT CHANGE DURING THE CLEARANCE INTERVAL.
2. THE RIGHT OF WAY MAY BE ASSIGNED TO ANY PHASE, OR ANY COMBINATION OF NON-CONFLICTING PHASES.
3. IF CALLS EXIST ON ALL PHASES, THE ASSIGNMENT OF RIGHT OF WAY SHALL BE IN ACCORDANCE

COORDINATION NOTES:

BURNCOAT STREET/MOUNTAIN STREET INTERSECTION SHALL BE SET AS "SLAVE" TO MOUNTAIN STREET/WEST BOYLSTON STREET CONTROLLER

PREFERENTIAL PHASE SEQUENCE

Ø2&Ø6 → Ø3 PED* → Ø4&Ø8

Based on the poor performance of the intersections during peak hours, if the two intersections are coordinated, it is not an adequate due to queue-length issues (refer to section 4.3.2 Queue). Also, from observing the signalization of the intersections during afternoon peak hour, they did not seem to have the coordination as specified in the reference. It is possible that the master/slave coordination between the two intersections is no longer in use.

Since the phase timings observed fell between the minimum and maximum times given in the documents, the maximum times, or the worst case scenario, were used in the level of service analysis using the program HCS2000.

4.4 Issues That Affect Re-Design

There are some characteristics of the site that must be taken into account in analyzing the possible redesigns of the intersections. These physical barriers challenge the implementation of major re-designs at this intersection.

4.4.1 Railroad Tracks

A railroad track runs underneath the west and north approaches to the intersection of West Boylston Street and West Mountain Street. This means that realigning these roads would be considerably more expensive because it would require tearing down and rebuilding the bridges over the railroad at those locations. The railroad also intersects with Burncoat Street further north of its intersection with East Mountain St., but far away enough that it does not affect the site. The track can be easily seen in the aerial map provided in Appendix D: Land Use Map, provided by Mr. Kempton.

4.4.2 Right of Way

The right of way of the area surrounding this intersection is described briefly in part by an aerial photograph with different parcels of land outlined, provided to the team by the Worcester DPW via Mr. Kempton. It is hard to see, but the individual parcels of land are outlined in a thin red line. This photograph can be found in Appendix D: Land Use Map. While the exact accuracy of this map is not known, it shows the commercial plaza on the north side of East Mountain St. to yield a significant right-of-way to the city between the two intersections. It seems to be around six feet, and there are a few feet available on the south side of the street also. This finding is important because it shows that there is a possibility of widening East Mountain St. between Burncoat and West Boylston. This is true because the width of the street is already barely enough to accommodate two eight foot lanes in each direction. Thus, only a few feet would be necessary to make the lanes realistically wide enough for operation.

4.4.3 Bus Staging Lane

On the North side of East Mountain Street, between the two intersections, there is a bus staging lane separated from the road by a median. This causes some confusion with drivers who are new to the area and the lane is sometimes used by accident. It is also used as a makeshift U-turn spot for other drivers, more experienced with the area. Both of these are problems. Upon investigation, it was discovered that this bus stop is no longer in use; therefore, the redesign could get rid of this hazard and perhaps even utilize the space for the road widening possibility.

Chapter 5: Analysis

The findings that were generated through various data collection activities and observations were then used to analyze the conditions of the intersection, and eventually lead to the evaluation of changes recommended at the intersection. The analysis consists of:

- Level of Service Analysis,
- Crash Data Analysis,
- Warrant Analysis,
- Critical Analysis and
- Visual Analysis.

5.1 Level of Service Analysis

The initial conditions of the intersection were analyzed using HCS 2000 Signals, a program that performs a level of service analysis of signalized intersections. The initial information entered into HCS 2000 was done with the turning movement volumes collected with the TMCs (i.e., see section 4.1.2 Turning Movement Counts). The maximum interval length for each phase was used in the analysis, because it was believed to be the most problematic situation. The afternoon peak hours were found to be more critical than the morning peak hour, therefore the level of service (LOS) conclusions were based off of the results for the afternoon peak hour.

A level of service analysis is based off of the delay the average vehicle must experience in order to go through the intersection. The volumes during the peak hour, the peak hour factors, the geometry of the intersection, and the signal timings are all inputted into HCS2000, and the average delay is calculated. This is done first for individual turning movements from all approaches, and then an average is taken for each approach, and then an average for the entire intersection. The amount of delay is then defined by a letter "grade." If the delay is between zero and ten seconds, the grade is an "A," between ten and twenty, a "B," between twenty and thirty, a "C," and so forth. Given below in Table 7, is a summary of the LOS results for the four approaches and the entire intersection for both intersections, as it operates in current conditions

Table 7: Level of Service of Each of the Intersections at the Peak Hours.

		EB	WB	NB	SB	Intersection
West Boylston- West Mountain Afternoon	**Delay (sec)**	52.5	21.7	53.4	55.3	**42.3**
	LOS	D	C	D	E	**D**
West Boylston-West Mountain Morning	**Delay (sec)**	21.2	30.7	49.9	50.0	**35.0**
	LOS	C	C	D	D	**C**
Burncoat-East Mountain Morning	**Delay (sec)**	14.1	16.4	17.1	16.6	**15.6**
	LOS	B	B	B	B	**B**
Burncoat-East Mountain Afternoon	**Delay (sec)**	13.0	40.1	18.9	18.1	**28.3**
	LOS	B	D	B	B	**C**

This shows that when examining the individual intersections, the East Mountain/Burncoat intersection should actually be a relatively well-performing intersection, while the West Boylston intersection gets to the point where three out of four approaches are waiting almost a minute to get through the intersection. With this in mind, it is important to note that these are the analyses of the individual intersections, with no accommodation for the effects of the interaction between the two. Thus, the problems mentioned in section “4.3.2 Queue” are not taken into account for this analysis.

In order to quantify these problems in a level of service analysis, HCS Arterials was used. It was found that West Boylston and Burncoat Streets are approximately 400 feet apart, or 0.07 miles. This distance was entered into HCS arterials as the length between the two intersections. However, the distances on either side of these intersections had to be assumed as zero, and the program analyzed it as such. This is why the initial analysis had an original result of a total delay of 50.6 seconds and an average speed of five miles per hour. This yielded an “F” grade.

This arterials analysis brought to attention the surrounding area of these intersections along Mountain St. The diagram in Figure 12 illustrates the nearest signalized intersections of the region.

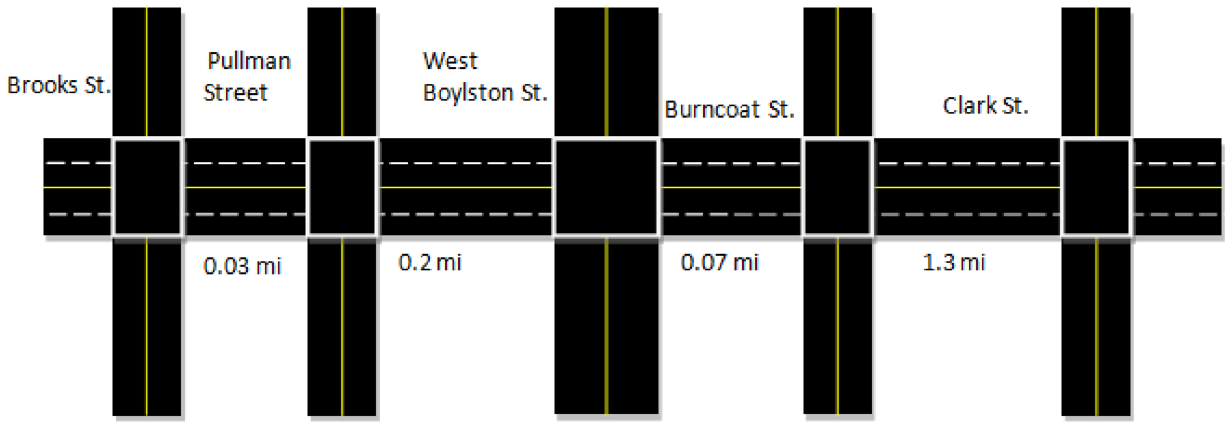


Figure 12: Nearest Signalized Intersections

The intersections shown, in order to be entered into the HCS Arterials analysis had to have complete signals files made for each of them. Assumed numbers were used to create mock HCS Signals files for these intersections, which were then analyzed with HCS Arterials. The mock intersection analyses all had LOS ratings of "C." The result of this arterials analysis can be seen below in Table 8.

Table 8: Arterials Results

Existing Arterials Analysis																
	L (mi)	time	Speed	LOS	L (mi)	time	Speed	LOS	L (mi)	time	Speed	LOS	L (mi)	time	Speed	LOS
Brooks St.									0.03	9.3	11.6	F	0.08	15.1	19.1	D
Pullman St.					0.2	28.9	24.9	C	0.2	28.9	24.9	C	0.03	9.3	11.6	F
Boylston	0.07	39.3	6.4	F	0.07	39.3	6.4	F	0.07	39.3	6.4	F	0.2	54.2	13.3	E
Burncoat	0	11.3	0	F	1.3	128	36.5	A	1.3	128	36.5	A	0.07	19.3	13	E
Clark St.													1.3	123	38.1	A
Overall	0.07	50.6	5	F	1.57	196	28.8	B	1.6	206	28	C	1.68	221	27.4	C

These results were substantially improved from the analysis of the first, inaccurate analysis due to the whole region being taken into account. The LOS by section of these results remains poorest for the area around West Boylston Street. The analysis of Burncoat street is seen to be more favorable since the nearest signalized intersection is 1.3 miles away.

An important part of the signal timings to note is that there was no way to input into HCS2000 that the intersection controller is programmed to have minimum and maximum timings for each phase, and the actual signal timing can be anywhere between them depending on when the vehicles approach. As mentioned before, the maximum timings were used in the analysis to accommodate for the worst case scenario. For reference, an analysis for the worst intersection peak hour (West Mountain/West Boylston Streets in the afternoon) was also done using the minimum times. The results of this analysis can be found below in Table 9. When the intersection performs to this extreme, three of the approaches become much more acceptable, and the eastbound approach reaches average delays of over two minutes and forty seconds.

Table 9: Example of Minimum Existing Signal Timings.

		EB	WB	NB	SB	Intersection
West Boylston- West Mountain Afternoon	**Delay (sec)**	169.3	24.2	21.3	17.9	**35.9**
	LOS	F	C	C	B	**D**

5.2 Warrant Analysis

In order to determine whether a traffic signal is necessary at an intersection there are series of eight different warrants outlined by the Manual on Uniform Traffic Control Devices (MUTCD) that needs to be met before a signal can be installed. (MUTCD, 2003) One or more of these warrants must be met for a traffic signal to be deemed necessary at a location where a signal currently does not exist. It is important to re-evaluate these warrants even after signals are installed to determine what the current situation is and ensure that the signal is still warranted. For this analysis, ATR data and other observations were compared with the outlined MUTCD signal warrant criteria.

Warrant 1: Eight Hour Vehicular Volume (Satisfied)

The first warrant to be evaluated is the Eight Hour Vehicular Volume. This is divided into two-directional volume for the major street and maximum one direction approach for the minor street. For the intersection of East/West Mountain and West Boylston Streets, West Boylston must be used as the major street due to initial ATR setup issues with directionally specific ATR counts on the northern leg of the street. This means, since both major and minor approaches are multi-channeled, West Boylston must have a total volume above 600 vehicles per hour (VPH) in both directions and West Mountain must have over 200 vehicles per hour in at least one direction to satisfy the warrant. The details of necessary criteria of this warrant are shown in Table 10. West Boylston St. easily satisfies the warrant with over 1000 VPH during nine hours of the day on average between 10:00 AM and 7:00 PM, and over 600 during the majority of the day. West Mountain Street also has high volumes in both directions. For the purpose of the analysis, West Mountain Street satisfies the warrant in the eastbound direction between 11:00 AM and 7:00 PM, along with West Boylston. (MUTCD, 2003)

Table 10: Warrant 1 Criteria (MUTCD, 2003)

Warrant 1, Eight-Hour Vehicular Volume		
Condition A—Minimum Vehicular Volume		
Number of lanes for	Vehicles per hour on major	Vehicles per hour on

moving traffic on each approach		street (total of both approaches)				higher-volume minor-street approach (one direction only)			
Major Street	**Minor Street**	**100% a**	**80% b**	**70% c**	**56% d**	**100% a**	**80% b**	**70% c**	**56% d**
1................	1................	500	400	350	280	150	120	105	84
2 or more.....	1................	600	480	420	336	150	120	105	84
2 or more.....	2 or more.....	600	480	420	336	200	160	140	112
1................	2 or more.....	500	400	350	280	200	160	140	112

For the intersection of East Mountain and Burncoat Streets, the volumes are analyzed as East Mountain having its existing one lane per direction and Burncoat as having two lanes in the heavier volume approach (northbound). According to this parameter, East Mountain must have over 500 VPH and Burncoat's most voluminous approach must have over 200 VPH in each of the same hours. This passes with East Mountain having over 900 VPH and Burncoat remaining above 250 VPH between the hours of 11:00am and 7:00pm. This satisfies condition A of the eight-hour vehicular volume warrant for the intersection of East Mountain Street and Burncoat Street. The eight-hour traffic volume warrant is, therefore, satisfied. (MUTCD, 2003)

Warrant 2: Four-Hour Vehicular Volume (Satisfied)

The four-hour vehicular volume is similar to the eight-hour vehicular volume warrant, with a curve of corresponding major and minor street requirements for the warrant that is referenced (Figure 13). For this analysis, the same major and minor street designations were used as in the eight-hour vehicular volume analysis shown above.

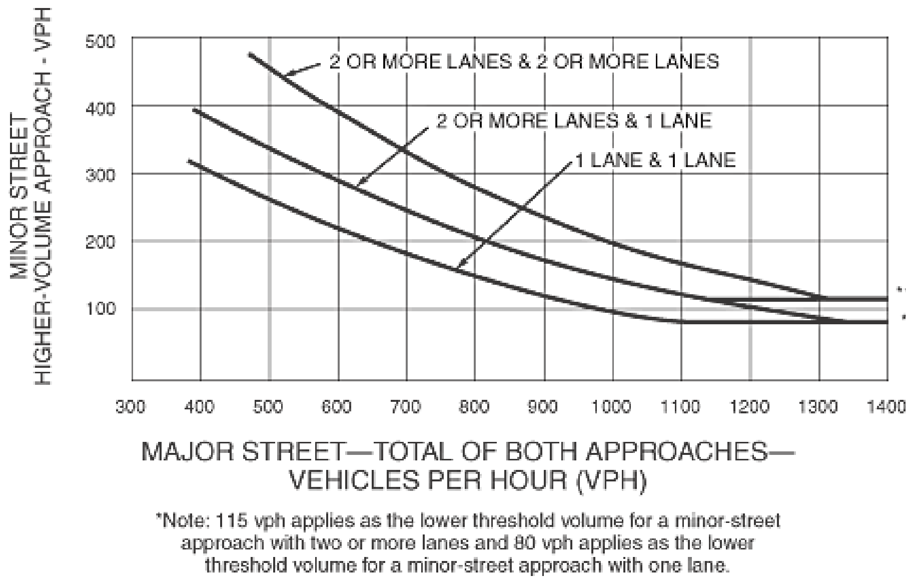


Figure 13: Warrant 2 Curve (MUTCD, 2003)

At the intersection of West Mountain and West Boylston Streets, the four hour volume warrant is satisfied during the highest hours of volume for West Boylston, and for many other hours. During the heaviest volumes of the day, between 11:00 AM and 7:00 PM, the number of vehicles per hour remains above the four-hour volume curve. From 11:00 AM to 3:00 PM, the volume on West Boylston waivers around 900 according to the ATR south of the intersection, and over 1200 for the ATR north of the intersection. In the best scenario of 900, West Mountain Street must have a volume of approximately 250 VPH, and this is easily satisfied with an average above 400 in one direction. (MUTCD, 2003)

The intersection of East Mountain and Burncoat Streets also satisfies this warrant. East Mountain Street has over 1000 VPH between the hours of 2:00 PM and 6:00 PM and the corresponding highest volume approach of Burncoat (northbound) has over 250 VPH in each of these hours, while only 200 was necessary. (MUTCD, 2003) Each of the intersections for this warrant has volumes above the highest curve, the one for two lanes in each direction, so this warrant is satisfied even if more lanes are added.

Warrant 3: Peak Hour (Satisfied)

While this warrant is intended only for intersections that do not have consistent volume, it is still useful to determine whether it is met. The intersection at West Boylston St. meets this warrant at many hours. During the 11:00 AM hour, which on average is highest in volume, West Boylston's volume is above 1300 vehicles with West Mountain Eastbound in the high 400's, which lies above the peak hour curve shown in Figure 14 below (MUTCD, 2003). The peak hour volume warrant is therefore satisfied.

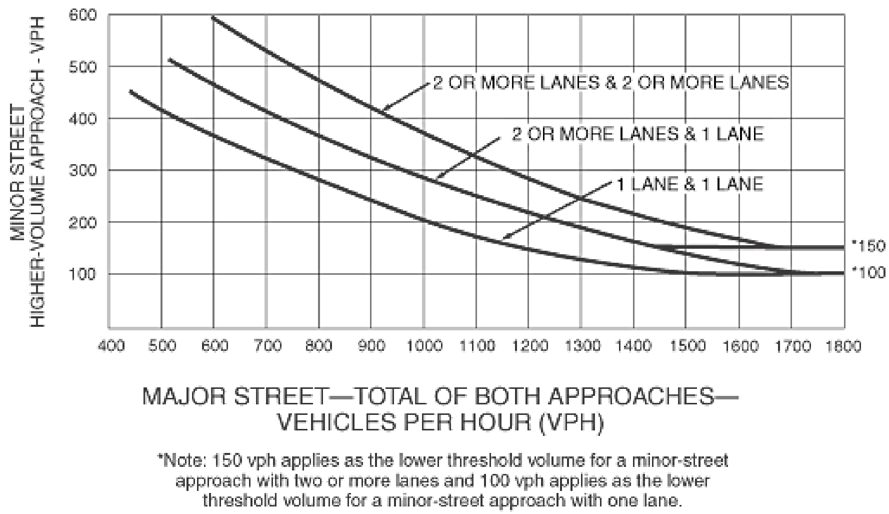


Figure 14: Warrant 3 curve (MUTCD, 2003)

Warrant 4: Pedestrian Volume (Not Satisfied)

This warrant is satisfied if there is a certain volume of pedestrians crossing the intersection or the traffic does not provide enough gaps to allow for pedestrian crossings. According to observations, the intersection does not meet this minimum for a four-hour volume of 100 pedestrians or a one hour volume of 190 pedestrians. (MUTCD, 2003)

Warrant 5: School Crossing (Not Satisfied)

This warrant is not met because there is no school crossing at either of the intersections in question.

Warrant 6: Coordinated Signal System (Satisfied)

This warrant is intended for intersections on a roadway that are between other signalized intersections and experience vehicle platooning. A major characteristic of the intersections being studied is that they are within 400 feet of each other and have coordinated signalization. If one of these intersections did not have a signal, the traffic looking to pass through that part would no doubt experience extreme difficulty. While this is hard to quantify, it can still be observed that the existence of the West Boylston/West Mountain signal does indeed necessitate the Burncoat/East Mountain signal, and vice versa so this warrant is also presumed to be satisfied (MUTCD, 2003).

Warrant 7: Crash Experience (Satisfied)

The crash experience warrant first asks whether there have been measures taken to alleviate crashes besides the implementation of traffic signals. These checks were to ensure that signalizing these intersections was warranted in the first place, not to put them in currently. These intersections are already signalized, and there is no information on these intersections from before signals were implemented. In this sense, it could not be determined if the number of intersection crashes exceeded five per year when not signalized, however, the number of crashes at the intersection currently exceeds five per year at West Boylston and West Mountain Streets and 29 overall from 2005 to 2007. In contrast, the number of crashes at the local intersection of Burncoat/East Mountain is less than five per year; with only three in 2005 and 2006 and zero reported in 2007. This series of intersections cannot simply be seen as two different ones, because they are so closely related. Many of the crashes reported are in the region between West Boylston Street and Burncoat Street, and are related to the excessive volume that travels through this way. In that respect, it can be said that the warrant is satisfied. (MUTCD, 2003)

Warrant 8: Roadway Network (Satisfied)

This final warrant is intended for organizing major routes of a region. The intersections in question easily pass the volume aspect of this warrant, with a total of all approaches of at least 1000 vehicles during a weekday peak hour. It also has five-year projected volumes that meet warrants 1, 2, and 3, meeting them currently. The next condition is that the roadways need to be either part of a major highway system, transcend city limits, or appear as a major route. West Boylston Street, since it is designated in the region as Massachusetts state route 12, is part of a major highway system. West Mountain Street also connects with interstate 190 within a mile of the intersection, passing this warrant. Burncoat Street is the least important of these roads, however it does show up as a bold route on maps (Google Maps, 2008) and in fact connects with interstate 290 a few miles south of the intersection. In these respects, each of the intersections fulfills the final warrant, Roadway Network. (MUTCD, 2003)

The conditions at these intersections do require signalized intersections since in both cases at least one warrant was met.

5.3 Crash Data Analysis

In the intersections' current states, there is a mechanism that causes the same types of accidents to occur. The information provided by the accident reports and the summary diagrams give more insight into the nature of these mechanisms, so that a solution can be found. This helped quantify the recommendations to be brought to the DPW.

The different correlations that were discovered by organizing the accident reports data included:

- Most accident prone times
- Types of accidents
- Location/Direction

Table 11: Accident Reports by Day and Time.

Accident	Accident Report	Date	Day	Time	Road Conditions	Property Damage or Injury
12		30-Apr	Sunday	1640		Injury
15		8-Oct	Sunday	900		Prop
11		13-Nov	Monday	2215	Night	Injury
22		18-Dec	Monday	1800	Night	Prop
18		26-Dec	Monday	1800	Night	Prop
21		16-Jul	Monday	1730	Night	Injury
27	63299	11-Jul	Monday	1345		Prop
24	107954	19-Nov	Monday	851		Prop
2		22-May	Monday	815		Prop
6		19-Jul	Tuesday	1630		Prop
9		15-Aug	Tuesday	530	Night	Injury
25	110609	28-Nov	Wednesday	1800	Night	Prop
28	13237	15-Feb	Wednesday	1415		Prop
3		13-Nov	Thursday	2130	Night	Injury
1		8-Dec	Thursday	1900		Prop
23		30-Jun	Thursday	1705	Night	Prop
4		9-Feb	Thursday	1600		Prop
7		9-Feb	Thursday	1600		Prop
8		21-Jul	Thursday	1539		Prop
5		25-May	Thursday	1530		Prop
16		6-Oct	Thursday	1000		Prop
17		15-Dec	Thursday	800		Prop
10		2-Jun	Friday	1700	Night	Prop
19		10-Nov	Friday	1600	SunGlare	Prop
14		10-Mar	Friday	1450		Prop
26	1993	7-Jan	Friday	1415		Prop
20		24-Aug	Friday	1400		Prop
13		17-Nov	Friday	1400		Prop
29	54133	16-Jun	Saturday	2345	Night	Prop

As seen in Table 11 above, the summary of the accident reports shows that there was a correlation between the days of the week. Monday, Thursday and Friday happen to be the most accident prone days of the week. Monday's accidents tend to happen around the evening hours, between 5PM and 10:30PM. Something else that could be unusual is that more than half of Monday's accidents occur in the winter months. This could be taken as caused by bad road conditions in the winter. The accidents ensuing on Thursday seem to take place during rush hour times, 3:30PM – 7PM.

This reinforces the argument for a change to the arterial to improve the flow of the intersections. Friday's accidents appear to take place during the hours of 2PM – 5PM. This, again, is close to the rush hour times and creates the same effect on the recommendations to change the flow of the intersection. These similar types of collisions, regardless of the day of the week, reinforce the importance of improving the flow through this arterial since there is evidence of a safety concern.

Small, yet important, correlations were noticed in the different types and locations of the collisions, specified in Appendix C: Collision Diagrams. By looking at the types of accidents, it was found that Eastbound through the West Boylston intersection was not only the most populated accident site, but seventy percent of the accidents Eastbound were side-swiping. Also, almost forty percent of the accidents involving an eastbound vehicle were ninety degree collisions. These correlations may possibly lead to a change in an attribute that effects the eastbound direction in an attempt to improve the intersection.

Also, the analysis shows that about 25 percent of the accidents occurred in between the Burncoat and West Boylston intersections; this corresponds with the gridlock problem that was discussed in section 4.3.2 Queue. This emphasizes the need for a redesign to get rid of this problem, since there is a proven safety issue in this area.

The Burncoat intersection tends not to have as much traffic as West Boylston, so the fact that Burncoat has less accidents total in the past three years is expected.

By using the accident reports, discussed in section 4.2 Crash Data, changes can be made to the intersection with the goal of decreasing the occurrence of collisions.

Chapter 6: Design Alternatives

The re-design process for the Burncoat-East Mountain and West Boylston-West Mountain intersections was conducted with the goal of improving the service level, flow, and overall functionality of this complex set of intersections. This process began by identifying several possible alternatives and evaluating the alternatives to see which would make the largest improvement at the least cost. The alternatives for redesigning the intersections considered are the following:

- Signal timing changes,
- Adding protected turning lanes on West Mountain Street,
- Closing Triangle Street and,
- Widening East Mountain Street.

6.1 Signal timing changes

The first possible method of re-designing the intersection is the adjustment of the signal timing. This is the most preferable form of Intersection change because it takes almost no time or money to accomplish compared to other types of changes. The only cost is the time it takes for a DPW employee already on payroll to go to the signal controls on site and change the signal times. According to the Table 5 and Table 6 in section 4.3.3, the intersections are already coordinated. This means that if the signal timing changes are adjusted, the relationship between the two intersections must be taken into account. Conversely, from observations during peak hours, the signals seem out of sync; therefore, various changes in signal timings are still examined. The evaluation of signal timing possibilities was done using the program HCS 2000 Signals, which is used to calculate the level of service of intersections. The overall evaluation of the intersections of Mountain with both West Boylston and Burncoat streets was done using HCS 2000 Arterials. This application uses multiple HCS Signals files and analyzes how they function in conjunction with one another.

6.1.1 Decreasing the Overall Cycle Length

While changing the signal timings would have been the best option economically, it is a very difficult solution to achieve with the circumstances of the intersection. If any change was made to the intersection timings that compromised the ratios between each of the directions, the overall level of service for the intersection decreased dramatically. The only changes that improved the intersection were to decrease the overall signal times of each phase at the West Boylston-West Mountain intersection by a percentage. This change does two things in theory: first, it decreases the total delay for each approach, and second, it decreases the maximum queue length on the westbound approach, so that it does not back up into the Burncoat intersection.

Table 12: Resulting Delay at 80 percent phase lengths vs. existing signal timing

Existing Conditions		EB	WB	NB	SB	Intersection
West Boylston - West Mountain Afternoon	**Delay (sec)**	52.5	21.7	53.4	55.3	**42.3**
	LOS	D	C	D	E	**D**
West Boylston - West Mountain Morning	**Delay (sec)**	21.2	30.7	49.9	50.0	**35.0**
	LOS	C	C	D	D	**C**
80% of Phase Lengths		**EB**	**WB**	**NB**	**SB**	**Intersection**
West Boylston - West Mountain Afternoon	**Delay (sec)**	49.4	19.0	46.5	48.6	**37.7**
	LOS	D	B	D	D	**D**
West Boylston - West Mountain Morning	**Delay (sec)**	18.6	26.3	42.7	42.8	**30.1**
	LOS	B	C	D	D	**C**

Table 12 above shows slight improvements in each phase, showing a correlation between having lower cycle lengths and better LOS results. When entered into HCS arterials, the total delay decreased from 37.2 seconds to 33.2 seconds, and the average speed increased from 6.8 miles per hour to 7.6 miles per hour. While there was a small improvement, the level of service was still an "F." Multiplying the Burncoat signal timings by 1.20 was also tested, but yielded a lower level of service for the intersection and did nothing to the level of service of the arterial. Other percentages of the West Boylston signal times were tried as well. As can be seen in Figure 15 below, as the cycle times decreased, the average delay for the intersection also decreases. This trend continues until the green time in any direction is equal to the amount of time that HCS2000 assumes it takes for the vehicles to come to a stop or to start up again. To bring the signal times to this point, even though it would technically create the smallest delay, would be clumsy in application and environmentally negligent since all of the stops and starts that would be created by such a set up would severely increase total vehicle emissions.

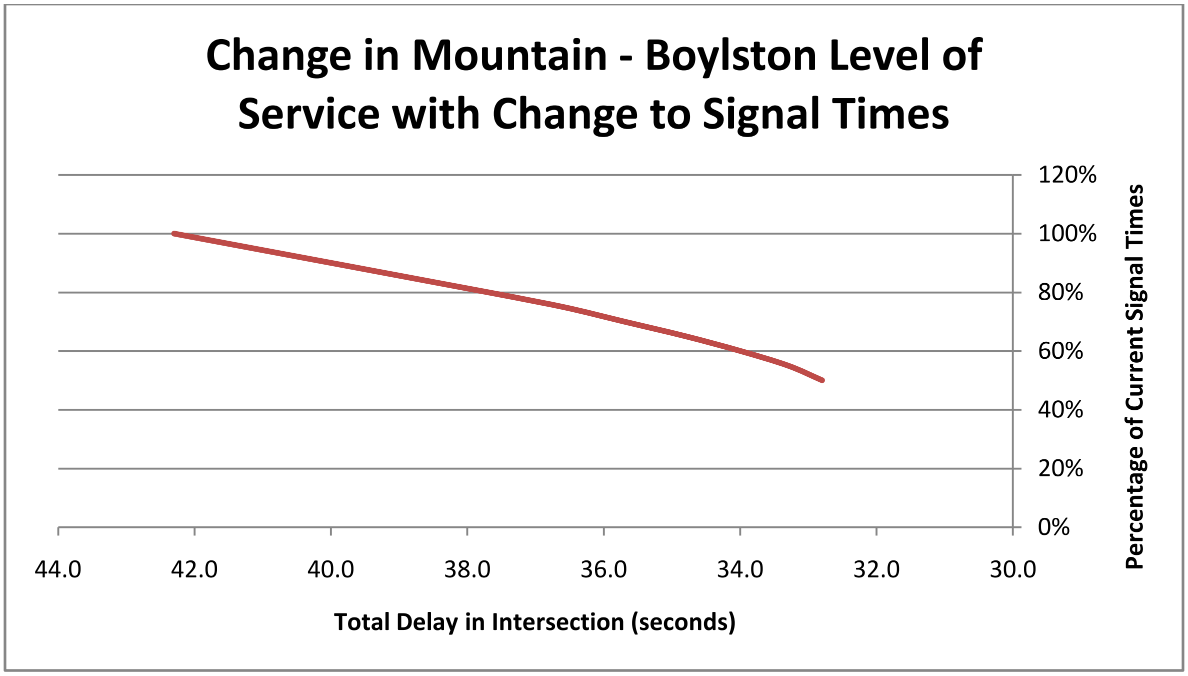


Figure 15: West Boylston-West Mountain Signal Times Resulting Delays

It would be best to find a compromise along this line, decreasing the delay by a few seconds overall, without compromising other aspects of the intersection. A useful element of HCS signals is the estimation/optimization feature. With this feature, the minimum and maximum phase intervals from the documented signal timing are able to be entered and it determines what the ideal timing is within the interval. The issue with this option is that it determines the average signal timings over the course of the day, with each phase being triggered by cars approaching. This, of course, results in a LOS that is improved compared with the maximum, worse-case scenario phase intervals that are shown in Chapter 5: Analysis.

6.1.2 Changing the Signal Timing of the Leading Left Turns at West Boylston/West Mountain

Currently, at the intersection of West Boylston and West Mountain streets, there is a leading left turn in the eastbound direction between 6:30 AM and 9:30 AM, and for the westbound direction between 3:30 PM and 6:30 PM. The desired change is to alter the leading left turn signals in the East/West portions of the intersection to be dependent on the average vehicle volumes for different times of day. Mr. Kempton suggested that the times of these leading left turn phases be extended to include the whole day.

According to the average volume data displayed in Table 1, it can be seen that the overall traffic flow switches from eastbound to westbound approximately 11:00 AM. This is true for both ATR readings on West Mountain Street and on East Mountain Street, East of Burncoat Street. It would be most logical to begin the westbound leading left turn phase at 11:00 AM and let it continue until 6:30 PM. The eastbound direction would then have a leading left turn from 6:30 AM to 11:00 AM. Table 5 from section 4.3.3 shows the existing leading left turn situation. The goal of these protected left turn changes is to increase safety for the entire day, and help to get rid of over-capacity queue lengths that occur on East Mountain St. going westbound between the two intersections.

6.2 Creating protected Left-turn lanes on West Mountain Street

The addition of protected left turn lanes was discussed because of the amount of accidents occurring for westbound vehicles going through the West Mountain/Boylston Streets intersection (see Section 5.3 Crash Data Analysis, for detailed information regarding the safety and crash history of the intersection). West Boylston already has a protected left turn lane both North and Southbound, so this is not the concern. The first question of adding a protected left turn lane is whether to simply re-assign the left lanes from the current status as shared thru-lefts to protected lefts or, to widen the street and create a third lane on West Mountain Street at its intersection with West Boylston.

Analysis and Design

Table 13, below, shows the level of service results of changing the eastbound and westbound thru/left lanes to left turn only lanes. When compared to the current level of service, it can be seen that it does not help improve the level of service for the east and west bound left turns since they are both still level of service E and F.

Table 13: Re-assigning Protected Lefts on West Mountain.

		EB-left	EB-total	WB-left	WB - total	NB	SB	Intersection
West Boylston- West Mountain Afternoon	**Delay (sec)**	92.6	51.0	56.3	161.2	49.0	42.6	**88.2**
	LOS	F	D	E	F	D	D	**F**
West Boylston- West Mountain Morning	**Delay (sec)**	54.5	106.3	55.1	35.9	47.8	49.6	**68.0**
	LOS	D	F	E	D	D	D	**E**

Putting in left turn lanes on Mountain Street at the east and westbound turns would help drivers proceed to turn north or south without causing back up in the left lane. This also leads to the drivers creeping out into the lane and taking advantage of the all of the two-second red time. This red time is sometimes not long enough, because there are aggressive drivers at other approaches that do not pay attention and accelerate immediately when the red turns green causing a dangerous situation. While this is just an observation, these types of collisions are common and shown in the collision diagrams in Appendix C: Collision Diagrams. This lane re-assignment modification would likely decrease the number of accidents occurring at the intersection of West Mountain and West Boylston streets.

Another way of achieving this would be to add an extra left-turn lane to the existing two thru lanes. This would likely decrease the number of accidents, while making the intersection significantly wider. This alternative was analyzed with HCS, with the change in phasing that it required. A 20 second left turn phase (i.e., lefts from both directions of West Mountain St.) was added, the leading left turn phase during peak hours (i.e., westbound in the afternoon, eastbound in the morning) was cut to 10 seconds, and the two-way thru phase was shortened to 35 seconds. This was done to keep the cycle length and the overall distribution of signal timing the same as the existing timing. The afternoon peak was analyzed, and the result was no better, in fact it was slightly worse. This was also done with the morning peak hour on HCS. The results of this alternative in HCS are shown in Table 14.

Table 14: Existing Conditions vs. Widened West Mountain St. with Protected Lefts

		EB-def-left	EB-total	WB-left	WB - total	NB-left	NB-total	SB - left	SB - total	Intersection
Existing Conditions										
West Boylston-West Mountain Afternoon	**Delay (sec)**	76.6	45.5	-	21.1	50.4	53.4	65.0	45.8	**40.1**
	LOS	E	D	-	C	D	D	E	D	**D**
West Boylston-West Mountain Morning	**Delay (sec)**	-	20.6	-	30.0	54.3	47.8	56.9	49.6	**33.8**
	LOS	-	C	-	C	D	D	E	D	**C**
Widened West Mountain St. with Protected Lefts										
West Boylston-West Mountain Afternoon	**Delay (sec)**	60.3	44.6	35.7	34.6	50.4	53.4	69.2	46.4	**45.2**
	LOS	E	D	D	C	D	D	E	D	**D**
West Boylston-West Mountain Morning	**Delay (sec)**	35.3	32.6	47.9	39.3	54.3	47.8	56.9	49.6	**40.5**
	LOS	D	C	D	D	D	D	E	D	**D**

This is an unexpected result, that adding protected turning lanes to the intersection would not improve the intersection flow. Also, when the afternoon alternative was put into HCS arterials to be compared with the existing flow, there was also a negative result. The estimated travel time was 56.7 seconds with an average speed of 4.4 seconds. Both are worse than the current arterial rating. This adds to the evidence that creating turn lanes on West Mountain St. would not be a suitable re-design.

Construction

Actually creating these protected turn lanes for West Mountain St. in both directions would involve a very large amount of construction work. The approach of West Mountain St. on the west side is on a bridge over train tracks. These tracks cross under the northern region of West Boylston Street. The widening of the road would thus involve widening the whole bridge. This would take months of expensive construction and labor that would likely cost the city of Worcester somewhere around two million dollars.

There would also be right of way issues, which are briefly discussed in section 4.4.2. To widen the east approach of East Mountain St., the city would have to seize around five feet of land from both Honey Farms and Hong Kong Island Restaurant, and likely from more businesses depending on how far back the turning lanes need to go. The construction of this alternative is much too expensive when paired with no real traffic improvements and only slight increases in safety.

6.3 Closing Triangle Street

The Closing of Triangle Street and re-opening of Burncoat Street for two-way traffic was also considered as an alternative design for the intersections. This was considered due to the gridlock and corresponding safety concerns discussed in sections 4.3.2 Queue, and 5.3 Crash Data Analysis.

Analysis & Design

The reasoning behind this alternative is not to improve the flow through the Burncoat intersection, because this intersection is not the major problem of the region but to improve the flow through the overall system. If the Burncoat intersection is modified to have multidirectional streets at all four approaches, there would be less confusion in the intersection because southbound drivers will not have to turn right onto East Mountain Street, stop between the two intersections, and hold up traffic while they try to find an opening to turn left onto Triangle Street. Thus, the traffic going south on Burncoat will no longer add to the congestion on East Mountain Street especially those vehicle queuing for a left turn onto West Boylston south. This may prove to be a significant difference because the morning and afternoon peak hours yield 76 and 58 cars per day, respectively, that make lefts onto Triangle St. This information is from the TMCs (see section 4.1.2 Turning Movement Counts). This scenario was examined in HCS2000, and the results are summarized in Table 15 below.

Table 15: Effects on E East Mountain/Burncoat Intersection

Existing Conditions		EB	WB	NB	SB	Intersection
Burncoat Morning	**Delay (sec)**	14.1	16.4	17.1	16.6	**15.6**
	LOS	B	B	B	B	**B**
Burncoat Afternoon	**Delay (sec)**	13.0	40.1	18.9	18.1	**28.3**
	LOS	B	D	B	B	**C**
No Triangle Alternative						
Burncoat Morning	**Delay (sec)**	25.4	10.5	19.0	14.4	**19.9**
	LOS	C	B	B	B	**B**
Burncoat Afternoon	**Delay (sec)**	16.5	54.3	32.7	15.4	**36.7**
	LOS	B	D	C	B	**D**

The results show more of a delay along East Mountain Street, which is expected to actually be a positive result for the arterial. Delaying the left turn movement from the northbound part of Burncoat Street decreases the eastbound congestion along East Mountain Street between Burncoat and West Boylston St. This would also theoretically decrease the volume approaching the West Boylston intersection.

Table 16: Effects on Local Arterials Analysis

Existing Conditions		West Boylston	Burncoat	Total
Morning	**Travel Time (sec)**	57.9	24.2	82.1
	Arterial Speed (mph)	0	10.4	3.1
	LOS	F	F	F
Afternoon	**Travel Time (sec)**	31.3	19.3	50.6
	Arterial Speed (mph)	0	13.0	5.0
	LOS	F	E	F
No Triangle Alternative				
Morning	**Travel Time (sec)**	57.9	30.7	88.6
	Arterial Speed (mph)	0	8.2	2.8
	LOS	F	F	F
Afternoon	**Travel Time (sec)**	31.3	20.3	51.6
	Arterial Speed (mph)	0	12.4	4.9
	LOS	F	F	F

When the existing morning West Boylston intersection signals file and this alternative's Burncoat intersection signals file are input into HCS arterials, (Table 16) the result is the same LOS of F with a travel time of 88.6 seconds at a speed of 2.8 mph. The afternoon peak results are 51.6 seconds and a speed of 4.9 mph. These results from HCS Arterials are confusing, because in theory the closing of

Triangle is supposed to alleviate queue and improve the flow of East Mountain St. An analysis was also done on the effectiveness of the alternative on the overall arterial, with other streets included. This is summarized in Table 17.

Table 17: Effects on Overall Arterials Analysis

Existing Arterials Analysis																
	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**
Brooks St.									0.03	9.3	11.6	**F**	0.08	15.1	19.1	**D**
Pullman St.					0.2	28.9	24.9	**C**	0.2	28.9	24.9	**C**	0.03	9.3	11.6	**F**
Boylston	0.07	39.3	6.4	**F**	0.07	39.3	6.4	**F**	0.07	39.3	6.4	**F**	0.2	54.2	13.3	**E**
Burncoat	0	11.3	0	**F**	1.3	128	36.5	**A**	1.3	128	36.5	**A**	0.07	19.3	13	**E**
Clark St.													1.3	123	38.1	**A**
Overall	0.07	50.6	5	**F**	1.57	196	28.8	**B**	1.6	206	28	**C**	1.68	221	27.4	**C**
Morning No Triangle																
	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**
Brooks St.									0.03	9.3	11.6	**F**	0.08	15.1	19.1	**D**
Pullman St.					0.2	28.9	24.9	**C**	0.2	28.9	24.9	**C**	0.03	9.3	11.6	**F**
Boylston	0.07	66.0	3.8	**F**	0.07	65.8	3.8	**F**	0.07	65.8	3.8	**F**	0.2	80.8	8.9	**F**
Burncoat	0	22.7	0	**F**	1.3	140	33.5	**B**	1.3	140	36.5	**B**	0.07	30.7	8.2	**F**
Clark St.													1.3	123	38.1	**A**
Overall	0.07	88.6	5	**F**	1.57	196	24.1	**B**	1.6	244	23.6	**C**	1.68	259	23.4	**C**
Afternoon No Triangle																
	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**	L (mi)	time	Speed	**LOS**
Brooks St.									0.03	9.3	11.6	**F**	0.08	15.1	19.1	**D**
Pullman St.					0.2	28.9	24.9	**C**	0.2	28.9	24.9	**C**	0.03	9.3	11.6	**F**
Boylston	0.07	39.3	6.4	**F**	0.07	39.3	6.4	**F**	0.07	39.3	6.4	**F**	0.2	54.2	13.3	**E**
Burncoat	0	15.4	0	**F**	1.3	132	35.4	**A**	1.3	132	35.4	**A**	0.07	23.4	10.8	**F**
Clark St.													1.3	123	38.1	**A**
Overall	0.07	54.7	4.6	**F**	1.57	201	28.2	**B**	1.6	210	27.4	**C**	1.68	225	26.9	**C**

Once again, there is no conclusive evidence that this causes any major improvements. However, it does not show any major setbacks or terrible consequences either. The effectiveness of this alternative cannot be entirely quantified using HCS Arterials, because the queue issues are not easily entered into the application. All in all, the reasoning behind opening up a Burncoat Southbound in the intersection and getting rid of Triangle St. would be to help congestion on Mountain Street, and decrease accidents entering Triangle Street.

Construction

There are different ways this could be done. The simplest way would be placing a jersey barrier at the end of Triangle St. The residences on Triangle St. would still have access via the southern leg where it intersects with Burncoat St. Other alternatives to a jersey barrier would be tearing up pavement or placing any sort of large object or signage at the end of Triangle St. making it clear to the public it is no longer open or placing a cul-de-sac bulb on the triangle property and a reconfiguration at Burncoat so residents can turn right from Burncoat Street.

Cost relative to this alternative would not be overbearing. The physical closing of Triangle St, with a jersey barrier, rock, and/or some pavement removal, would take no more than a few man hours from the DPW and the cost of a block of concrete, which could be found for just under $200 (http://www.crowdcontrolexperts.com/b-sbr.html). The re-directing of Burncoat Street traffic would involve a large amount of road striping and patching with paint, and maybe a slight reprogramming of signal timing. This would also take a few hours of work from DPW employees and incur a negligible cost, just the cost of paint and using the machinery. For these reasons, it can be said that the cost of this alternative is relatively inexpensive.

6.4 Widening East Mountain Street

Another alternative that could be used, possibly in conjunction with others would be to widen East Mountain Street to add a second lane. By widening the lanes, the city can officially create two lanes of traffic wide enough to sustain the traffic loads that cross during the peak hours. This is logical because it is already in use unofficially because the lanes are very wide and the volume in this region necessitates it. With the widening of East Mountain Street, the Burncoat St. intersection would be affected in a positive manner. The analysis states that the increase in lanes from one to two on East Mountain Street would most likely lead to a steadier flow of traffic. To accompany this, the Collision Analysis shows many correlations that include accidents occurring on East Mountain Street that could be associated with the traffic problems on East Mountain. To accomplish this maneuver the city needs to buy land in the right-of-way and start construction on the expansion of the lanes on East Mountain Street. This would cost $1.2 million if all the land in the right-of-way between Burncoat and West Boylston Streets were purchased. Fortunately, not all the land would be necessary to make this change only a percentage of the total land and cost would be necessary.

Chapter 7: Recommendations

The recommended alternatives should be used to improve the intersections separately and the arterial as a whole. The goal is to increase safety, decrease queue lines, and improve the overall flow of both of the intersections. The recommendations consist of the most cost-effective choices from the redesign alternatives section.

7.1 Recommendation #1 – Signal Timing

The first of the recommendations is the signal timing, which is discussed in detail in the design alternatives section. The initial changes made to the signal timing should include changing the timing from the current timing to eighty percent of the current timing. This would help decrease the queue lengths and improve the flow of traffic as shown in Table 11 of section 6.1.1.

7.2 Recommendation #2 – Closing of Triangle Street

The closing of Triangle Street is also an alternative that will be recommended to the DPW for improvements to the intersections. It is believed through collision diagram analysis, along with HCS analysis software, that triangle street is causing more problems than it maybe solving. What the recommendation is suggesting, is that after closing Triangle Street, Burncoat is reopened as a two way street. This would take the extra traffic off Mountain directing it southbound through the intersection of Burncoat.

These recommendations have been suggested to the DPW because these are the most inexpensive ways to develop the intersections, with the greatest positive impact on both the surrounding business and residential environments.

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Appendices

Appendix A: ATR Data

Maximum ATR Volumes

Maximum Volumes Arranged by Hour

Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT			MT East of Burn.			Burn./Triangle		
	WB	EB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	EB	WB	Total	SB	NB	Total
12:00:00 AM	56	77	133	8	112	120	81	74	155	90	88	178	16	10	21	42	63	105	41	36	77
1:00:00 AM	39	42	81	3	59	60	56	38	75	43	50	93	18	5	23	31	52	80	28	26	49
2:00:00 AM	27	36	63	6	41	44	42	26	56	39	36	71	10	6	15	20	23	41	20	18	36
3:00:00 AM	19	24	37	3	34	34	24	25	43	29	28	55	14	8	22	21	25	37	12	14	26
4:00:00 AM	38	30	65	4	56	59	38	40	70	47	42	85	17	9	24	41	36	71	8	17	25
5:00:00 AM	149	85	234	7	147	154	90	95	185	123	86	205	26	18	43	133	80	213	33	48	79
6:00:00 AM	372	196	568	27	332	354	188	271	448	360	201	538	49	67	107	378	201	554	124	130	254
7:00:00 AM	593	403	996	98	749	806	317	475	792	541	382	880	86	85	169	551	411	962	259	193	425
8:00:00 AM	640	348	962	63	731	762	335	422	736	540	394	895	103	99	196	567	346	913	212	175	371
9:00:00 AM	435	374	802	111	869	980	395	389	784	446	388	805	84	98	182	423	379	787	179	178	349
10:00:00 AM	418	445	821	146	1065	1188	480	392	871	421	431	835	92	93	175	423	441	852	186	229	415
11:00:00 AM	431	515	902	202	1280	1387	508	466	892	460	506	941	110	102	206	479	526	996	252	274	526
12:00:00 PM	522	525	999	329	1182	1351	523	433	944	461	526	945	120	100	212	562	546	1108	229	288	490
1:00:00 PM	491	527	999	352	1113	1239	512	412	921	443	547	988	112	105	211	563	598	1161	237	270	467
2:00:00 PM	533	582	1079	303	1138	1224	528	413	879	433	566	969	131	95	226	545	568	1102	262	251	508
3:00:00 PM	497	672	1169	286	1119	1215	436	402	815	458	592	1034	135	143	266	486	691	1132	301	271	572
4:00:00 PM	470	704	1169	265	1213	1298	474	359	789	471	570	1038	148	105	252	518	704	1217	311	321	625
5:00:00 PM	464	758	1222	252	1243	1360	470	373	834	447	580	1002	174	117	281	503	808	1267	281	335	616
6:00:00 PM	374	516	890	310	1037	1116	432	387	801	402	485	874	114	88	202	369	529	897	252	257	498
7:00:00 PM	266	410	651	279	809	907	363	316	642	290	380	669	87	74	161	334	394	728	201	166	358
8:00:00 PM	199	311	510	147	506	590	285	247	516	225	302	527	71	45	116	208	307	515	131	117	248
9:00:00 PM	167	223	385	77	405	472	270	227	472	252	258	492	38	37	74	180	233	400	120	84	204
10:00:00 PM	142	178	311	38	303	332	172	157	327	157	199	347	30	25	53	155	193	327	74	79	153
11:00:00 PM	83	148	216	21	183	202	114	127	241	125	149	274	26	16	39	88	144	232	60	61	112

Complete ATR volume counts

	Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT				MT East of Burn.				Burn./Triangle		
		WB	EB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	WK 2	EB	WB	Total	WK 3	SB	NB	Total
24-Sep	10:00:00 AM	405	382	787										92	80	172	10am				10am			
	11:00:00 AM	431	471	902	184	805	989							80	85	165	11am				11am			
	12:00:00 PM	491	486	977	229	854	1083	479	419	898	309	327	636	97	93	190	12pm	444	488	932	12pm	214	203	417
	1:00:00 PM	446	475	921	245	801	1046	448	398	411	429	476	905	102	77	179	1pm	433	437	870	1pm	190	220	410
	2:00:00 PM	527	533	1060	235	801	1036	490	368	858	433	519	952	131	95	226	2pm	461	504	965	2pm	256	244	500
	3:00:00 PM	497	672	1169	286	876	1162	373	343	716	425	547	972	133	127	260	3pm	486	596	1082	3pm	301	271	572
	4:00:00 PM	449	704	1153	265	971	1236	474	344	357	435	549	984	119	98	217	4pm	499	701	1200	4pm	311	314	625
	5:00:00 PM	464	758	1222	235	899	1134	470	344	814	428	530	958	164	117	281	5pm	503	752	1255	5pm	269	303	572
	6:00:00 PM	335	511	846	310	678	988	426	360	786	395	456	851	114	88	202	6pm	340	529	869	6pm	252	246	498
	7:00:00 PM	266	385	651	279	543	822	363	316	329	290	379	669	87	74	161	7pm	243	346	589	7pm	201	157	358
	8:00:00 PM	183	279	462	108	420	528	249	198	447	193	262	455	71	45	116	8pm	194	249	443	8pm	110	89	199
	9:00:00 PM	167	162	329	77	301	378	238	154	392	172	217	389	36	29	65	9pm	167	154	321	9pm	92	71	163
	10:00:00 PM	100	139	239	38	166	204	132	112	125	109	122	231	26	18	44	10pm	103	136	239	10pm	47	45	92
	11:00:00 PM	45	105	150	9	120	129	53	71	124	62	94	156	14	12	26	11pm	55	114	169	11pm	36	24	60
25-Sep	12:00:00 AM	29	43	72	3	49	52	25	33	58	41	45	86	8	2	10	12am	35	38	73	12am	16	10	26
	1:00:00 AM	8	22	30	2	29	31	28	21	34	18	21	39	4	4	8	1am	16	31	47	1am	8	10	18
	2:00:00 AM	13	13	26	5	29	34	13	11	24	15	24	39	4	4	8	2am	13	13	26	2am	9	4	13
	3:00:00 AM	17	10	27	1	30	31	15	21	36	29	26	55	10	8	18	3am	21	14	35	3am	6	7	13
	4:00:00 AM	32	30	62	2	48	50	33	35	48	43	42	85	12	6	18	4am	41	29	70	4am	8	13	21
	5:00:00 AM	125	66	191	1	129	130	76	83	159	101	75	176	19	18	37	5am	133	80	213	5am	17	48	65
	6:00:00 AM	327	193	520	6	332	338	186	208	394	312	174	486	41	54	95	6am	378	175	553	6am	116	98	214
	7:00:00 AM	544	393	937	52	749	801	303	474	487	528	257	785	80	80	160	7am	527	377	904	7am	228	193	421
	8:00:00 AM	549	321	870	25	681	706	330	366	696	520	333	853	103	92	195	8am	551	321	872	8am	176	154	330
	9:00:00 AM	435	367	802	61	784	845	382	371	753	446	359	805	84	98	182	9am	351	370	721	9am	175	155	330
	10:00:00 AM	407	381	788	120	781	901	427	344	357	369	377	746	82	93	175	10am	384	341	725	10am	164	165	329
	11:00:00 AM	402	470	872	124	850	974	483	409	892	406	424	830	94	74	168	11am	433	453	886	11am	173	206	379
	12:00:00 PM	474	525	999	265	845	1110	457	393	850	461	477	938	120	92	212	12pm	509	483	992	12pm	221	184	405
	1:00:00 PM	479	520	999	187	952	1139	507	394	407	428	494	922	112	99	211	1pm	491	524	1015	1pm	209	257	466
	2:00:00 PM	510	557	1067	218	918	1136	486	364	850	390	514	904	120	89	209	2pm	499	568	1067	2pm	230	239	469
	3:00:00 PM	445	666	1111	221	993	1214	421	351	772	458	576	1034	126	123	249	3pm	454	631	1085	3pm	257	247	504
	4:00:00 PM	470	699	1169	262	969	1231	444	340	353	429	570	999	129	105	234	4pm	482	673	1155	4pm	246	308	554
	5:00:00 PM	442	720	1162	250	984	1234	461	373	834	442	536	978	165	91	256	5pm	469	746	1215	5pm	281	335	616
	6:00:00 PM	355	487	842	170	868	1038	414	387	801	402	436	838	99	82	181	6pm	368	529	897	6pm	219	257	476
	7:00:00 PM	224	410	634	135	675	810	350	302	315	286	380	666	82	71	153	7pm	266	391	657	7pm	171	166	337
	8:00:00 PM	199	311	510	77	506	583	285	231	516	225	302	527	54	37	91	8pm	164	303	467	8pm	131	117	248
	9:00:00 PM	162	223	385	36	405	441	270	202	472	147	258	405	37	37	74	9pm	143	178	321	9pm	98	69	167
	10:00:00 PM	89	139	228	38	203	241	142	122	135	102	173	275	28	20	48	10pm	104	109	213	10pm	66	55	121
	11:00:00 PM	64	105	169	8	120	128	88	88	176	73	112	185	26	13	39	11pm	68	110	178	11pm	38	38	76

	Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT				MT East of Burn.				Burn./Triangle		
		WB	EB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	WK 2	EB	WB	Total	WK 3	SB	NB	Total
26-Sep	12:00:00 AM	27	46	73	5	58	63	46	41	87	41	54	95	3	6	9	12am	28	57	85	12am	27	13	40
	1:00:00 AM	16	15	31	0	22	22	22	18	31	22	32	54	3	4	7	1am	22	23	45	1am	11	8	19
	2:00:00 AM	10	12	22	0	29	29	24	14	38	21	16	37	9	1	10	2am	14	11	25	2am	3	9	12
	3:00:00 AM	16	13	29	1	28	29	16	19	35	25	21	46	8	6	14	3am	18	18	36	3am	7	4	11
	4:00:00 AM	37	23	60	0	55	55	30	26	39	44	29	73	12	3	15	4am	29	23	52	4am	3	9	12
	5:00:00 AM	136	69	205	7	147	154	90	95	185	116	75	191	18	18	36	5am	132	65	197	5am	21	31	52
	6:00:00 AM	321	188	509	10	331	341	187	211	398	301	201	502	49	53	102	6am	329	199	528	6am	68	100	168
	7:00:00 AM	545	365	910	35	687	722	287	460	473	541	254	795	76	68	144	7am	539	377	916	7am	230	144	374
	8:00:00 AM	510	308	818	31	731	762	335	401	736	538	338	876	102	94	196	8am	558	340	898	8am	201	142	343
	9:00:00 AM	389	350	739	53	822	875	383	368	751	402	335	737	65	77	142	9am	408	379	787	9am	177	157	334
	10:00:00 AM	350	347	697	54	860	914	444	348	361	366	372	738	64	68	132	10am	423	363	786	10am	186	186	372
	11:00:00 AM	388	497	885	40	1028	1068	468	372	840	404	445	849	80	76	156	11am	479	483	962	11am	178	256	434
	12:00:00 PM	440	424	864	90	1131	1221	484	419	903	432	435	867	97	79	176	12pm	562	546	1108	12pm	229	244	473
	1:00:00 PM	450	527	977	78	1064	1142	512	402	415	443	476	919	102	75	177	1pm	563	598	1161	1pm	197	270	467
	2:00:00 PM	494	582	1076	86	1138	1224	528	348	876	390	566	956	116	92	208	2pm	545	557	1102	2pm	197	251	448
	3:00:00 PM	436	630	1066	96	1119	1215	395	311	706	380	567	947	112	122	234	3pm	441	691	1132	3pm	244	243	487
	4:00:00 PM	470	676	1146	85	1213	1298	394	354	367	471	567	1038	148	104	252	4pm	518	699	1217	4pm	237	317	554
	5:00:00 PM	436	668	1104	117	1243	1360	417	359	776	447	555	1002	121	93	214	5pm	480	713	1193	5pm	250	297	547
	6:00:00 PM	374	516	890	79	1037	1116	424	360	784	389	485	874	90	85	175	6pm	369	502	871	6pm	230	255	485
	7:00:00 PM	261	354	615	98	809	907	358	284	642	283	371	654	52	49	101	7pm	334	394	728	7pm	185	165	350
	8:00:00 PM	176	228	404	147	443	590	246	247	260	221	249	470	40	40	80	8pm	208	307	515	8pm	126	109	235
	9:00:00 PM	163	216	379	75	397	472	188	227	415	235	257	492	28	26	54	9pm	180	220	400	9pm	120	84	204
	10:00:00 PM	142	143	285	29	303	332	172	155	327	138	199	337	30	23	53	10pm	155	172	327	10pm	74	79	153
	11:00:00 PM	68	148	216	21	160	181	102	123	136	105	139	244	22	10	32	11pm	88	144	232	11pm	51	61	112

	Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT				MT East of Burn.				Burn./Triangle		
		WB	EB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	WK 2	EB	WB	Total	WK 3	SB	NB	Total
27-Sep	12:00:00 AM	43	65	108	7	86	93	71	61	132	63	81	144	16	5	21	12am	42	63	105	12am	40	31	71
	1:00:00 AM	26	32	58	2	46	48	43	32	75	42	47	89	9	4	13	1am	28	52	80	1am	28	21	49
	2:00:00 AM	27	18	45	6	33	39	42	17	30	31	36	67	10	4	14	2am	18	23	41	2am	18	18	36
	3:00:00 AM	13	24	37	1	19	20	24	19	43	20	28	48	11	6	17	3am	12	25	37	3am	12	14	26
	4:00:00 AM	22	20	42	0	36	36	28	21	49	27	28	55	9	4	13	4am	22	11	33	4am	3	12	15
	5:00:00 AM	66	29	95	1	57	58	44	42	55	50	38	88	6	8	14	5am	63	32	95	5am	8	12	20
	6:00:00 AM	125	96	221	3	138	141	82	75	157	106	89	195	21	22	43	6am	111	86	197	6am	27	49	76
	7:00:00 AM	139	135	274	10	271	281	154	162	316	169	149	318	37	38	75	7am	177	173	350	7am	63	75	138
	8:00:00 AM	193	213	406	9	521	530	228	251	264	253	224	477	42	43	85	8am	228	214	442	8am	104	138	242
	9:00:00 AM	300	311	611	111	869	980	395	389	784	332	310	642	58	59	117	9am	340	363	703	9am	179	170	349
	10:00:00 AM	362	365	727	123	1065	1188	480	391	871	404	431	835	88	72	160	10am	411	441	852	10am	186	229	415
	11:00:00 AM	410	474	884	107	1280	1387	508	466	479	460	481	941	110	96	206	11am	470	526	996	11am	252	274	526
	12:00:00 PM	492	447	939	169	1182	1351	510	433	943	420	415	835	94	100	194	12pm	486	535	1021	12pm	202	288	490
	1:00:00 PM	408	504	912	126	1113	1239	509	412	921	429	475	904	104	92	196	1pm	496	527	1023	1pm	237	216	453
	2:00:00 PM	398	523	921	81	1075	1156	483	399	412	414	512	926	107	87	194	2pm	471	505	976	2pm	187	207	394
	3:00:00 PM	378	493	871	70	1111	1181	436	379	815	400	454	854	114	100	214	3pm	457	548	1005	3pm	227	196	423
	4:00:00 PM	363	422	785	74	979	1053	421	359	372	397	431	828	81	79	160	4pm	384	444	828	4pm	206	232	438
	5:00:00 PM	312	378	690	88	883	971	416	308	724	375	421	796	81	73	154	5pm	368	396	764	5pm	186	194	380
	6:00:00 PM	319	347	666	177	772	949	352	282	634	376	429	805	79	59	138	6pm	317	380	697	6pm	208	172	380
	7:00:00 PM	250	300	550	152	623	775	299	251	264	233	358	591	51	69	120	7pm	243	333	576	7pm	148	149	297
	8:00:00 PM	179	264	443	61	475	536	184	202	386	213	286	499	34	37	71	8pm	206	260	466	8pm	105	80	185
	9:00:00 PM	161	192	353	47	355	402	163	190	353	252	229	481	29	26	55	9pm	144	233	377	9pm	92	73	165
	10:00:00 PM	133	178	311	25	250	275	150	157	170	157	190	347	27	25	52	10pm	118	193	311	10pm	70	64	134
	11:00:00 PM	83	133	216	19	183	202	114	127	241	125	149	274	20	16	36	11pm	86	122	208	11pm	60	35	95

	Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT				MT East of Burn.				Burn./Triangle		
		WB	EB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	WK 2	EB	WB	Total	WK 3	SB	NB	Total
28-Sep	12:00:00 AM	56	77	133	8	112	120	81	74	155	90	88	178	14	7	21	12am	40	57	97	12am	41	36	77
	1:00:00 AM	39	42	81	1	59	60	56	38	51	43	50	93	18	5	23	1am	31	33	64	1am	18	26	44
	2:00:00 AM	27	36	63	3	41	44	30	26	56	39	32	71	5	2	7	2am	20	21	41	2am	20	14	34
	3:00:00 AM	17	13	30	1	18	19	19	8	27	24	14	38	9	2	11	3am	7	18	25	3am	9	6	15
	4:00:00 AM	13	16	29	3	28	31	24	14	27	19	19	38	9	4	13	4am	9	15	24	4am	4	6	10
	5:00:00 AM	50	22	72	1	45	46	33	32	65	45	30	75	5	6	11	5am	45	20	65	5am	5	13	18
	6:00:00 AM	105	51	156	2	85	87	72	57	129	80	52	132	9	15	24	6am	100	46	146	6am	22	31	53
	7:00:00 AM	85	100	185	11	212	223	112	100	113	111	109	220	23	27	50	7am	114	117	231	7am	54	69	123
	8:00:00 AM	145	125	270	3	320	323	185	185	370	181	164	345	47	35	82	8am	150	137	287	8am	79	96	175
	9:00:00 AM	232	224	456	26	595	621	252	247	499	257	263	520	57	63	120	9am	236	226	462	9am	104	178	282
	10:00:00 AM	334	256	590	70	737	807	353	315	328	308	342	650	73	80	153	10am	332	290	622	10am	151	171	322
	11:00:00 AM	347	345	692	126	862	988	409	315	724	301	359	660	98	102	200	11am	294	348	642	11am	187	218	405
	12:00:00 PM	353	406	759	129	945	1074	463	371	834	398	437	835	102	96	198	12pm	351	412	763	12pm	187	232	419
	1:00:00 PM	340	455	795	139	988	1127	466	391	404	382	428	810	107	79	186	1pm	387	411	798	1pm	171	186	357
	2:00:00 PM	390	499	889	180	941	1121	472	381	853	348	490	838	117	81	198	2pm	387	481	868	2pm	169	202	371
	3:00:00 PM	357	489	846	88	882	970	404	402	806	381	442	823	90	90	180	3pm	388	425	813	3pm	193	161	354
	4:00:00 PM	296	398	694	209	721	930	372	328	700	312	437	749	93	84	177	4pm	293	401	694	4pm	199	189	388
	5:00:00 PM	285	309	594	252	641	893	371	335	348	331	338	669	83	80	163	5pm	273	407	680	5pm	202	190	392
	6:00:00 PM	240	298	538	173	564	737	327	269	596	293	325	618	75	69	144	6pm	231	319	550	6pm	203	174	377
	7:00:00 PM	185	260	445	156	363	519	211	191	402	208	266	474	63	48	111	7pm	184	233	417	7pm	114	135	249
	8:00:00 PM	123	166	289	94	276	370	160	177	190	165	165	330	42	26	68	8pm	148	151	299	8pm	96	80	176
	9:00:00 PM	104	117	221	56	157	213	130	140	270	143	148	291	37	18	55	9pm	89	122	211	9pm	67	67	134
	10:00:00 PM	96	105	201	29	112	141	97	88	185	102	113	215	20	17	37	10pm	76	60	136	10pm	46	44	90
	11:00:00 PM	33	86	119	9	69	78	54	63	76	56	82	138	10	7	17	11pm	36	75	111	11pm	46	32	78

	Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT				MT East of Burn.				Burn./Triangle		
		WB	EB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	WK 2	EB	WB	Total	WK 3	SB	NB	Total
29-Sep	12:00:00 AM	19	28	47	1	39	40	41	28	69	27	44	71	6	10	16	12am	24	30	54	12am	27	23	50
	1:00:00 AM	7	27	34	3	25	28	19	15	34	14	22	36	4	4	8	1am	10	22	32	1am	7	12	19
	2:00:00 AM	15	10	25	3	14	17	13	10	23	20	12	32	3	3	6	2am	8	10	18	2am	9	6	15
	3:00:00 AM	19	9	28	0	26	26	16	19	35	27	13	40	12	2	14	3am	20	10	30	3am	2	10	12
	4:00:00 AM	35	30	65	2	56	58	27	32	59	43	39	82	15	9	24	4am	35	36	71	4am	6	15	21
	5:00:00 AM	145	78	223	4	133	137	80	81	94	119	86	205	15	14	29	5am	116	60	176	5am	8	24	32
	6:00:00 AM	349	180	529	13	325	338	188	243	431	323	168	491	41	52	93	6am	351	172	523	6am	50	48	98
	7:00:00 AM	569	373	942	97	686	783	317	475	792	521	289	810	65	73	138	7am	499	406	905	7am	98	83	181
	8:00:00 AM	558	348	906	56	700	756	330	422	435	540	304	844	93	79	172	8am	533	338	871	8am	105	115	220
	9:00:00 AM	420	365	785	75	740	815	377	376	753	379	318	697	79	85	164	9am	405	333	738	9am	115	139	254
	10:00:00 AM	418	371	789	135	799	934	394	353	747	421	380	801	63	68	131	10am	356	355	711	10am	151	165	316
	11:00:00 AM	380	437	817	109	901	1010	500	365	378	377	419	796	69	72	141	11am	382	446	828	11am	182	205	387
	12:00:00 PM	469	468	937	196	905	1101	523	421	944	398	526	924	112	90	202	12pm	475	477	952	12pm	181	208	389
	1:00:00 PM	448	462	910	142	914	1056	476	373	849	366	532	898	99	80	179	1pm	481	426	907	1pm	180	185	365
	2:00:00 PM	533	546	1079	221	862	1083	416	321	334	401	544	945	129	95	224	2pm	481	542	1023	2pm	200	210	410
	3:00:00 PM	469	624	1093	247	865	1112	432	322	754	399	592	991	123	143	266	3pm	442	621	1063	3pm	233	200	433
	4:00:00 PM	428	666	1094	161	1013	1174	434	355	789	424	563	987	121	103	224	4pm	431	651	1082	4pm	215	268	483
	5:00:00 PM	451	733	1184	166	991	1157	448	325	338	428	547	975	174	97	271	5pm	426	699	1125	5pm	210	238	448
	6:00:00 PM	329	423	752	129	760	889	381	345	726	358	421	779	101	64	165	6pm	314	439	753	6pm	203	150	353
	7:00:00 PM	225	355	580	100	539	639	281	270	551	247	335	582	57	68	125	7pm	221	308	529	7pm	117	106	223
	8:00:00 PM	177	236	413	77	400	477	234	195	208	181	236	417	47	35	82	8pm	170	228	398	8pm	96	86	182
	9:00:00 PM	130	158	288	40	258	298	240	126	366	128	201	329	38	30	68	9pm	112	142	254	9pm	87	72	159
	10:00:00 PM	108	110	218	32	161	193	114	114	228	103	111	214	18	17	35	10pm	86	94	180	10pm	43	42	85
	11:00:00 PM	52	137	189	17	94	111	58	69	82	57	105	162	13	5	18	11pm	63	104	167	11pm	29	26	55

	Intersection:	MT East of Burn.			WB North of MT			WB South of MT			MT West of WB			Burn. North of MT				MT East of Burn.				Burn./Triangle		
		WB	EB	Total	SB	NB	Total	NB	SB	Total	EB	WB	Total	NB	SB	Total	WK 2	EB	WB	Total	WK 3	SB	NB	Total
30-Sep	12:00:00 AM	18	48	66	3	34	37	40	33	73	34	49	83	7	3	10	12am	27	49	76	12am	11	15	26
	1:00:00 AM	12	20	32	3	28	31	23	17	40	19	27	46	3	2	5	1am	15	23	38	1am	4	8	12
	2:00:00 AM	8	11	19	0	17	17	7	15	28	12	13	25	3	5	8	2am	14	6	20	2am	4	9	13
	3:00:00 AM	17	16	33	3	27	30	14	18	32	28	23	51	9	6	15	3am	20	11	31	3am	10	10	20
	4:00:00 AM	38	24	62	1	42	43	28	40	53	47	32	79	16	6	22	4am	36	29	65	4am	8	17	25
	5:00:00 AM	148	72	220	3	132	135	84	95	179	123	80	203	26	17	43	5am	125	62	187	5am	33	46	79
	6:00:00 AM	372	196	568	22	332	354	179	217	396	326	194	520	34	53	87	6am	353	201	554	6am	124	130	254
	7:00:00 AM	593	403	996	82	724	806	313	428	441	498	382	880	86	83	169	7am	541	376	917	7am	259	166	425
	8:00:00 AM	640	322	962	63	666	729	322	397	719	501	394	895	89	98	187	8am	567	346	913	8am	173	175	348
	9:00:00 AM	397	374	771	70	664	734	352	348	700	413	388	801	67	71	138	9am	423	340	763	9am	172	157	329
	10:00:00 AM	376	445	821	146	790	936	426	392	405	412	415	827	88	69	157	10am	365	369	734	10am	170	170	340
	11:00:00 AM	374	515	889	202	836	1038	445	446	891	396	506	902	81	68	149	11am	384	439	823	11am	168	216	384
	12:00:00 PM	522	468	990	329	776	1105	500	423	923	424	521	945	102	87	189	12pm	491	502	993	12pm	220	226	446
	1:00:00 PM	491	463	954	352	758	1110	506	406	419	441	547	988	96	105	201	1pm	448	448	896	1pm	194	238	432
	2:00:00 PM	514	563	1077	303	849	1152	466	413	879	412	557	969	118	90	208	2pm	484	548	1032	2pm	262	246	508
	3:00:00 PM	433	651	1084	241	925	1166	423	377	800	413	572	985	135	101	236	3pm	447	639	1086	3pm	245	262	507
	4:00:00 PM	465	700	1165	190	1003	1193	450	310	323	446	546	992	148	96	244	4pm	457	704	1161	4pm	266	321	587
	5:00:00 PM	418	704	1122	214	952	1166	467	350	817	415	580	995	137	90	227	5pm	459	808	1267	5pm	259	292	551
	6:00:00 PM	341	508	849	238	689	927	432	344	776	399	460	859	108	72	180	6pm	343	512	855	6pm	237	234	471
	7:00:00 PM	192	379	571	84	586	670	308	241	254	237	347	584	71	71	142	7pm	224	335	559	7pm	170	134	304
	8:00:00 PM	161	226	387	61	428	489	205	165	370	186	254	440	52	40	92	8pm	176	234	410	8pm	119	104	223
	9:00:00 PM	131	164	295	37	329	366	221	165	386	159	218	377	38	21	59	9pm	141	159	300	9pm	84	61	145
	10:00:00 PM	90	86	176	11	150	161	108	96	109	95	107	202	25	16	41	10pm	87	99	186	10pm	47	46	93
	11:00:00 PM	50	108	158	5	124	129	79	82	161	66	104	170	17	12	29	11pm	52	108	160	11pm	26	27	53
1-Oct	12:00:00 AM	22	34	56	3	44	47	35	25	60	43	28	71	7	2	9	12am	24	36	60	12am	14	17	31
	1:00:00 AM	5	12	17	0	19	19	13	21	34	19	24	43	7	4	11	1am	15	14	29	1am	10	11	21
	2:00:00 AM	7	12	19	0	28	28	14	7	21	15	15	30	9	6	15	2am	7	7	14	2am	4	6	10
	3:00:00 AM	15	15	30	0	34	34	18	25	43	22	25	47	14	8	22	3am	14	16	30	3am	3	6	9
	4:00:00 AM	35	21	56	4	55	59	38	32	70	38	34	72	17	6	23	4am	37	30	67	4am	6	16	22
	5:00:00 AM	149	85	234	7	121	128	74	85	98	120	84	204	25	16	41	5am	107	74	181	5am	28	34	62
	6:00:00 AM	363	173	536	27	321	348	177	271	448	360	178	538	40	67	107	6am	350	179	529	6am	114	113	227
	7:00:00 AM	532	387	919	98	605	703	295	446	741	531	318	849	83	85	168	7am	551	411	962	7am	244	180	424
	8:00:00 AM	542	330	872	44	694	738	332	418	431	496	334	830	79	99	178	8am	544	326	870	8am	212	159	371
	9:00:00 AM	396	348	744	64	678	742	330	318	648	387	322	709	74	71	145	9am	387	377	764	9am	160	176	336
	10:00:00 AM	370	386	756					142	142				59	60	119	10am	355	323	678	10am	169	212	381
	11:00:00 AM																11am				11am	172	194	366
	12:00:00 PM																12pm				12pm	220	203	423

Appendix B: Peak Hour and Peak Hour Factor Calculations

Morning Peak Hour at East Mountain and Burncoat Streets

Morning Mountain/Burncoat																		
	Burncoat St. Southbound				Mountain St. Westbound				Burncoat St. Northbound				Mountain St. East Eastbound				Total Traffic	
Start Time	Right	Thru	Left	Total	Right	Thru	Left	Total	Right	Thru	Left	Total	Right	Thru	Left	Total		
7:00	12	0	7	19	4	51	0	55	4	11	36	51	0	73	4	77	202	
7:15	9	0	8	17	4	89	0	93	5	9	23	37	0	89	5	94	241	
7:30	11	0	7	18	2	89	0	91	6	10	42	58	0	127	6	133	300	
7:45	10	0	10	20	5	195	0	200	10	4	34	48	0	150	14	164	432	1175
8:00	12	0	10	22	2	82	0	84	1	5	40	46	0	149	7	156	308	1281
8:15	12	0	8	20	2	84	0	86	2	9	31	42	0	128	9	137	285	1325
8:30	26	0	6	32	4	71	0	75	3	6	29	38	0	113	9	122	267	1292
8:45	15	0	3	18	8	75	0	83	11	12	31	54	0	109	15	124	279	1139
	45	0	35		11	450	0		19	28	147		0	554	36			
	Peak Hour Total:			80	Peak Hour Total:			461	Peak Hour Total:			194	Peak Hour Total:			590		
		PHF:		0.9091		PHF:		0.5763		PHF:		0.8362		PHF:		0.8994	PHF:	0.76678

Afternoon Peak Hour at East Mountain and Burncoat Streets

Afternoon Mountain/Burncoat																		
	Burncoat St. Southbound				Mountain St. Westbound				Burncoat St. Northbound				Mountain St. East Eastbound				Total Traffic	
Start Time	Right	Thru	Left	Total	Right	Thru	Left	Total	Right	Thru	Left	Total	Right	Thru	Left	Total		
4:00	18	0	4	22	4	139	0	143	5	11	47	63	0	103	7	110	338	
4:15	19	0	10	29	11	149	0	160	3	16	62	81	0	111	10	121	391	
4:30	22	0	13	35	29	165	0	194	4	12	61	77	0	72	12	84	390	
4:45	19	0	8	27	9	172	0	181	7	21	61	89	0	91	6	97	394	1513
5:00	17	0	7	24	17	245	0	262	5	10	65	80	0	110	13	123	489	1664
5:15	14	0	4	18	17	182	0	199	8	21	65	94	0	78	8	86	397	1670
5:30	13	0	6	19	13	136	0	149	6	10	64	80	0	112	14	126	374	1654
5:45	7	0	7	14	10	136	0	146	4	8	49	61	0	73	5	78	299	1559
	72	0	32		72	764	0		24	64	252		0	351	39			
	Peak Hour Total:			104	Peak Hour Total:			836	Peak Hour Total:			340	Peak Hour Total:			390		
		PHF:		0.7429		PHF:		0.7977		PHF:		0.9043		PHF:		0.7927	PHF:	0.85378

Morning Peak Hour at West Mountain Street and West Boylston Streets

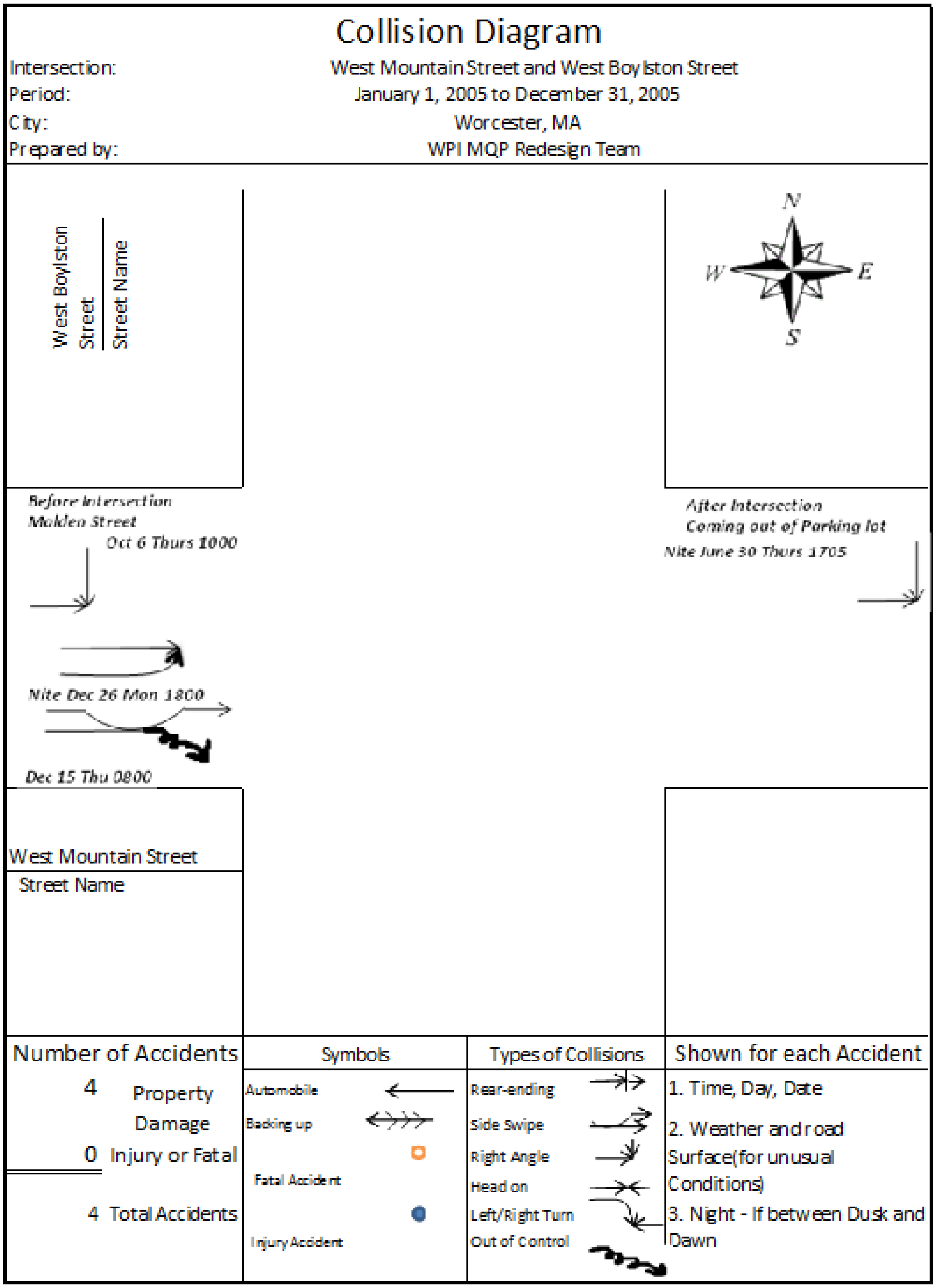
Morning Mountain/Boylston																		
	West Boylston Southbound				E Mountain Westbound				West Boylston Northbound				W Mountain Eastbound				Total Traffic	
Start Time	Right	Thru	Left	Total	Right	Thru	Left	Total	Right	Thru	Left	Total	Right	Thru	Left	Total		
7:00	8	36	21	65	26	53	13	92	18	25	26	69	52	88	11	151	377	
7:15	10	39	28	77	32	52	20	104	26	36	22	84	65	98	6	169	434	
7:30	15	66	47	128	38	63	34	135	21	36	38	95	84	135	17	236	594	
7:45	20	59	37	116	43	68	14	125	34	47	40	121	75	133	23	231	593	1998
8:00	29	64	42	135	30	56	13	99	23	31	33	87	46	131	24	201	522	2143
8:15	18	47	36	101	30	68	18	116	15	24	34	73	44	106	11	161	451	2160
8:30	17	41	24	82	36	53	12	101	29	18	29	76	57	105	18	180	439	2005
8:45	17	33	26	76	31	59	25	115	30	43	34	107	53	99	15	167	465	1877
	82	236	162		141	255	79		93	138	145		249	505	75			
	Peak Hour Total:			480	Peak Hour Total:			475	Peak Hour Total:			376	Peak Hour Total:			829		
		PHF:		0.8888889		PHF:		0.8796		PHF:		0.7768595		PHF:		0.8782	PHF:	0.90909

Afternoon Peak Hour at West Mountain and West Boylston Streets

Afternoon Mountain/ Boylston																			
	West Boylston Southbound				E Mountain Westbound				West Boylston Northbound				W Mountain Eastbound				Total Traffic		
Start Time	Right	Thru	Left	Total	Right	Thru	Left	Total	Right	Thru	Left	Total	Right	Thru	Left	Total			
4:00	22	53	42	117	49	112	25	186	44	88	29	161	12	61	47	120	584		
4:15	40	58	44	142	68	113	29	210	36	75	25	136	27	69	56	152	640		
4:30	28	55	48	131	68	155	20	243	47	86	29	162	30	74	38	142	678		
4:45	25	53	48	126	64	139	23	226	51	73	34	158	21	70	48	139	649	2551	
5:00	26	46	59	131	62	155	21	238	45	82	24	151	33	64	56	153	673	2640	
5:15	26	68	55	149	64	170	25	259	38	87	28	153	30	66	42	138	699	2699	
5:30	16	53	44	113	66	114	22	202	43	78	31	152	25	68	55	148	615	2636	
5:45	20	52	45	117	47	138	25	210	49	68	26	143	19	42	45	106	576	2563	
	105	222	210		258	619	89		181	328	115		114	274	184				
	Peak Hour Total:			537	Peak Hour Total:			966	Peak Hour Total:			624	Peak Hour Total:			572			
		PHF:		0.9010067		PHF:		0.9324		PHF:		0.962963		PHF:		0.9346		PHF:	0.96531

Appendix C: Collision Diagrams

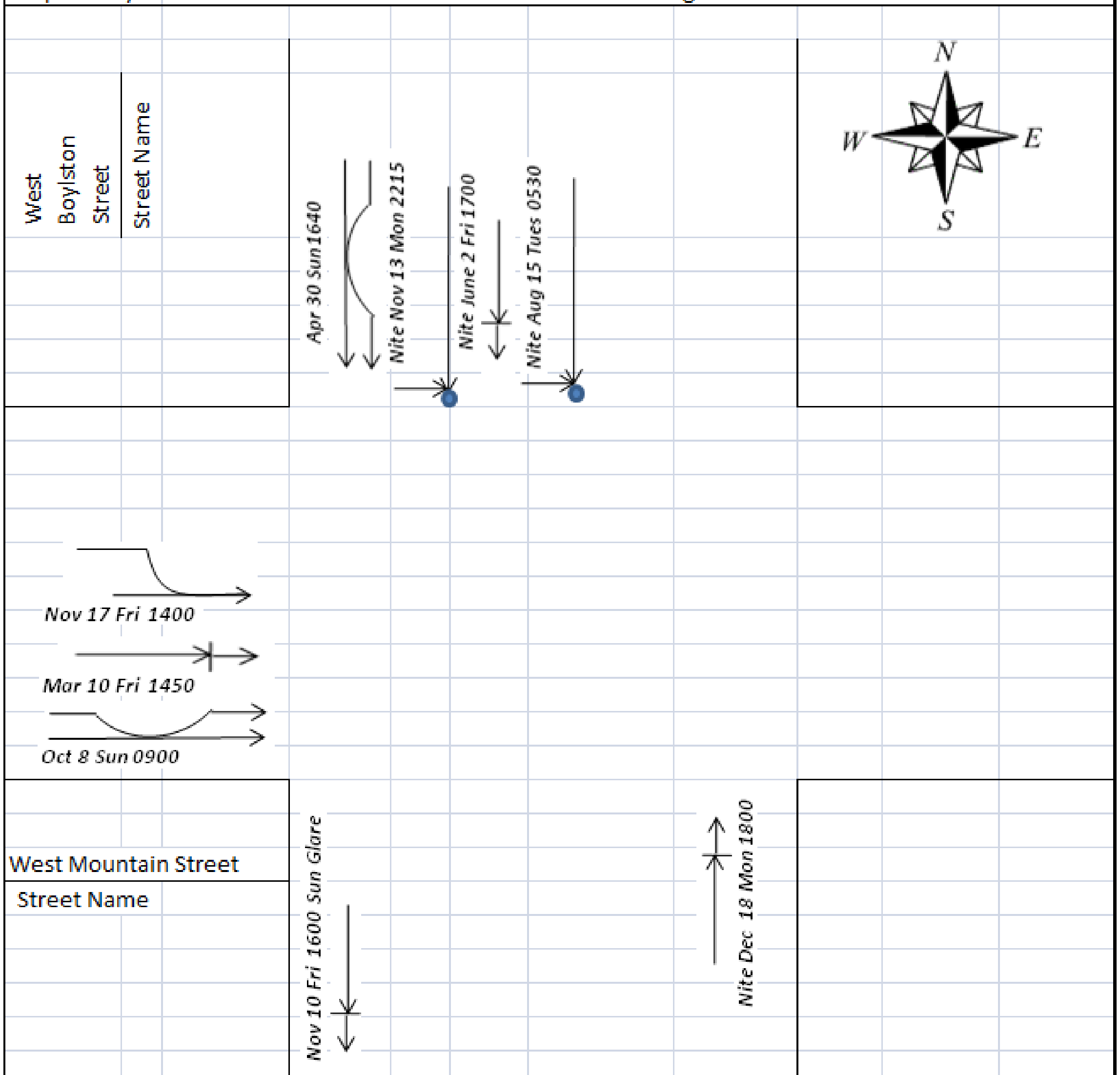
Collisions at West Mountain and West Boylston Streets in 2005



Collisions at West Mountain and West Boylston Streets in 2006

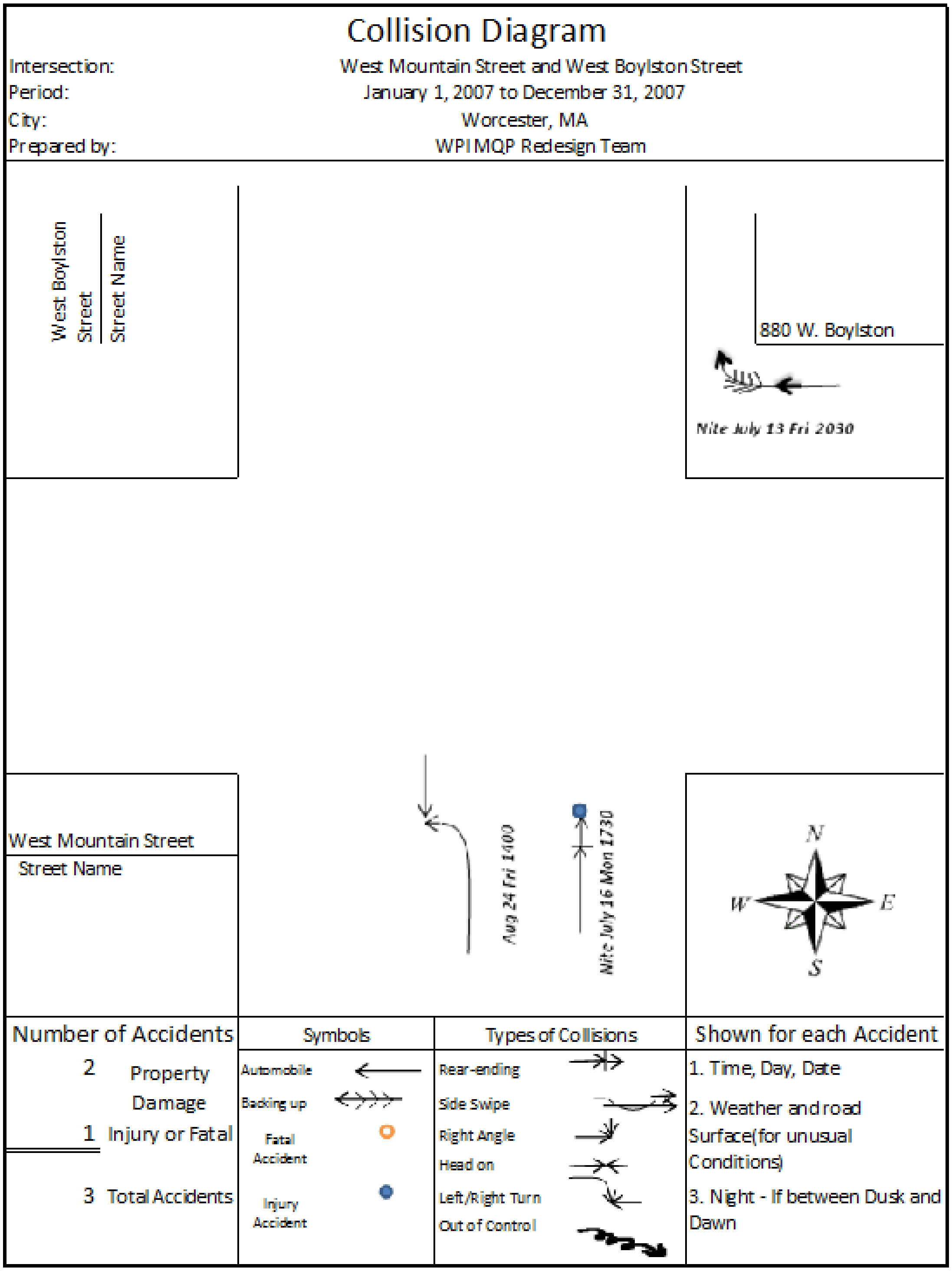
Collision Diagram

Intersection:	West Mountain Street and West Boylston Street
Period:	January 1, 2006 to December 31, 2006
City:	Worcester, MA
Prepared by:	WPI MQP Redesign Team

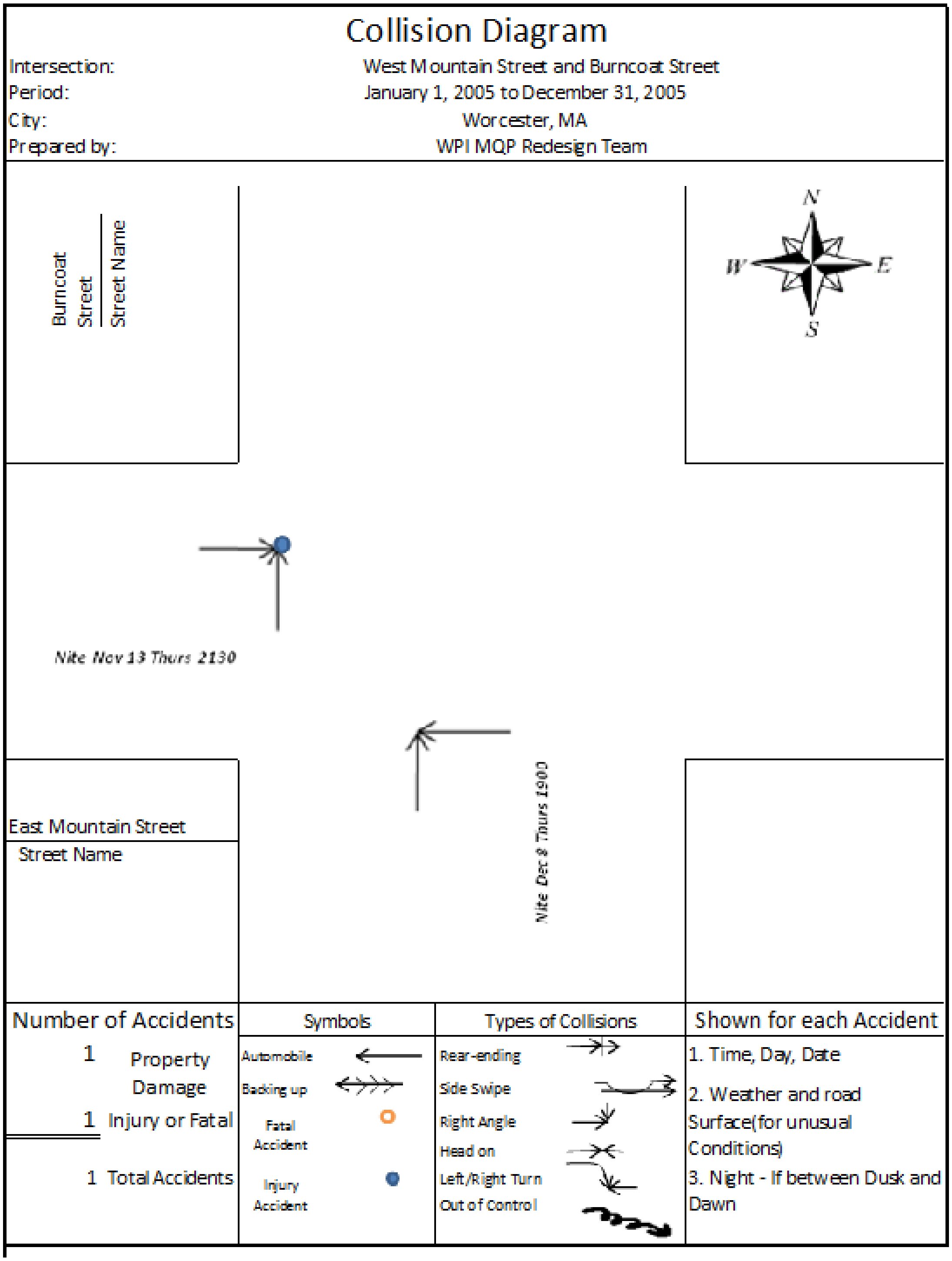


Number of Accidents		Symbols	Types of Collisions	Shown for each Accident
6	Property Damage	Automobile	Rear-ending	1. Time, Day, Date
		Backing up	Side Swipe	2. Weather and road Surface(for unusual Conditions)
2	Injury or Fatal	Fatal Accident	Right Angle	
			Head on	
8	Total Accidents	Injury Accident	Left/Right Turn	3. Night - If between Dusk and Dawn
			Out of Control	

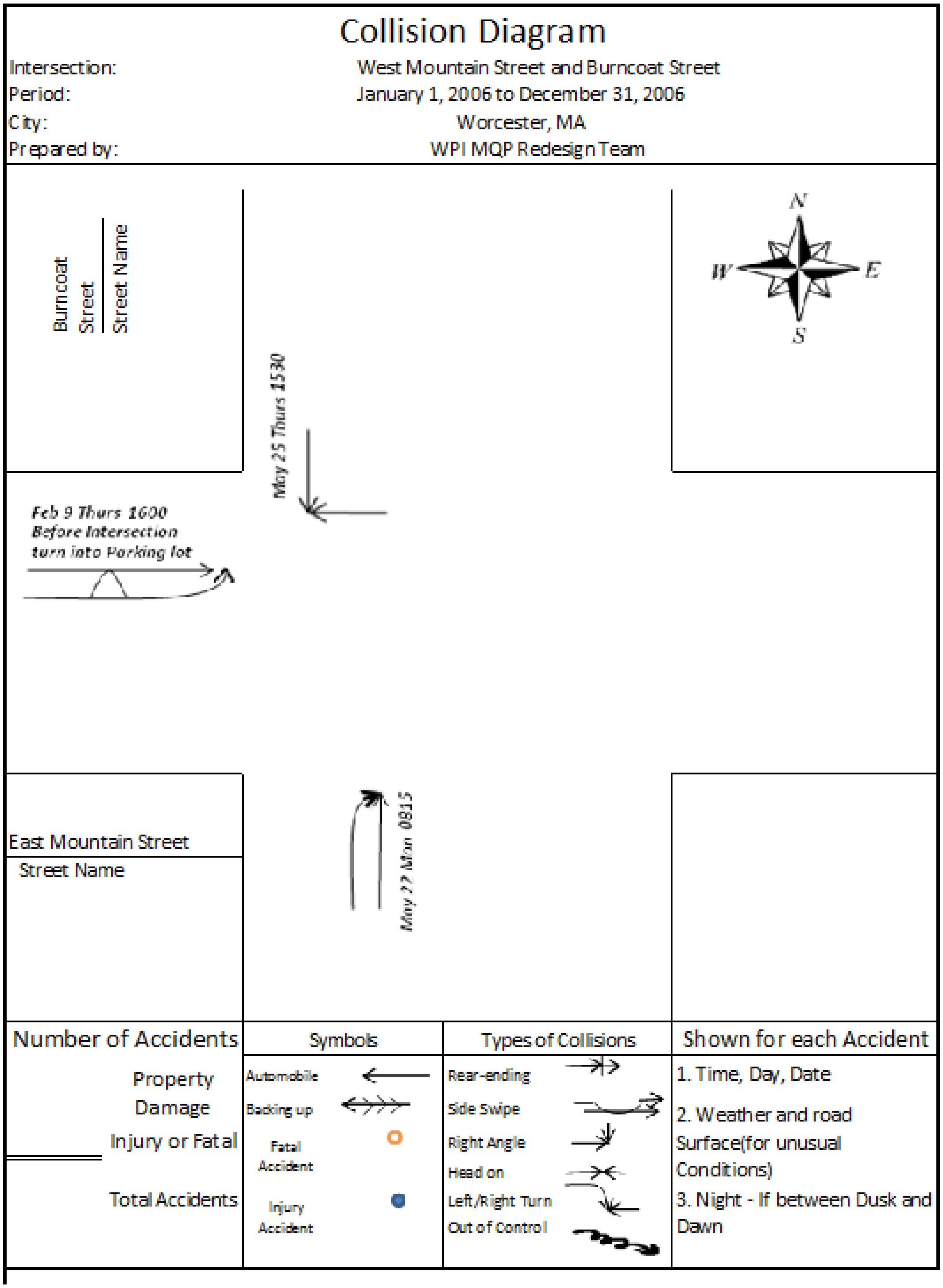
Collisions at West Mountain and West Boylston Streets in 2007



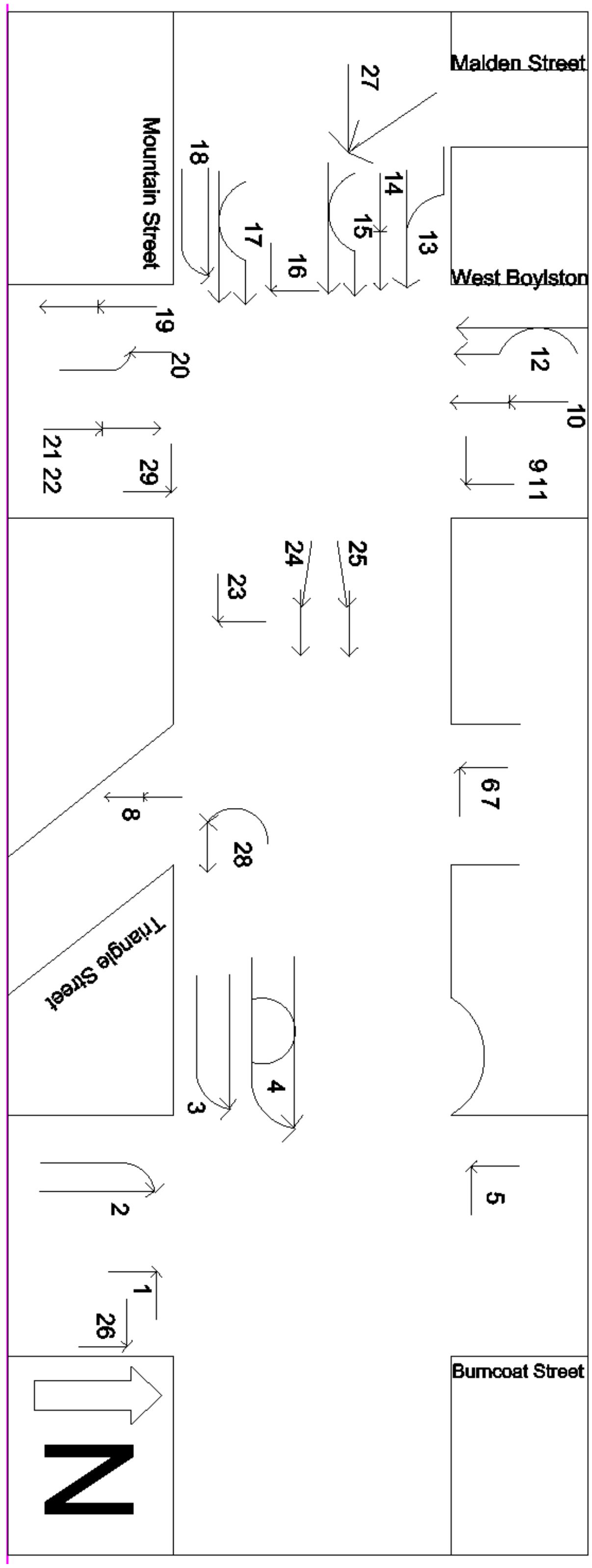
Collisions at East Mountain and Burncoat Streets in 2005



Collisions at East Mountain and Burncoat Streets in 2006



Total Collisions (AutoCAD)



Appendix D: Land Use Map